Élan™SC400 and ÉlanSC410 Microcontrollers User's Manual

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INTRODUCTION

Élan™SC400 AND ÉlanSC410 MICROCONTROLLERS

The Élan™SC400 and ÉlanSC410 microcontrollers are the latest in a series of E86™ family microcontrollers, which integrate proven x86 CPU cores with a comprehensive set of on-chip peripherals.

The ÉlanSC400 and ÉlanSC410 microcontrollers combine a 32-bit, low-voltage Am486® CPU with a complete set of PC/AT-compatible peripherals, along with sophisticated power management features.

PURPOSE OF THIS MANUAL

This manual describes the technical features and programming interface of the ÉlanSC400 and ÉlanSC410 microcontrollers.

Intended Audience

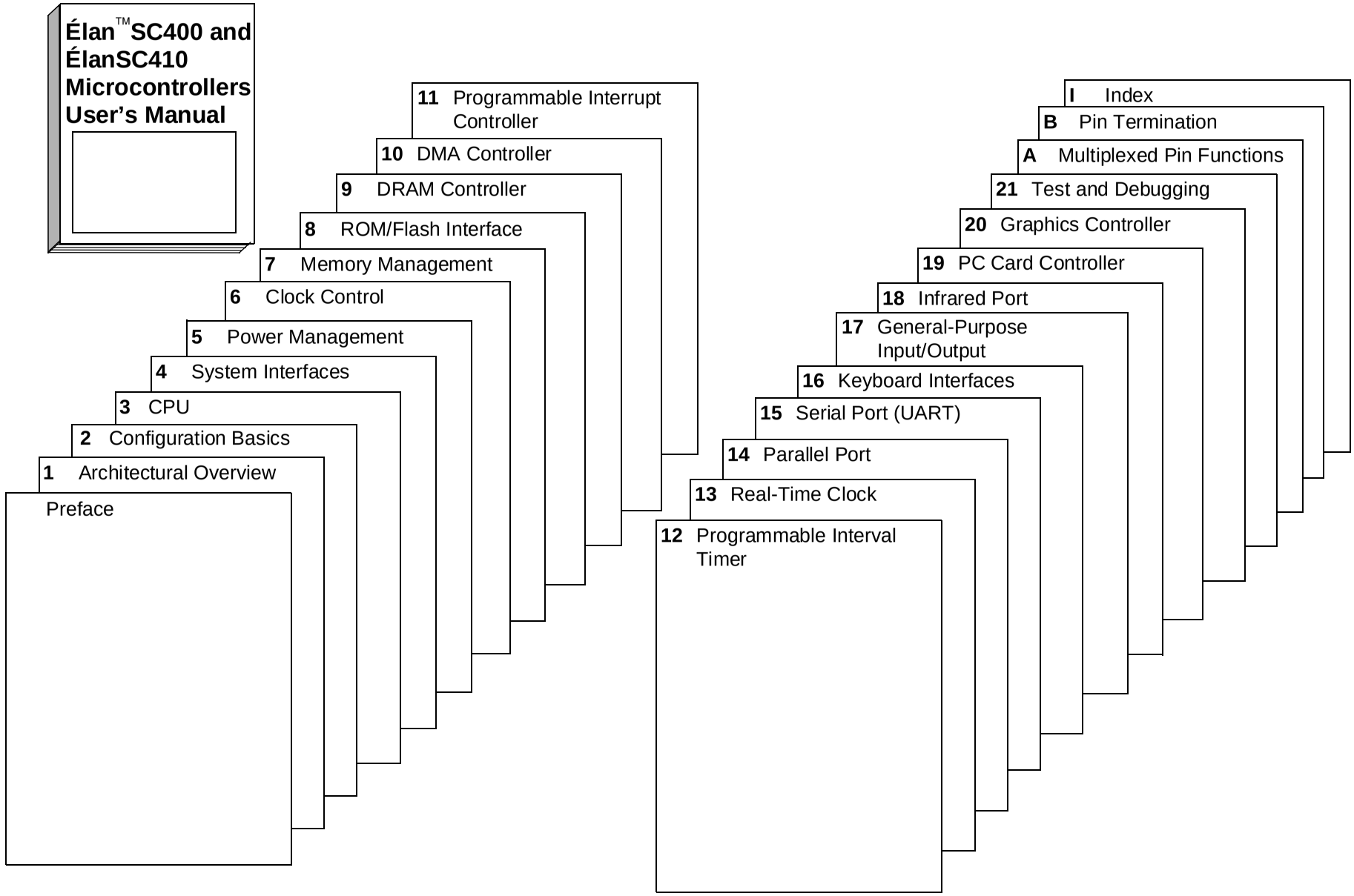
The *Élan™SC400 and ÉlanSC410 Microcontrollers User's Manual* is intended for computer software and hardware architects and system engineers who are designing or are considering designing systems based on the ÉlanSC400 and ÉlanSC410 microcontrollers.

Overview of This Manual

This manual is organized into the following chapters.

- Chapter 1 provides an architectural overview of the ÉlanSC400 and ÉlanSC410 microcontrollers, including system trade-offs and block and system diagrams.
- Chapter 2 is an overview of the basic concepts required to configure the microcontroller. It discusses the direct-mapped and indirect-mapped (indexed) register spaces.
- Chapter 3 discusses the integrated Am486 CPU and how it differs from other Am486 CPUs. Also included is information on cache memory management, System Management Mode (SMM), and core CPU identification methods.
- Chapter 4 describes the system interfaces on the microcontroller, including initialization, pin descriptions and configuration, data and address buses, and example bus configurations. The ISA and VESA local (VL) bus interfaces, as well as the PC/AT port logic, are also described.
- Chapter 5 describes the power management features of the microcontroller, including power management modes of operation, flowcharts, and control functions.
- Chapter 6 describes how to control the clocks on the microcontroller. Also included is a description of clock generation.
- Chapter 7 discusses memory management on the microcontroller. Subjects include address decoding and aliasing, memory spaces, and translated and non-translated memory management.
- Chapter 8 describes the ROM/Flash interface, including configuration and initialization.
- Chapter 9 covers the DRAM controller, including system design issues, system address decoding, timing and control signal generation, and initialization.

- Chapter 10 describes the PC/AT-compatible DMA controller.
- Chapter 11 describes the PC/AT-compatible programmable interrupt controller (PIC).
- Chapter 12 describes the PC/AT-compatible programmable interval timer (PIT).
- Chapter 13 describes the PC/AT-compatible real-time clock (RTC).
- Chapter 14 covers the parallel port, including PC/AT Compatible mode, Bidirectional mode, and Enhanced Parallel Port (EPP) mode.
- Chapter 15 describes the serial port (UART).
- Chapter 16 describes the keyboard interfaces available on the microcontroller, including the matrix (scan) keyboard interface, System Control Processor (SCP) emulation, and the XT interface.
- Chapter 17 covers the general-purpose input/output signals and the programmable chip selects available on the microcontroller.
- Chapter 18 describes the infrared port and using DMA for high-speed infrared transfers.
- Chapter 19 describes the integrated PC Card controller available on the ÉlanSC400 microcontroller.
- Chapter 20 describes the integrated LCD graphics controller available on the ÉlanSC400 microcontroller.
- Chapter 21 covers the test and debugging features of the microcontroller, including the boundary-scan interface, test access port operation, and scan paths.
- Appendix A describes multiplexed pin configuration control. It includes a table listing which signals are traded for others and how each multiplexed signal is enabled.
- Appendix B covers pin termination and includes a table with control bits and affected pins.


Élan™SC400 and ÉlanSC410 Microcontrollers User's Manual
Preface
1 Architectural Overview
2 Configuration Basics
3 CPU
4 System Interfaces
5 Power Management
6 Clock Control
7 Memory Management
8 ROM/Flash Interface
9 DRAM Controller
10 DMA Controller
11 Programmable Interrupt Controller
12 Programmable Interval Timer
13 Real-Time Clock
14 Parallel Port
15 Serial Port (UART)
16 Keyboard Interfaces
17 General-Purpose Input/Output
18 Infrared Port
19 PC Card Controller
20 Graphics Controller
21 Test and Debugging
A Multiplexed Pin Functions
B Pin Termination
I Index

RELATED DOCUMENTS

AMD Documentation

The following AMD documents provide additional information about the ÉlanSC400 and ÉlanSC410 microcontrollers. In addition to this manual, the documentation set for the ÉlanSC400 and ÉlanSC410 microcontrollers includes the following documents:

- The *Élan™ SC400 and ÉlanSC410 Microcontrollers Data Sheet* (order #21028) includes complete pin lists, pin state tables, timing and thermal characteristics, and package dimensions for the ÉlanSC400 and ÉlanSC410 microcontrollers.
- The *Élan™ SC400 Microcontroller Register Set Reference Manual* (order #21032) provides a complete description of all the registers required to program the ÉlanSC400 and ÉlanSC410 microcontrollers.
- The *Am486® Microprocessor Software User's Manual* (order #18497) includes the Am486 microprocessor instruction set. Appendices provide useful information about programming the base architecture and system level registers. A glossary of terms is also included. Note that this document describes floating-point features not supported on the ÉlanSC400 and ÉlanSC410 microcontrollers.

Other documents of interest:

- *Enhanced Am486® Microprocessor Family Data Sheet* (order #19225)
- *Am486® DX/DX2 Microprocessor Hardware Reference Manual* (order #17965). Note that this document describes floating-point features not supported on the ÉlanSC400 and ÉlanSC410 microcontrollers.

Additional Information

The following non-AMD documents provide additional information that may be of interest to users of the ÉlanSC400 and ÉlanSC410 microcontrollers.

IEEE Std 1149.1-1990 Standard Test Access Port and Boundary-Scan Architecture, (order #SH16626-NYF), Institute of Electrical and Electronic Engineers, Inc., 800-678-4333, www.ieee.org.

Infrared Data Association Serial Infrared Physical Layer Link Specification, Version 1.1, Infrared Data Association (IrDA), 510-943-6546, www.irda.org. October 1995.

Infrared Data Association Serial Infrared Link Access Protocol (IrLAP), Version 1.1, IrDA, 510-943-6546, www.irda.org. June 1996.

ISA Bus/PC AT Bus Draft Standard 996, D2.02 (order #DS0224), Institute of Electrical and Electronic Engineers, Inc., 800-678-4333, www.ieee.org. July 1990.

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PC Card Standard, Personal Computer Memory Card International Association (PCMCIA), 408-433-2273, www.pc-card.com. February 1995.

PCMCIA Standard Release 2.1, PCMCIA, 408-433-2273, www.pc-card.com. July 1993.

The Indispensable PC Hardware Book, Hans-Peter Messmer, Second Edition. Wokingham, England: Addison-Wesley, 1995.

VL-Bus Standard 2.0, Video Electronics Standards Association (VESA), 408-435-0333, www.vesa.org. November 1993.

DOCUMENTATION CONVENTIONS

The following table lists the documentation conventions used throughout this manual.

Documentation Conventions Table

Notation	Meaning
Reference Notation	
CSC index 00h[1]	ÉlanSC400 Chip Setup and Control (CSC) indexed register 00h, bit 1
Graphics index 00h[1]	Graphics controller indexed register 00h, bit 1
PC Card index 00h[1]	PC Card controller indexed register 00h, bit 1
Port 0014h[1]	Direct-mapped register 0014h, bit 1
RTC index 00h[1]	RTC and configuration RAM indexed register 00h, bit 1
Pin Naming	
/	Two functions available on the pin at the same time
{ }	Pin function during hardware reset
[ ]	Alternative pin function selected by firmware configuration
[[ ]]	Alternative pin function selected by a hardware configuration pin state at power-on reset
$\overline{\text{ROMCS1}}$	An overbar indicates that the signal assumes the logic Low state when asserted
RSTDRV	The absence of an overbar indicates that the signal assumes the logic High state when asserted
$\overline{\text{ROMCS2}}$–$\overline{\text{ROMCS0}}$	All three ROM chip select signals
$\overline{\text{ROMCSx}}$	Any of the three ROM chip select signals
Numbers	
b	Binary number
d	Decimal number Decimal is the default radix
h	Hexadecimal number
x in register address	Any of several legal values; e.g., 3x4h as a graphics index address register can be either 3B4h or 3D4h, depending on the mode selected

Documentation Conventions Table (continued)

Notation	Meaning
[X–Y, Z]	The bit field that consists of bits X through Y, and the bit field consisting of the single bit Z. Example: Use CSC index 52h[5–3,1]
General	
field	Bit field in a register (one or more consecutive and related bits)
can	It is possible to perform an action if properly configured
will	A certain action is going to occur
XMI	SMI or NMI
Set 29h[1]	Write bit 1 of index 29h to 1. ***Note:*** *The applicable indexed register space will either be obvious from the surrounding text, or will be stated explicitly. For example, RTC index 0h[1] would be a reference to bit 1 in real-time clock indexed register space.*
Clear 29h[1]	Write bit 1 of index 29h to 0.

CHAPTER

1 ARCHITECTURAL OVERVIEW

1.1 ÉlanSC400 AND ÉlanSC410 MICROCONTROLLERS

The ÉlanSC400 and ÉlanSC410 microcontrollers combine a 32-bit, low-voltage Am486 CPU with a complete set of PC/AT-compatible peripherals, along with the power management features required for battery operation. The ÉlanSC400 and ÉlanSC410 microcontrollers use the industry-standard 486 microprocessor instruction set. All software written for the x86 architecture family is compatible with the ÉlanSC400 and ÉlanSC410 microcontrollers.

The ÉlanSC400 and ÉlanSC410 microcontrollers include the following distinctive characteristics.

- E86 family of x86 embedded processors
  - — Offers improved time-to-market, software migration, and field-proven development tools
- Highly integrated single-chip CPU with a complete set of common peripherals
  - — Accelerates time-to-market with simplified hardware
  - — Low-power 0.35 micron process technology
  - — Single chip delivers smallest system form factor
  - — 33-MHz, 66-MHz, and 100-MHz operating frequencies
  - — No floating point unit
- Am486® CPU core
  - — Robust Microsoft® Windows® compatible CPU
  - — 8-Kbyte write-back cache for enhanced performance
  - — Fully static design with System Management Mode (SMM) for power savings
- Comprehensive power management unit
  - — Seven modes of operation allow fine-tuning of power requirements for maximum battery life
  - — Provides a superset of Advanced Power Management (APM) 1.2 features
- Glueless burst-mode ROM/Flash interface
  - — Reduces system cost by allowing static memory such as mask ROM, Flash, and SRAM with three ROM/Flash chip selects
- Glueless DRAM controller
  - — Extended Data Out (EDO) and Fast Page Mode (FPM) DRAMs supported
  - — Allows mixed DRAM types on a per-bank basis to reduce system cost

- Standard PC/AT system logic, including dual Programmable Interrupt Controllers (PIC), dual DMA controllers, Programmable Interval Timer (PIT), and Real-Time Clock (RTC)
  - — DOS, ROM-DOS, Windows, and industry-standard BIOS support
  - — Leverages the benefits of desktop software at embedded price points
- Local bus and ISA bus interface
  - — Reduces time-to-market with a wide variety of off-the-shelf companion chips
- Bidirectional parallel port with EPP mode
- 16550-compatible UART
- Infrared port for wireless communication
  - — Standard and high-speed
- Keyboard interface
  - — Matrix keyboard support with up to 15 rows and 8 columns

1.1.1 ÉlanSC400 Microcontroller

The ÉlanSC400 microcontroller includes the following additional features designed specifically for mobile computing applications. A block diagram of the ÉlanSC400 microcontroller is shown in Figure 1-1. Figure 4-1 shows how signals are multiplexed on the ÉlanSC400 microcontroller.

- Dual PC Card (PCMCIA Version 2.1) controller supports 8- or 16-bit data bus
  - — Provides end-user (after-market) system expansion
  - — Compliant with Exchangeable Card Architecture (ExCA), also called QuickSwap
  - — 82365-register set compatible
  - — Leverages off-the-shelf card and socket services
  - — Supports DMA transfers between I/O PC cards and system DRAM
- LCD graphics controller
  - — Supports both color and monochrome SuperTwisted Nematic (STN) LCDs
  - — Internal unified memory architecture (UMA) eliminates separate video memory

1.1.2 ÉlanSC410 Microcontroller

Targeted specifically at embedded systems, the ÉlanSC410 microcontroller includes all the features of the ÉlanSC400 microcontroller, without the PC Card controller and the internal graphics controller. A complete list of pin changes for the ÉlanSC410 microcontroller is included in Section 4.3. A block diagram of the ÉlanSC410 microcontroller is shown in Figure 1-2. Figure 4-2 shows how signals are multiplexed on the ÉlanSC410 microcontroller.

Figure 1-1 ÉlanSC400 Microcontroller Block Diagram

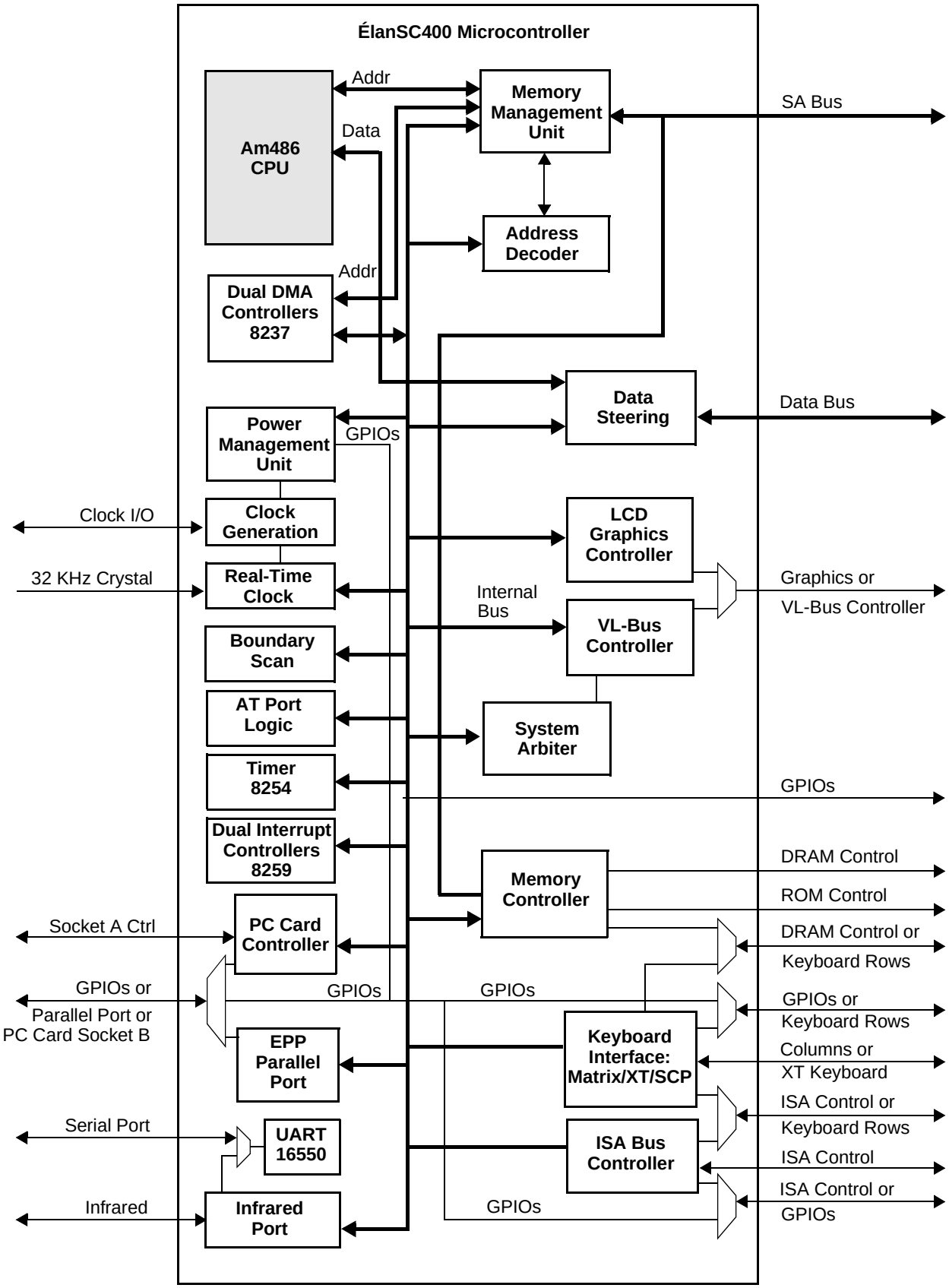
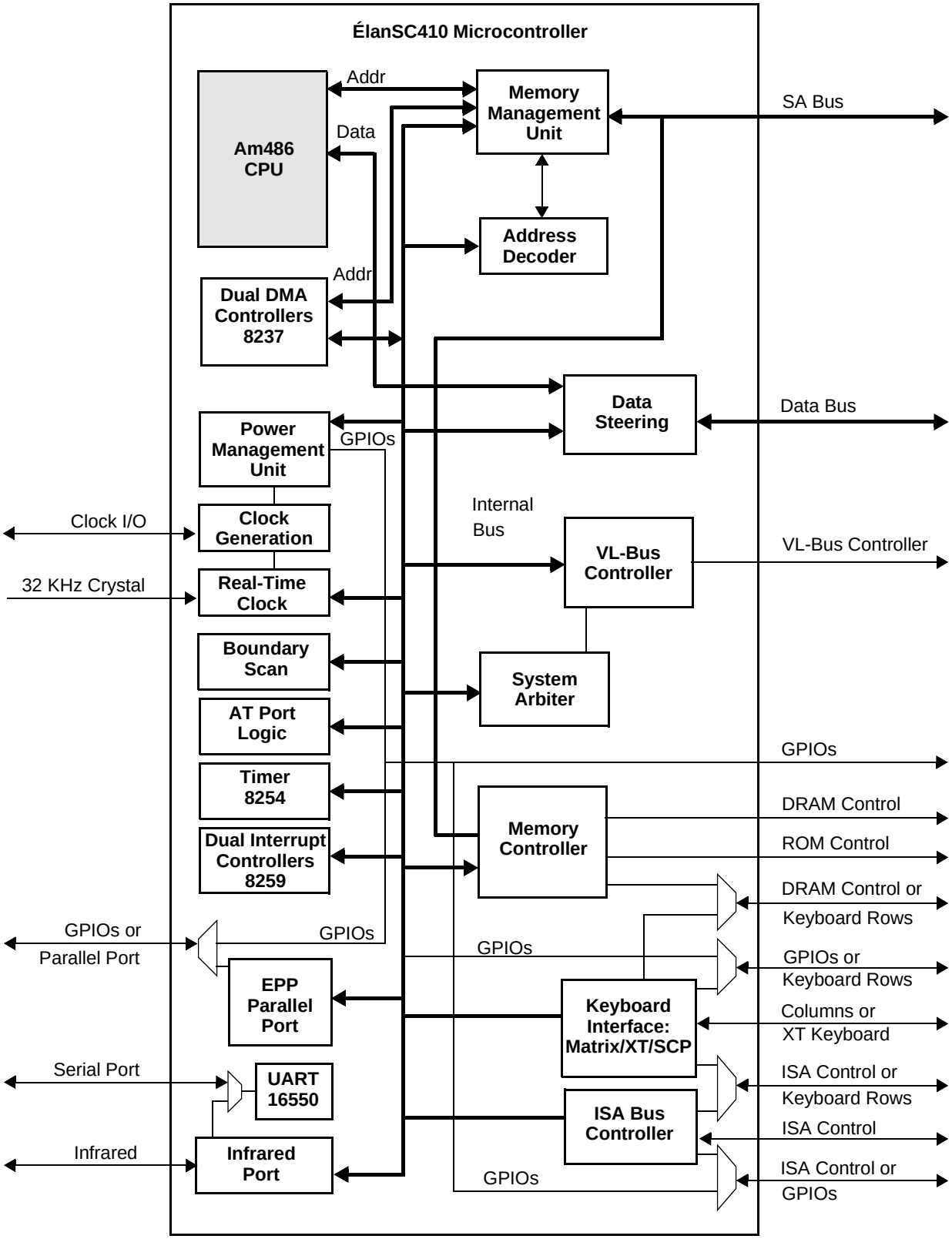


Figure 1-2 ÉlanSC410 Microcontroller Block Diagram



1.2 ARCHITECTURAL OVERVIEW

The architectural goals of the ÉlanSC400 microcontroller included a focus on CPU performance, CPU-to-memory performance, and internal graphics controller performance. The resulting architecture includes several distinguishing features of interest to the system designer:

- The main system DRAM is shared between the CPU and graphics controller, so that the graphics controller can be serviced quickly to maintain video display performance at higher panel resolutions. The internal unified memory architecture (UMA) implemented on the ÉlanSC400 microcontroller means lower cost and less complication for the system designer, with only one DRAM interface, fewer pins, and a much smaller board for many designs.
- CPU-to-memory performance is critical for both DRAM and ROM accesses. The CPU on the ÉlanSC400 microcontroller has a concurrent path to the ROM/Flash interface and can execute code out of ROM/Flash at the same time as the graphics controller is accessing DRAM for a screen refresh. Many system designs will be able to take advantage of this concurrency without sacrificing performance.
- The ROM/Flash interface provides the flexibility to optimize the performance of ROM cycles, including the support of burst-mode ROMs. This is beneficial because products based on the ÉlanSC400 and ÉlanSC410 microcontrollers may be implemented such that the operating system or application programs are executed from ROM.
- Because the microcontrollers support a large number of external buses and interfaces, the address and data buses are shared between the various interfaces to reduce pin count on the chip.

The result is a versatile architecture that can use various combinations of data bus sizes to achieve cost and performance goals. The architecture provides maximum performance and flexibility for high-end vertical applications, but contains functionality for a wider horizontal market that may demand less performance.

- A typical lower performance/lower cost system might implement 16-bit DRAM banks, an 8-bit ISA bus, an 8/16-bit PC Card bus, and use the internal graphic controller.
- A higher performance, full-featured system might include 32-bit DRAM, VL-bus to an external graphics controller, and a 16-bit ISA/PC Card bus.

The following basic data bus configuration rules apply. (A complete list of feature trade-offs to be considered in system design can be found in Section 1.3.)

- When the internal graphics controller on the ÉlanSC400 microcontroller is enabled, DRAM is always 16-bits wide, and no 32-bit targets are supported. This is because the graphics controller needs a guaranteed short latency for adequate video performance. If either 32-bit DRAMs, 32-bit ROMs, or the VL-bus is enabled, the internal graphics controller is unavailable.

Note that, as a derivative of the original ÉlanSC400 microcontroller, the ÉlanSC410 microcontroller shares the primary architectural characteristics of the ÉlanSC400 microcontroller described above, minus the graphics controller.

The following sections provide an overview of the features of the ÉlanSC400 and ÉlanSC410 microcontrollers, including on-chip peripherals and system interfaces.

1.2.1 Low-Voltage Am486 CPU Core (Chapter 3)

The ÉlanSC400 and ÉlanSC410 microcontrollers are based on the low-voltage Am486 CPU core. It includes the following features:

- 2.7–3.3-V operation reduces power consumption
- Industry-standard 8-Kbyte unified code and data write-back cache improves both CPU and total system performance by significantly reducing traffic on the DRAM bus.
- System Management Mode (SMM) facilitates designs requiring power management by providing a mechanism to control power to unneeded peripherals transparently to application software.

To reduce power consumption, the floating point unit has been removed from the Am486 CPU core. Floating point instructions are not supported on the ÉlanSC400 and ÉlanSC410 microcontrollers, although normal software emulation can be implemented easily.

The ÉlanSC400 and ÉlanSC410 microcontrollers use the industry-standard 486 instruction set. Software written for the 486 microprocessor and previous members of the x86 architecture family can run on the ÉlanSC400 and ÉlanSC410 microcontrollers.

1.2.2 Power Management (Chapter 5)

Power management on the ÉlanSC400 and ÉlanSC410 microcontrollers includes a dedicated power management unit and additional power management features built into each integrated peripheral. The ÉlanSC400 and ÉlanSC410 microcontrollers can use the following techniques to conserve power:

- Slow down clocks when the system is not in active use
- Shut off clocks to parts of the chip that are idle
- Switch off power to parts of the system that are idle
- Automatically reduce power use when batteries are low

The power management unit (PMU) controls stopping and changing clocks, SMI generation, timers, activities, and battery-level monitoring. It provides:

- Hyper-Speed, High-Speed, Low-Speed, Temporary Low-Speed, Standby, Suspend, and Critical Suspend modes
- Dynamically adjusted clock speeds for power reduction
- Programmable activity and wake-up monitoring
- General-purpose I/O pins to control external devices and external power management
- Battery low and AC power monitoring
- SMI/NMI synchronization and generation

1.2.3 Clock Generation (Chapter 6)

The ÉlanSC400 and ÉlanSC410 microcontrollers require only one 32.768 KHz crystal to generate all the other clock frequencies required by the system. The output of the on-chip crystal oscillator circuit is used to generate the various frequencies by utilizing four Phase-Locked Loop (PLL) circuits. An additional PLL in the CPU is used for Hyper-Speed mode.

1.2.4 ROM/Flash Interface (Chapter 8)

The integrated ROM/Flash interface supports the following features:

- 8-, 16-, and 32-bit ROM/Flash interfaces
- Three ROM/Flash chip selects
- Burst-mode ROMs
- ROM accesses at both ISA and CPU speeds (normal and fast-speed modes)
- Dedicated ROM Read and ROM Write signals for better performance

Each ROM space can accommodate up to 64 Mbytes of ROM. The three ROM spaces may be individually write-protected. This is useful for protecting code residing in Flash devices.

Three ROM access modes are supported: Normal mode, Fast mode, and Burst mode. A different set of timings is used in each mode. In Normal ROM access mode, the bus cycles follow ISA-like timings. In Fast ROM access mode, the bus cycle timing occurs at the CPU clock rate with controls for wait state insertion. Burst ROM access timing is used when the ROM/Flash interface is fulfilling an internal CPU burst request to support a cache line refill.

Wait states are supported for all ROM and Flash accesses, including burst mode. Burst-mode (page-mode) ROM reads are supported for either 16- or 32-bit ROM interface running in Fast mode.

1.2.5 DRAM Controller (Chapter 9)

The integrated DRAM controller provides the signals and associated timing necessary to support an external DRAM array with minimal software programming and overhead. Internal programmable registers are provided to select the DRAM type and operating mode, as well as refresh options. A wide variety of commodity DRAMs are supported, and substantial flexibility is built into the DRAM controller to optimize performance of the CPU and (on the ÉlanSC400 microcontroller) the internal graphics controller, which uses system DRAM for its buffers.

The DRAM controller supports the following features:

- 3.3-V, 70-ns DRAMs
- Up to four banks
- 16-bit or 32-bit banks
- Up to 64 Mbytes of total memory
- Self-refresh DRAMs
- Fast page and Extended Data Out (EDO) DRAMs
- Two-way interleaved operation among identically populated banks using fast-page mode devices
- Mixed depth and width of DRAM banks in non-interleaved mode
- Symmetrical and asymmetrical DRAM support

1.2.6 Integrated Standard PC/AT Peripherals

The ÉlanSC400 and ÉlanSC410 microcontrollers include all the standard peripheral controllers that make up a PC/AT system.

1.2.6.1 Dual DMA Controllers (Chapter 10)

Dual, cascaded, 8237A-compatible DMA controllers provide seven user DMA channels. Of the seven internal channels, four are 8-bit channels and three are 16-bit channels. Channel 4 is used for the cascade function.

Any two of the seven channels can be mapped simultaneously to external DMA request/acknowledge lines.

The DMA controller on the ÉlanSC400 and ÉlanSC410 microcontrollers is software-compatible with the PC/AT cascaded 8237 controller pair. Its features include:

- Single, block, and demand transfer modes
- Enable/disable channel controller
- Address increment or decrement
- Software priority
- 64-Mbyte system address space for increased performance
- Dynamic clock-enable design reduces clocked elements during DMA inactivity
- Programmable clock frequency for performance

1.2.6.2 Dual Interrupt Controllers (Chapter 11)

Dual, cascaded, 8259-compatible programmable interrupt controllers support 15 user interrupt levels. Eight external interrupt requests can be mapped to any of the 15 internal IRQ inputs.

The interrupt controller block includes these features:

- Software-compatibility with PC/AT interrupt controllers
- 15-level priority controller
- Programmable interrupt modes
- Individual interrupt request mask capability
- Accepts requests from peripherals
- Resolves priority on pending interrupts and interrupts in service
- Issues interrupt request to processor
- Provides interrupt vectors for interrupt service routines
- Tied into the PMU for power management

The interrupt controller block is functionally compatible with the standard cascaded 8259A controller pair as implemented in the PC/AT system. The master controller drives the CPU's interrupt input signal based on the highest priority interrupt request pending at the master controller's IRQ7–IRQ0 inputs. The master IRQ2 input is configured for Cascade mode and is driven only by the slave controller's interrupt output pin. The highest pending interrupt at the slave's IRQ inputs will therefore drive the IRQ2 input of the master.

The interrupt controller has programmable sources for interrupts that are controlled through extended configuration registers and (on the ÉlanSC400 microcontroller) through PC Card controller configuration registers.

1.2.6.3 Programmable Interval Timer (PIT) (Chapter 12)

The programmable interval timer on the ÉlanSC400 and ÉlanSC410 microcontrollers is software-compatible with PC/AT 8254 system timers. The PIT provides three 16-bit counters that can be operated independently in six different modes. The PIT is generally used for timing external events, counting and producing repetitive waveforms. The PIT can be programmed to count in binary or in BCD.

1.2.6.4 Real-Time Clock (RTC) (Chapter 13)

The RTC designed into the ÉlanSC400 and ÉlanSC410 microcontrollers is compatible with the MC146818A device used in PC/AT systems. The RTC consists of time-of-day clock with alarm interrupt and a 100-year calendar. The clock/calendar has a programmable periodic interrupt, 114 bytes of static user RAM, and can be represented in either binary or BCD. The RTC includes the following features:

- Counts seconds, minutes, and hours of the day
- Counts days of the week, date, month, and year
- 12–24 hour clock with AM and PM indication in 12-hour mode
- 14 clock, status, and control registers
- 114 bytes of general purpose RAM
- Three interrupts are separately software-maskable and testable
  - — Time-of-day alarm is programmable to occur from once-per-second to once-per-day
  - — Periodic interrupts can be continued to occur at rates from 122 μs to 500 ms
  - — Update-ended interrupt provides cycle status
- Dedicated power pin directly supports lithium backup battery when the rest of the chip is completely powered down (RTC-only mode)
- Voltage monitor circuit checks the voltage level of the lithium backup battery and sets a bit when the battery is below specification.
- Internal RTC reset signal performs a reset when power is applied to the RTC core.

1.2.6.5 PC/AT Support Features (Chapter 4)

The ÉlanSC400 and ÉlanSC410 microcontrollers provide all of the support functions found in the original IBM PC/AT. These include the Port B status and control bits, speaker control, SCP-based CPU-core reset, and A20 gate control, as well as extensions for fast CPU core reset and A20 gate control. In addition, a CPU shutdown cycle (e.g., as a result of a triple fault) will generate a CPU core reset.

1.2.7 Bidirectional Enhanced Parallel Port (EPP) (Chapter 14)

The parallel port on the ÉlanSC400 and ÉlanSC410 microcontrollers is functionally compatible with IBM PC/AT and PS/2 systems, with an added EPP mode for faster transfers. The microcontroller's parallel port interface provides all the status inputs, control outputs, and the control signals necessary for the external parallel port data buffers.

The parallel port interface on both microcontrollers is shared with some of the GPIO signals and, on the ÉlanSC400 microcontroller, with the second PC Card socket interface. Only one of these interfaces can be enabled at one time.

The parallel port interface can be configured to operate in one of three different modes of operation:

- **PC/AT Compatible mode**–This mode provides a byte-wide forward (host-to-peripheral) channel with data and status lines used according to their original (Centronics) definitions in the IBM PC/AT.
- **Bidirectional mode**–This mode offers byte-wide bidirectional parallel data transfers between host and peripheral, equivalent to the parallel interface on the IBM PS/2.
- **Enhanced Parallel Port (EPP) mode** –This mode provides a byte-wide bidirectional channel controlled by the microcontroller. It provides separate address and data cycles over the eight data lines of the interface with an automatic address and data strobe for the address and data cycles, respectively. EPP mode offers wider system bandwidth and increased performance over both the PC/AT Compatible and Bidirectional modes.

1.2.8 Serial Port (Chapter 15)

The ÉlanSC400 and ÉlanSC410 microcontrollers include an industry-standard 16550A UART. The UART can be used to drive a standard 8-pin serial interface or a 2-pin infrared interface. The 8-pin serial interface and infrared interface pins are available on the ÉlanSC400 and ÉlanSC410 microcontrollers at all times, though only one is available at any given time.

The UART powers up as a 16450-compatible device. It can be switched to and from the FIFO (16550) mode under software control. In the FIFO mode, the receive and the transmit circuitry are each enhanced by separate 16-byte FIFOs to off-load the CPU from repetitive service routines.

The serial port includes the following features:

- Eight pin interface: serial in, serial out, two modem control lines, and four modem status lines
- Separately enabled receiver line status, receiver data, character time-out, transmitter holding register, and modem status interrupts
- Baud rate generator provides input clock divisor from 1 to 65535 to create 16x clock
- 5, 6, 7, or 8 bit data
- Even, odd, stick, or no parity generation and checking
- 1, 1-1/2 or 2 stop-bit generation
- Break generation/detection

1.2.9 Keyboard Interfaces (Chapter 16)

The integrated keyboard controller has the following features:

- Matrix keyboard support with up to 15 rows and 8 columns
- Hardware support for software emulation of the System Control Processor (SCP) emulation logic
- XT keyboard interface

1.2.10 Programmable General-Purpose Inputs and Outputs (Chapter 17)

The chip supports several general-purpose I/O pins (GPIOs) that can be used on the system board. There are two classifications of GPIO available, the GPIOx signals, which are programmable as inputs or outputs only, and the GPIO_CSx signals.

The GPIO_CSx signals have many programmable options. They can be configured as chip selects. As outputs, these pins are individually programmable to be High or Low for the following PMU modes: Hyper, High-Speed, Low-Speed, Standby, and Suspend. As inputs or outputs, they can be programmed to cause System Management Interrupts (SMIs), Non-Maskable Interrupts (NMIs), wake ups, or activities for the power management unit. They can also be used as I/O or memory chip selects.

1.2.11 Infrared Port (Chapter 18)

The ÉlanSC400 and ÉlanSC410 microcontrollers support infrared data transfer. This support consists of adding additional transmit and receive serializers as well as a controlling state machine and DMA interface to the internal UART.

The integrated infrared port includes these features:

- Low-speed mode supports all bit rates from UART, up to 115 Kbit/s
- High-speed mode transfers 1.152 Mbit/s using DMA

1.2.12 Dual PC Card Controller (Chapter 19) (ÉlanSC400 Microcontroller Only)

The PC Card host bus adapter included on the ÉlanSC400 microcontroller conforms to *PCMCIA Standard Release 2.1*. It provides support for two sockets, each implementing the PC Card memory and I/O interfaces. The PC Card controller is not supported on the ÉlanSC410 microcontroller.

The PC Card controller includes the following features:

- ExCA-compliant, 82365-register-set compatible
- 8- and 16-bit data bus
- DMA transfers between I/O PC cards and system DRAM
- Ten available memory windows, five per socket

Of the two PC Card sockets supported, only one is available in all modes of operation. The second socket is multiplexed with the parallel port and GPIO features.

Register set compatibility with the 82365SL PC Card Interface Controller is maintained where features are common to both controllers.

Of the ten memory windows available, six are dedicated to the PC Card controller and four are shared with MMS Windows C–F.

1.2.13 Graphics Controller for CGA-Compatible Text and Graphics (Chapter 20) (ÉlanSC400 Microcontroller Only)

The graphics controller included on the ÉlanSC400 microcontroller offers a low-cost integrated graphics solution for the mobile terminal market. Integration with the main processor and system logic affords the advantages of an integrated local-bus interface and frame and font buffers which are shared with main memory. The graphics controller is not supported on the ÉlanSC410 microcontroller.

The graphics controller includes the following features:

- Supports multiple panel resolutions
- Provides internal unified memory architecture (UMA) with optional write-through caching of graphics buffers
- Stores frame and font buffer data in system DRAM, eliminates extra memory chip
- Provides software compatibility with Color Graphics Adapter (CGA), Monochrome Display Adapter (MDA), and Hercules Graphics Adapter (HGA) text and graphics
- Supports single-scan or dual-scan monochrome LCD panels with 4- or 8-bit data interface
- Typical panels supported include:
  - — 640x200, 640x240, 640x480, 480x320, 480x240, 480x128, 320x200, 320x240
  - — Other resolutions may be supported
- Supports single-scan color STN panels with 8-bit interface, same resolutions as monochrome mode
- Internal local-bus interface provides high performance
- Logical screen may be larger than physical window.
- Supports panning and scrolling
- Supports horizontal dot doubling and vertical line doubling

The following MDA/CGA-compatible text mode features are supported:

- 40, 64, or 80 columns with characters 16, 10, or 8 pixels wide
- Variable height characters up to 32 lines
- Variable width characters—8, 10, or 16 pixels
- MDA Monochrome, or CGA 4 gray shades, 16 gray shades, or 16-colors
- 16-Kbyte downloadable font area, relocatable on 16-Kbyte boundaries within lower 16 Mbytes of system DRAM (may be write protected)
- 16-Kbyte frame buffer, relocatable on either 16-Kbyte boundaries within lower 16 Mbytes of system DRAM (CGA-compatible mode) or 32-Kbyte boundaries when the frame buffer is larger than 16 Kbytes (flat-mapped mode)

The following graphics mode features are supported:

- 640x200 1 bit-per-pixel, CGA-compatible graphics buffer memory map
- 320x200 2 bits-per-pixel, CGA-compatible graphics buffer memory map
- 640x480 2 bits-per-pixel, flat memory map (lower resolutions supported)

- 640x480 1 bit-per-pixel, flat memory map
- 1, 2, or 4 bits-per-pixel packed-pixel flat-mapped graphics up to 640x240/480x320 with two mapping modes:
  - — 16-Kbyte window with bank swapping to address up to 64 Kbytes of graphics frame buffer while consuming only 16 Kbytes of DOS/Real-mode CPU address space
  - — Direct-mapped (no bank swapping) with locatable base address, up to 128-Kbyte direct addressability
- Hercules Graphics mode emulation (HGA)

1.2.14 JTAG Test Features (Chapter 21)

The ÉlanSC400 and ÉlanSC410 microcontrollers provide a boundary-scan interface based on the *IEEE Std 1149.1, Standard Test Access Port and Boundary-Scan Architecture*. The test access port provides a scan interface for testing the microcontroller and system hardware in a production environment. It contains extensions that allow a hardware-development system to control and observe the microcontroller without interposing hardware between the microcontroller and the system.

1.2.15 System Interfaces (Chapter 4)

1.2.15.1 Data Buses

The ÉlanSC400 and ÉlanSC410 microcontrollers provide 32 bits of data that are divided into two separate 16-bit buses.

- **System Data Bus**—The system (or peripheral) data bus (SD15-SD0) is always 16 bits wide and is shared between ISA, 8- or 16-bit ROM/Flash, and PC Card peripherals. It can be directly connected to all of these devices. In addition, these signals are the upper word of the VESA local (VL) data bus, the 32-bit DRAM interface, and the 32-bit ROM interface.
- **Data Bus**—The D15–D0 data bus is used during 16-bit DRAM cycles. For 32-bit DRAM, VL-bus, and ROM cycles, this bus is combined with the system data bus. In other words, the data bus pins D31–D16 are shared with the system data bus pins SD15–SD0.

The ÉlanSC400 and ÉlanSC410 microcontrollers support the data bus configurations listed below. External transceivers or buffers are required in some bus configurations to isolate the buses and to provide proper data steering.

- 16-bit DRAM bus, 8/16-bit ROM, 32-bit VL-bus disabled, internal graphics controller enabled/disabled
- 16/32-bit DRAM bus, 8/16-bit ROM, 32-bit VL-bus enabled/disabled, internal graphics controller disabled
- 16/32-bit DRAM bus, 32-bit ROM, 32-bit VL-bus enabled/disabled, internal graphics controller disabled

See Figure 1-3 and Figure 1-4 for block diagrams of example systems.

The ÉlanSC400 and ÉlanSC410 microcontrollers offer flexibility in configuring the ROM and DRAM data buses for different widths. The widths (8/16/32 bits) for $\overline{\text{ROMCS0}}$ are programmed during power-up through two pin straps, CFG0 and CFG1. The DRAM widths (16/32 bits) are programmed through configuration registers. Up to four 16- or 32-bit banks of DRAM are supported.

1.2.15.2 Address Buses

There are two external address buses on the ÉlanSC400 and ÉlanSC410 microcontrollers.

- **System Address Bus**—The SA25–SA0 system address bus outputs the physical memory or I/O port latched addresses. These addresses are used by all external peripheral devices other than main system DRAM. In addition, the system address bus is the local address bus in VL-bus mode.
- **DRAM Address Bus**—DRAM row and column addresses are multiplexed onto the DRAM address bus (MA12–MA0). Row addresses are driven onto this bus and are valid upon the falling edge of $\overline{RAS}$. Column addresses are driven onto this bus and are valid upon the falling edge of $\overline{CAS}$.

The SA bus is shared between the ISA bus, the VL-bus, the ROM/Flash controller, and, on the ÉlanSC400 microcontroller, the PC Card controller. The ÉlanSC400 and ÉlanSC410 microcontrollers provide programmable drive strengths in the I/O buffers to accommodate loading for various system configurations.

1.2.15.3 Memory Management (Chapter 7)

The ÉlanSC400 and ÉlanSC410 microcontrollers manage up to nine separate physical device memory address spaces. All but the ISA memory address space can have a depth of up to 64 Mbytes each. The ISA bus memory area is limited to 16 Mbytes. The nine memory spaces are listed below.

- System memory address space (DRAM)
- ROM0 memory address space ($\overline{ROMCS0}$ pin)
- ROM1 memory address space ($\overline{ROMCS1}$ pin)
- ROM2 memory address space ($\overline{ROMCS2}$ pin)
- PC Card Socket A memory address spaces (common and attribute) (ÉlanSC400 microcontroller only)
- PC Card Socket B memory address spaces (common and attribute) (ÉlanSC400 microcontroller only)
- External ISA/VL-bus memory address space

The system memory address space (DRAM) is accessible using direct-mapped CPU addresses and can also be accessed by the CPU in an indirect method using the Memory Mapping System (MMS). DRAM is also accessible by the integrated graphics controller on the ÉlanSC400 microcontroller, if enabled.

The ROM0 address space is partially accessible via a direct mapping of the CPU address bus and partially accessible via the MMS. The ROM1 and ROM2 address spaces are only accessible indirectly using the MMS.

On the ÉlanSC400 microcontroller, the PC Card address spaces are accessed through a separate, 82365SL-compatible address mapping system.

The ISA/VL-bus address space is accessible as a direct mapping of the CPU address bus. ISA memory cycles are generated when the CPU generates a memory cycle that is not detected as an access to any other memory space. An ISA bus memory cycle may also be generated if the CPU generates a memory address that resides in the ISA overlapping memory region window. This window can be defined to overlay any system memory region below 16 Mbytes.

1.2.15.4 ISA Bus Interface For External ISA Peripherals (Chapter 4)

The ISA interface consists of a subset of ISA-compatible bus signals, allowing for the connection of 8- or 16-bit devices supporting ISA-compatible I/O, memory, and DMA cycles. The following features are supported:

- 8.2944 MHz maximum bus clock speed
- Programmable DMA clock speed up to 16 MHz
- 8-bit and 16-bit ISA I/O and memory cycles (ISA memory is non-cacheable)
- Direct connection to 3- or 5-volt peripherals

Eight programmable IRQ input pins are available. These interrupts may be routed via software to any available PC/AT-compatible interrupt channel.

Two programmable DMA channels are available for external DMA peripherals. These DMA channels may be routed to software to any available ISA DMA channel.

1.2.15.5 VESA Local (VL) Bus Interface Supports 32-Bit Memory and I/O Targets (Chapter 4)

The VESA local (VL) bus controller provides the signals and associated timing necessary to support a single VESA compliant VL-bus target. Multiple VL-bus targets can be supported using external circuitry to allow multiple VL devices to share the $\overline{\text{VL_LDEV}}$ signal. This allows the ÉlanSC400 and ÉlanSC410 microcontrollers to operate as a normal VL-bus motherboard controller, in accordance with the *VL-Bus Standard 2.0*.

On the ÉlanSC400 microcontroller, the VL-bus is available only when the internal graphics controller is disabled.

The microcontroller's VL-bus controller includes the following features:

- 33-MHz operation at 3.3 V
- 32-bit data bus
- Burst-mode transfers
- Register control of local bus reset

VESA bus mastering and DMA transfers to and from the VL-bus target are not supported. VL memory is non-cacheable.

1.3 SYSTEM CONSIDERATIONS

Figure 1-3 shows the ÉlanSC400 microcontroller as it might be used in a typical mobile terminal design.

Figure 1-4 and Figure 1-5 show more complex system designs for each microcontroller and the features that are traded for others because of pin multiplexing.

- The ÉlanSC400 and ÉlanSC410 microcontrollers support a maximum of 4 banks of 32-bit DRAM, but because the $\overline{\text{RAS}}$ and $\overline{\text{CAS}}$ signals for the high word and for banks 2 and 3 are traded for keyboard row signals, the minimum system would have one or two banks of DRAM (either Bank 0 or Bank 1) populated with 16-bit DRAMs. The MA12 signal for asymmetrical support is also traded with a keyboard row signal.
- Because the VL-bus and the graphics controller share control signals on the ÉlanSC400 microcontroller, use of the internal graphics controller is traded with having an external VL-bus on that microcontroller.
- If either 32-bit DRAMs, 32-bit ROMs, or the VL-bus is enabled, the internal graphics controller on the ÉlanSC400 microcontroller is unavailable because of internal design constraints.
- The ÉlanSC400 and ÉlanSC410 microcontrollers provide an absolute minimum of dedicated ISA control signals. Any additional ISA controls are traded with GPIOs or keyboard rows and columns.
- The SD buffer shares control signals with some of the GPIOs. This buffer controls the high word of the D data bus (D31–D16). Note that using the SD buffer is optional. The high word of the D data bus can be hooked up directly to devices that want the SD data bus (SD15–SD0). Buffering aids in voltage translation or isolation for heavy loading.
- The $\overline{\text{R32BFOE}}$ signal buffers the high word of the D data bus (D31–D16) for 32-bit ROMs. The control signal associated with the ROM32 buffer is shared with a keyboard row.
- On the ÉlanSC400 microcontroller, the parallel port is traded for PC Card Socket B. It requires an external buffer and latch.
- The serial and infrared ports share the same internal UART. Real-time switching between the two is supported; however, only one is available at any given time.
- $\overline{\text{ROMCS2}}$ is not connected to a dedicated pin. Software may enable and map it to any of the 15 GPIO_CS pins.

Figure 1-3 Typical Mobile Terminal Design—ÉlanSC400 Microcontroller

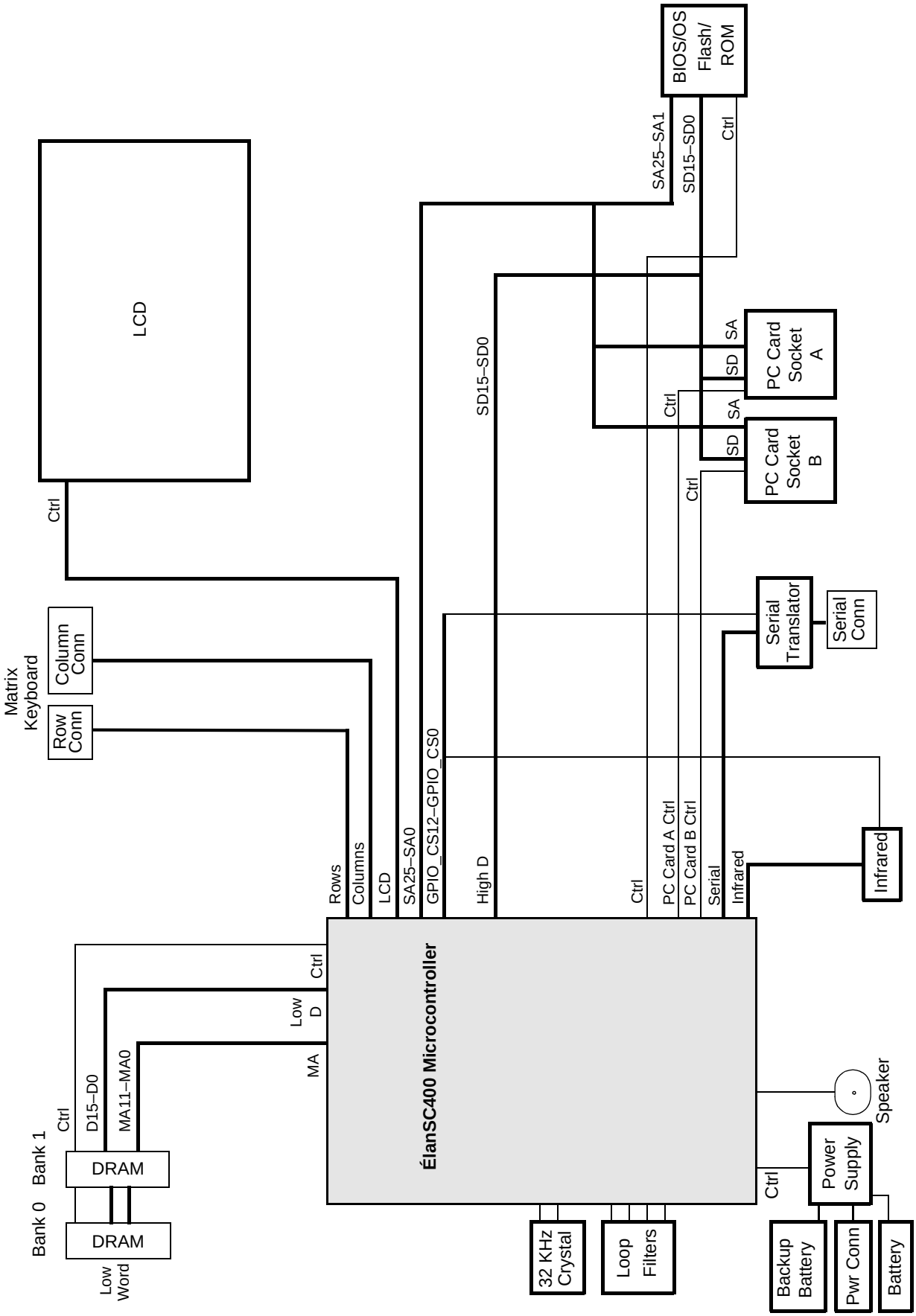


Figure 1-4 System Diagram with Trade-offs—ÉlanSC400 Microcontroller

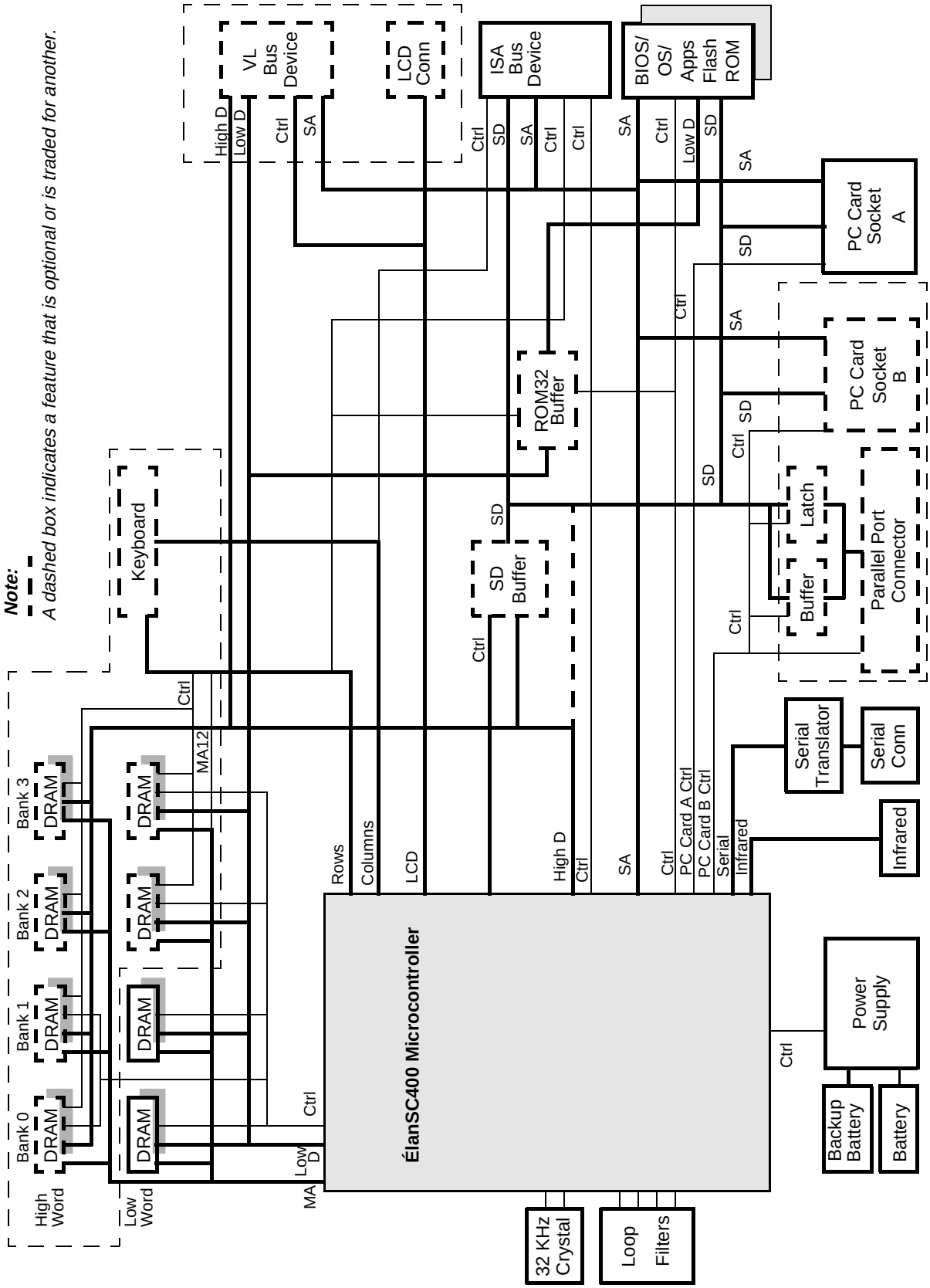
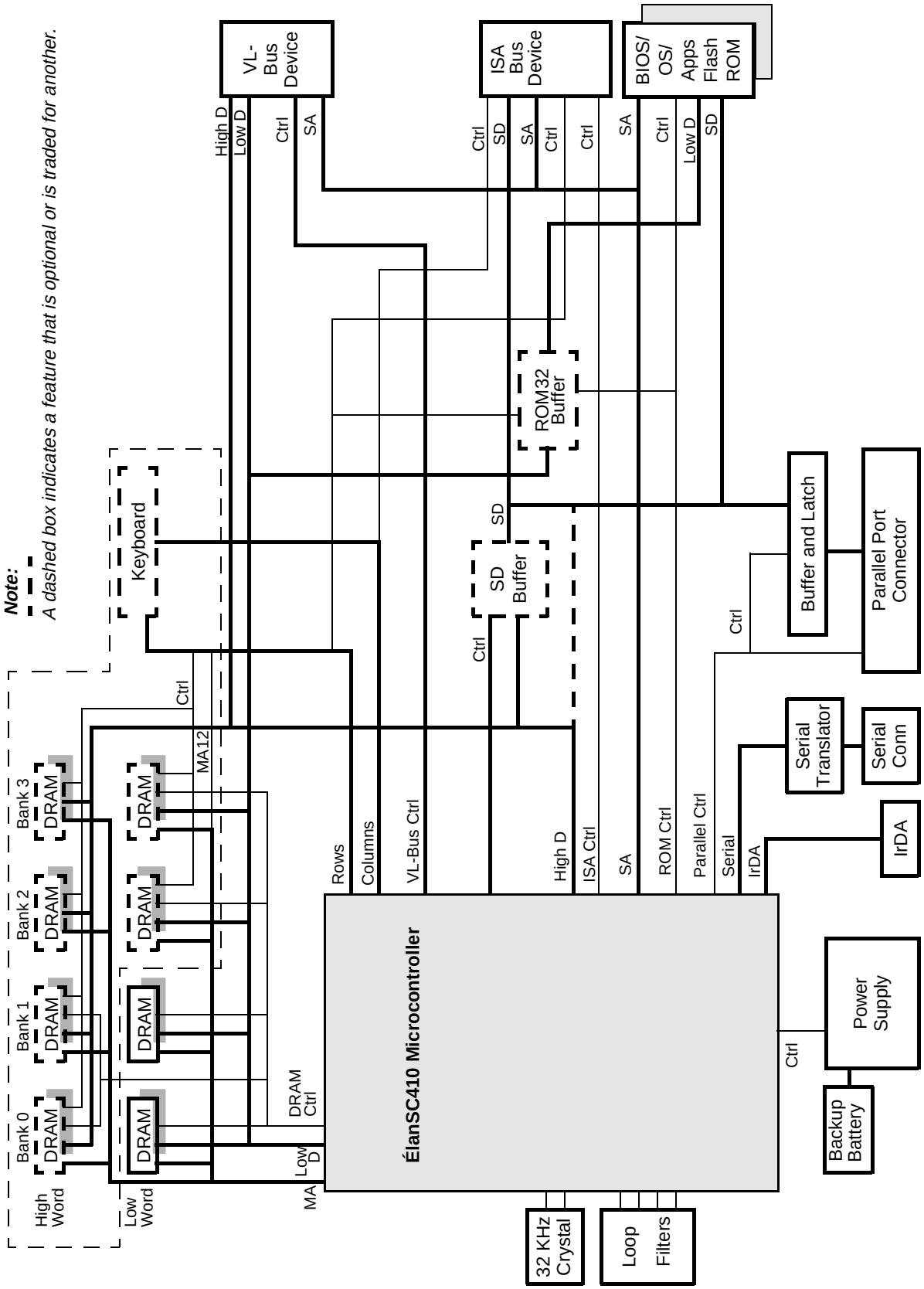


Figure 1-5 System Diagram with Trade-offs—ÉlanSC410 Microcontroller



CHAPTER

2 CONFIGURATION BASICS

2.1 OVERVIEW

This chapter provides basic information about configuring the ÉlanSC400 and ÉlanSC410 microcontrollers. It discusses the various configuration and control register spaces available on the chip, and briefly describes the pin-strapping options available.

The word *configuration* is used to indicate chip setup that is typically done once during system initialization, whereas *operational control* (abbreviated to "control") is used to indicate operations that must be performed as an integral part of actually doing work with the chip. For example, on the ÉlanSC400 microcontroller, selecting the number of PC card sockets that will be available to the system is a clear example of configuration, whereas using the PC card controller registers to turn on power to a PC card socket is an example of operational control.

The term *register* refers to a data storage element.

The term *port* refers to an I/O address that is read from or written to in order to access data that is stored in an associated register.

2.2 CONFIGURATION METHODS

The ÉlanSC400 and ÉlanSC410 microcontrollers can be configured to operate in several different modes, or to have certain operational characteristics that are selected by the system designer.

Any modes that must be available immediately upon system reset (i.e., boot ROM data path width) are configured via pin-strapping options.

The term *pin-strapping* as used in this chapter refers to connecting a weak external terminating resistor to certain pins of the ÉlanSC400 and ÉlanSC410 microcontrollers. These pins are sampled at reset time, and their states at that time are used to configure specific aspects of the chip. The pins used for this on the ÉlanSC400 and ÉlanSC410 microcontrollers are not dedicated to this function. As soon as the reset is deasserted and normal system operation begins, the pins are used to implement part of the DRAM interface. (See Section 4.1.1.1 for more detail.)

Each of the pin-strap pins has a very weak internal pull-down resistor. Thus, if no external termination is connected, the configuration will act as if external pull-downs were applied. To select the alternate pin-strap function for a particular pin, a stronger pull-up must be applied externally. The external pull-ups, if used, should be 10 kilohms.

Most configuration options do not need to be configured before the boot code begins to execute. In these cases, system firmware must configure the chip using Chip Setup and Control (CSC) registers that are unique to the ÉlanSC400 and ÉlanSC410 microcontrollers and are accessed using direct-mapped I/O ports 22h/23h as described in the following section. Although some configuration options are controlled by non-CSC registers, the vast majority of system configuration is done using the CSC registers.

2.3 CONFIGURATION REGISTER SPACES AND INDEXED ADDRESSING

2.3.1 Direct-Mapped Registers

The ÉlanSC400 and ÉlanSC410 microcontrollers contain hundreds of configuration and control registers. Some of these registers are accessed directly without using an indexed addressing scheme. Many of the PC/AT legacy registers fall into this category. An example of a direct-mapped register is the System Control Port A Register, which can be accessed using x86 assembly language shown below. (Note that accesses to direct-mapped registers with 8-bit addresses can omit the use of the DX Register.)

```
in      AL,92h          ;Read the register
.
.
mov     AL,1
out     92h,AL          ;Write a value of 1 to System Control Port A
```

Accesses to direct-mapped registers with 16-bit addresses must use the DX Register (as is the case for any x86-compatible CPU) as follows:

```
mov     DX,3FFh
mov     AL,0AAh
out     DX,AL           ;Write a value of AAh to the serial port scratch
                        ;pad register.
```

Table 2-1 shows a summary of the direct-mapped registers that are implemented in the ÉlanSC400 and ÉlanSC410 microcontrollers.

Table 2-1 Internal I/O Port Address Map

Internal I/O Device	I/O Address Range
Slave DMA (DMA1)	0000–000Fh
Master Programmable Interrupt Controller (PIC)	0020–0021h
CSC Index, Data	0022h, 0023h
Programmable Interval Timer (PIT)	0040–0043h
Keyboard	0060h, 0064h
System Control Port B/NMI Status	0061h
RTC Index, Data	0070h, 0071h
General 8x Registers	0080h, 0084–0086h, 0088h, 008C–008Fh
DMA Page Registers	0081–0083h, 0087h, 0089–008Bh
System Control Port A	0092h
Slave PIC	00A0–00A1h
Master DMA (DMA0)	00C0–00DEh (even addresses only)
Alternate A20 Gate Control	00EEh
Alternate CPU Reset Control	00EFh
Parallel Port LPT2	0278–027Fh
Serial Port COM2	02F8–02FFh
Parallel Port LPT1	0378–037Fh
MDA Graphics Index, Data	03B4h, 03B5h
CGA Graphics Index, Data	03D4h, 03D5h
PC Card Index, Data	03E0h, 03E1h
Serial Port COM1	03F8–03FFh

2.3.2 Indirect-Mapped Registers (Indexed Registers)

While most of the PC/AT legacy registers are direct-mapped, the vast majority of the configuration and control registers are *indirect-mapped* or *indexed*.

When adding registers to a particular architecture, one must be careful to maintain compatibility with the existing registers. Because of the openness of the ISA architecture and the length of time that the architecture has been evolving, this can be difficult to do. It is impossible to say *exactly* what "PC/AT compatibility" is at this point. The use of an indexed addressing scheme makes this compatibility task easier by creating separate address spaces in which the new registers can be placed, thus avoiding the possibility for new registers to conflict with legacy registers. This technique is far from new; it has been used in the PC/AT architecture since the original PC used it for the Monochrome Display Adapter (MDA) register interface.

The term *index* appears often in the following text. An *indexed register* is one that is accessed via an index, or secondary address, into an array of registers. Because of the use of this secondary address, the indexed register may be thought of as residing in a separate *indexed register I/O space.* The secondary address itself is often referred to as an *index* with many of the same properties as the index of an array. Finally, the storage element itself which holds the index while data is being read from or written to an indexed register is known as *the index register*.

There are four indexed register spaces on the ÉlanSC400 and ÉlanSC410 microcontrollers. The names of these spaces, and the direct-mapped port addresses through which their index and data registers are accessed are listed in Table 2-2. Refer to the appropriate chapter in this manual for detailed information on the function and usage of registers within the indexed register spaces. Refer to the *Élan™ SC400 Microcontroller Register Set Reference Manual* for bit-level reference information concerning registers in these indexed spaces.

Table 2-2 Indexed Register Space

Indexed Register Space	Access through Direct-Mapped Ports
Chip Setup and Control (CSC)	0022h = index; 0023h = data
Real-Time Clock (RTC) and CMOS RAM	0070h = index; 0071h = data
LCD Graphics Controller (ÉlanSC400 microcontroller only): MDA CGA	 03B4h = index,03B5h = data 03D4h = index, 03D5h = data
PC Card Controller (ÉlanSC400 microcontroller only)	03E0h = index, 03E1h = data

- **CSC indexed registers** are the main method for configuring the ÉlanSC400 and ÉlanSC410 microcontrollers and are discussed in more detail in Section 2.3.3.
- **RTC indexed registers** allow access to the real time clock configuration, time and date status, and the 114 bytes of CMOS RAM that is typically used by system firmware (BIOS) in a PC/AT-compatible system.
- **LCD graphics controller indexed registers** (ÉlanSC400 microcontroller only) allow LCD panel configuration and control. To conform to different standards in the PC/AT architecture, the LCD controller can use one of the two different index and data register port addresses listed above. If configured to support MDA (Monochrome Display Adapter) compatibility, 03B4h/03B5h are the port addresses that allow access to the

graphics controller's index and data registers. If CGA compatibility (Color Graphics Adapter) is configured, 03D4h and 03D5h are used instead.

- **PC Card indexed registers** (ÉlanSC400 microcontroller only) provide PC Card controller configuration, status, and control.

The indexed register spaces on the ÉlanSC400 and ÉlanSC410 microcontrollers are accessed via index and data registers, which are in turn accessed via sets of direct-mapped I/O ports. This is the "double addressing" mentioned earlier. For each indexed space, there is an index port and a data port.

For example, in the case of the original MDA, the index port was 03B4h, and the data port was 03B5h. In order to access an indexed register, first write an index to the index register (via the index port), and then write to or read from the data register (via the data port). An example of an access to the MDA registers follows:

```
mov     DX,3B4h          ;Access to IO ports with 16-bit addresses
                         ;requires the use of DX

mov     AL,10h           ;Select the MDA Light Pen Register
out     DX,AL            ;Write the index of the Light Pen Register
                         ;to the hardware
inc     DX               ;Point to the MDA data port
in      AL,DX            ;Read the MDA Light Pen Register into AL
```

Note that the CSC and RTC register sets listed in Table 2-2 have index and data ports that use only 8-bit addressing. Indexed register schemes that utilize 8-bit I/O port addressing have two main advantages over those that require 16-bit addresses. First, 8-bit addresses do not require the use of DX. The AL Register is the minimum requirement (see earlier examples). This can be useful if the initialization code needs to conserve CPU register use in cases where the DRAM is not available yet, etc. The second advantage of using 8-bit I/O addresses is that common 16-bit instructions can be used to store data very easily. For example, to store the value 81h to CSC index 65h (as shown in Figure 2-2), the following 16-bit I/O instruction may be executed:

```
mov     AX,08165h
out     22h,AX
```

This technique is widely used when a table of indexed registers needs to be written to known values. Simply create a table of registers and indexes, point to this table using the x86 SI register, and then use the x86 OUTSW (out string word) to write the desired data to the specified indexed register. This 16-bit I/O write with the OUTSW instruction is broken down internally into the two required 8-bit writes to the respective index and data registers.

Figure 2-1 and Figure 2-2 show the configuration and control registers spaces graphically.

Figure 2-1 Indexed Configuration Register Space

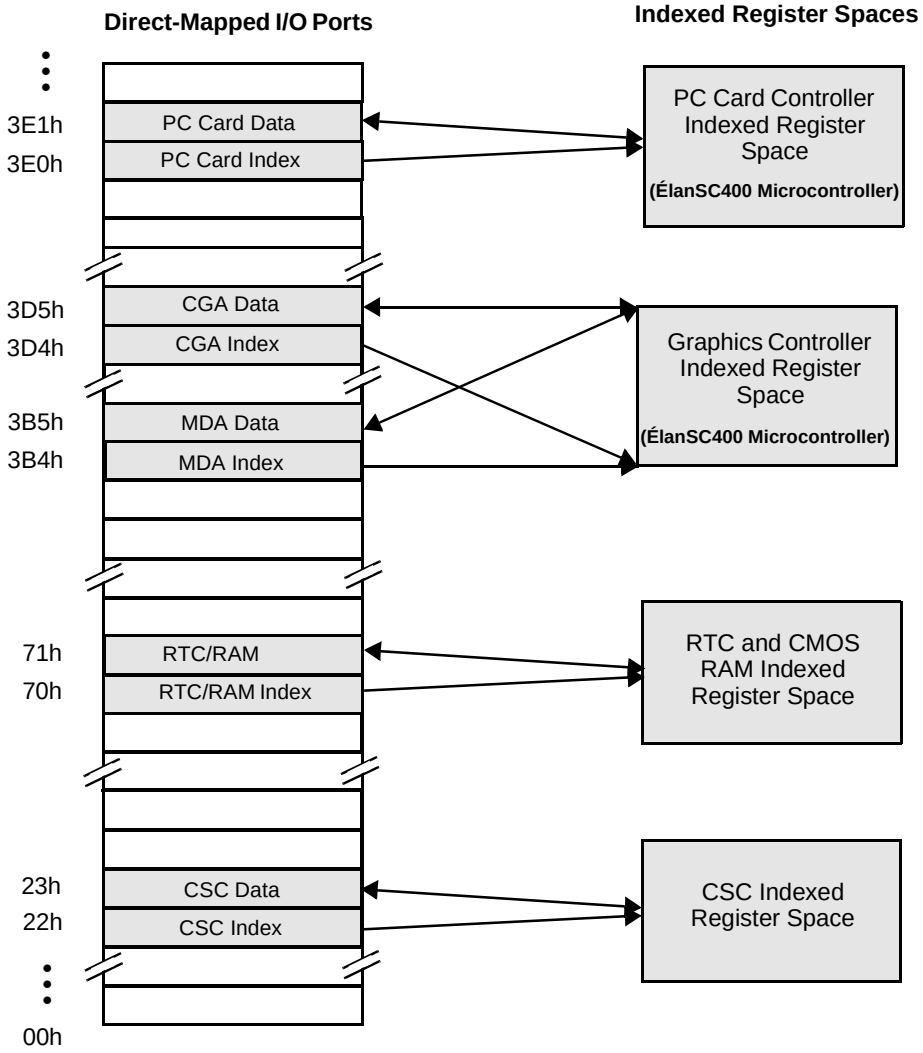
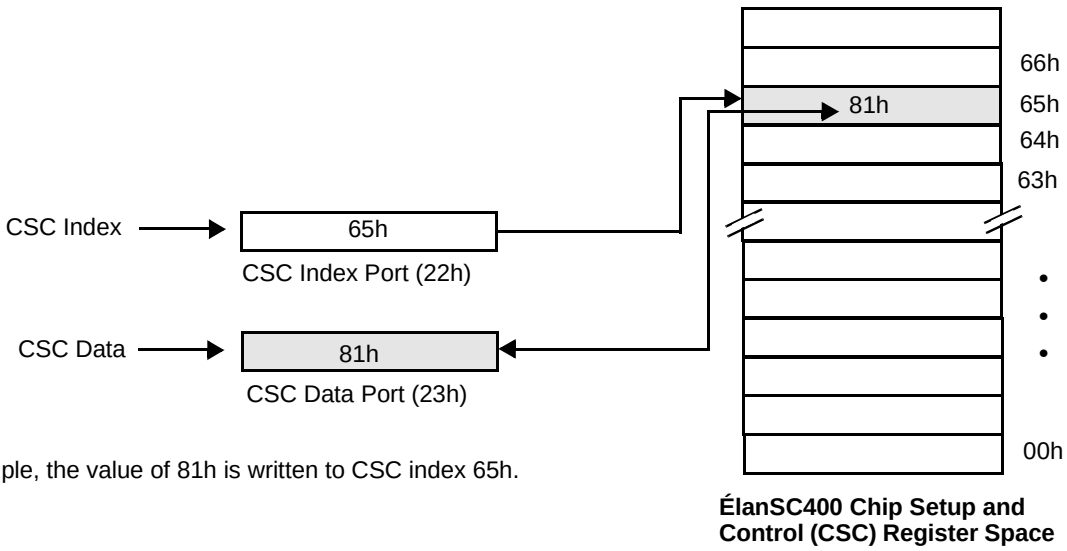


Figure 2-2 Using the Index and Data I/O Ports to Access CSC Register Space



In this example, the value of 81h is written to CSC index 65h.

2.3.3 Chip Setup and Control (CSC) Indexed Registers

The registers specific to the ÉlanSC400 and ÉlanSC410 microcontrollers that are indirectly accessed using ports 22h/23h are used for most of the important chip configuration.

It is important to remember that all of the index registers must be treated as system resources. Interrupt handlers, in particular, must always save any index register used by the handler and then restore the index register before returning control to the interrupted routine.

The indexes for these CSC registers were chosen such that related functions are, as much as possible, grouped together in the register map.

The groups start on either 8- or 16-byte boundaries in the map. For example, all of the DRAM control functions are accessed starting at CSC index 00h. Even though there are only eight DRAM control registers (indexes 00-07h), the next block (cache control) starts at 10h. Table 2-3 shows the organization of the CSC registers by functional grouping, and the index at which the group begins:

Table 2-3 Chip Setup and Control (CSC) Indexed Register Map

Start Index	Register Group Name
00h	DRAM Setup and Configuration
10h	Cache Control
20h	ROM Configuration, Setup, and Control
30h	MMS Configuration, Setup, and Control
38h	GPIO Pin Multiplexing and Termination
40h	PMU Mode Control and Status
50h	PMU Wake Up Control and Status
60h	PMU Activity Control and Status
70h	Battery Level (BL) Pin Control and Status
80h	Clock Control and Status
88h	Factory Level Debug Registers
90h	SMI/NMI Generation and Status
A0h	GPIO Pin Control, Status, and Multiplexing
C0h	Matrix and XT Keyboard Control and Status
D0h	Extended PC/AT Features and Peripheral Control
E0h	ISA Bus Configuration
EAh	Infrared Port Control and Status
F0h	PC Card Controller Configuration
FFh	Chip Revision

Note: *While all possible effort was made to group the controls for related functions together, some control bits affect several functional areas of the chip, and so may be located in a group other than expected. For a complete listing of registers that belong to each of the above groups, refer to the Élan™ SC400 Microcontroller Register Set Reference Manual.*

Do not mistake the PC Card controller configuration group as listed in Table 2-3 for the 82365-compatible indexed registers that are accessed via I/O ports 03E0h and 03E1h. This is a good example of configuration versus operational control. Configure the PC Card controller (will there be one socket or two?, DMA capable or not?, etc.) with the CSC indexed registers. When it is configured, operate the PC Card controller (control PC Card V_{CC}, V_{PP}, windows, etc.) with the PC Card controller indexed registers.

2.4 FEATURE TRADE-OFFS

The ÉlanSC400 and ÉlanSC410 microcontrollers are extremely versatile devices that can be configured to support several different feature sets. For example, on the ÉlanSC400 microcontroller, you can have either an LCD controller *or* a VESA Local bus, a second PC Card socket o*r* a parallel port, etc. All of these feature trade-offs are configured using CSC indexed registers, except the selection of the $\overline{\text{R32BFOE}}$ signal, which is an indirect result of selecting a 32-bit ROM interface via pin strapping options. For a complete list of system level trade-offs that are available for the ÉlanSC400 and ÉlanSC410 microcontrollers, see Section 1.3, on page 1-16.

2.4.1 Pin Multiplexing

To support these feature trade-offs, many pins on the ÉlanSC400 and ÉlanSC410 microcontrollers are also traded off (i.e., have multiple and usually mutually exclusive functions). Figure 4-1 and Figure 4-2 show the pins and their alternate functions for each microcontroller. A table showing how to configure each pin on the ÉlanSC400 and ÉlanSC410 microcontrollers can be found in Appendix A.

2.4.2 Pin Termination

When a particular function is configured to be available to the user/system, the functions of the pins on the ÉlanSC400 and ÉlanSC410 microcontrollers change accordingly. When the pin function changes, the termination of the pin can, and often does change. Where there may have been an internal pull-up, the signal may now just be three-stated, or have a pull-down connected.

Internal design considerations on the ÉlanSC400 and ÉlanSC410 microcontrollers require that system firmware “latch in” or activate the new termination(s) as a separate operation from the actual pin function selection. This is done by setting the TERM_LATCH bit in the Suspend Mode Pin State Override Register (CSC index E5h[0]) after configuring one or more of the pin functions. The typical usage is to configure the chip at boot time from system firmware, and then set the termination latch bit one time after all the configuration is complete.

There may be times, however, when the chip is reconfigured after the system firmware has performed the initial chip configuration. When all reconfiguration is completed, the TERM_LATCH bit must once again be set. Note that it does not hurt to set the TERM_LATCH bit over and over, but it will probably negatively affect system operation to fail to set it after changing pin functions.

Appendix B includes a listing of pins and their respective termination control bits. When any of the pin functions shown in Table B-1 are changed, the TERM_LATCH bit must be set.

CSC indexed registers that affect pad pull-up/pull-down termination include: 00–03h, 14h, 38–3Eh, A0–A5h, CAh, D1h, D2h, DDh, EAh, and F2h.

CHAPTER

3 Am486® CPU

3.1 OVERVIEW

The ÉlanSC400 and ÉlanSC410 microcontrollers are based on the low-voltage Am486 CPU core. It includes the following features:

- 2.7–3.3-V operation reduces power consumption
- Industry-standard 8-Kbyte unified code and data write-back cache improves both CPU and total system performance by significantly reducing traffic on the DRAM bus.
- System Management Mode (SMM) facilitates designs requiring power management by providing a mechanism to control power to unneeded peripherals transparently to application software.

To reduce power consumption, the floating point unit has been removed from the Am486 CPU core. Floating point instructions are not supported on the ÉlanSC400 and ÉlanSC410 microcontrollers, although normal software emulation can be implemented easily.

The ÉlanSC400 and ÉlanSC410 microcontrollers use the industry-standard 486 instruction set. All software written for the 486 microprocessor and previous members of the x86 architecture family can run on the ÉlanSC400 and ÉlanSC410 microcontrollers.

3.2 REGISTERS

A summary listing of the direct-mapped and chip setup and control (CSC) index registers used to control the CPU on the ÉlanSC400 and ÉlanSC410 microcontrollers is shown in Table 3-1. Complete register descriptions can be found in the *Élan™SC400 Microcontroller Register Set Reference Manual* (order #21032).

Table 3-1 CPU Control Register Summary

Register	I/O Address	CPU Control Function Keyword	Description in Register Set Manual
Direct-Mapped Registers			
RTC/CMOS RAM Index Register	0070h	Master NMI enable	page 2-52
Chip Setup and Control (CSC) Index Registers			
Non-Cacheable Window 0 Address/Attributes/SMM Register	22h/23h Index 11h	SMM cache enable and auto-flush on SMM entry	page 3-20
Cache and VL Miscellaneous Register	22h/23h Index 14h	CPU write-through or write-back cache select, write-back bus cycle status, flush cycle status, CPU shutdown cycle status, graphics memory write-through cache	page 3-23
Various SMI/NMI Enable and Status Registers	22h/23h Index 90–9Ch	See Chapter 5, Table 5-1 for complete listing.	various

Table 3-1 CPU Control Register Summary (continued)

Register	I/O Address	CPU Control Function Keyword	Description in Register Set Manual
XMI Control Register	22h/23h Index 9Dh	Master SMI enable	page 3-109
ÉlanSC400 Microcontroller Revision ID Register	22h/23h Index FFh	Major and minor stepping level of ÉlanSC400 and ÉlanSC410 microcontrollers	page 3-201

3.3 CPU FEATURES SPECIFIC TO THE ÉlanSC400 AND ÉlanSC410 MICROCONTROLLERS

The ÉlanSC400 and ÉlanSC410 microcontrollers are fully integrated systems in silicon, and the CPU is central to this integration. Most of the details of the communication between the CPU core and the peripherals are transparent to the user and are not documented here.

While we have tried to provide most of the information designers will require to incorporate the ÉlanSC400 and ÉlanSC410 microcontrollers into products, a full description of the operation of a 486 microprocessor is well beyond the scope of this chapter, which discusses programming issues related to this specific implementation, rather than general x86 or 486 programming.

Any bookstore with a good computer section will have many good books on x86 programming, and the following AMD publications are a good starting point for learning about the Am486 microprocessor as it has evolved over time. The oldest publication is listed first. The subsequent publications enhance the original functional descriptions.

- *Am486® DX/DX2 Microprocessor Hardware Reference Manual*, 1994 (order #17965)
- *Am486® Microprocessor Software User's Manual*, 1994, (order #18497)
- *Enhanced Am486® Microprocessor Family Data Sheet*, 1995, (order #19225)
- *Am5x86™ Microprocessor Family Data Sheet*, 1996 (order #19751)

The CPU core in the ÉlanSC400 and ÉlanSC410 microcontrollers is derived from the Enhanced Am486 microprocessor Family (as described in order #19225). The following differences may be relevant to the programmer:

- There is no floating point unit (FPU).
- There is no provision for an L2 cache.
- From a CPU-core perspective only, the cache is always in write-back mode and will report this state in response to the CPUID instruction. However, other logic within the ÉlanSC400 and ÉlanSC410 microcontrollers actually controls whether cache operation is write-through or write-back on an access-by-access basis. The true default on the ÉlanSC400 and ÉlanSC410 microcontrollers is write-through, although all accesses can be write-back, if desired. This is discussed in Section 3.4.

One feature of the enhanced Am486 CPU that is fully supported by the ÉlanSC400 and ÉlanSC410 microcontrollers is System Management Mode (SMM), which is a powerful mechanism for adding transparent BIOS support for device emulation and power management. Because SMM is unfamiliar to many experienced x86 programmers, its implementation in the ÉlanSC400 and ÉlanSC410 microcontrollers is covered in Section 3.5.

Because there are now many x86 CPU variants available from several different vendors, programs sometimes require the ability to determine the hardware they are running on. The ÉlanSC400 and ÉlanSC410 microcontrollers can themselves itself via the CPUID instruction. This is discussed in Section 3.6.

3.4 CACHE MEMORY MANAGEMENT

The ÉlanSC400 and ÉlanSC410 microcontrollers contain an 8-Kbyte unified code and data cache. Cache operation defaults to write-through, although write-back mode can be enabled at any time by setting bit 0 in the Cache and VL Miscellaneous Register (CSC index 14h[0]).

Only the L1 cache is supported on the ÉlanSC400 and ÉlanSC410 microcontrollers; there is no support for an L2 cache.The L1 cache can be configured through the standard cache configuration bits in the CPU's machine status register (CRO register). The CD (cache disable bit [bit 30]) and NW (not write-through [bit 29]) are decoded as shown in Table 3-2.

Table 3-2 Cache Configuration Options

CD	NW	Operating Mode
1	1	Cache line fills, cache write-throughs, and cache invalidations are disabled. To completely disable the cache, set both CD and NW to 1 and flush the cache by executing a WBINVD or INVD instruction.
1	0	Cache line fills are disabled. Cache write-throughs and cache invalidations are enabled. This configuration allows software to disable the cache for a short time, then re-enable it without flushing the original contents.
0	1	Invalid setting. A general-protection exception with an error code of 0 is generated.
0	0	Cache line fills, cache write-throughs, and cache invalidations are enabled. This is the normal operating configuration.

Caching is controlled by the memory management subsystem on a per-access basis. For example, ISA bus accesses are not cached. The programmer has some control over which regions of memory are cacheable and which are not. This is discussed in Chapter 7.

3.5 SYSTEM MANAGEMENT MODE (SMM)

System Management Mode (SMM) is a separate operating mode of the CPU (apart from Real, Virtual, and Protected modes) with distinct hardware and software features. SMM is intended for use only by system firmware (e.g., BIOS) and not by application software or general-purpose system software. SMM lets the system designer add to computer products software-controlled features that operate transparently to the operating system and software applications.

This section presents basic information on using SMM on the ÉlanSC400 and ÉlanSC410 microcontrollers; more complete information is available in the *Enhanced Am486 Microprocessor Family Data Sheet (order #19225).*

3.5.1 Uses of SMM

SMM provides an operating-system-independent method of adding support for specialized hardware features. Two uses that may be quite common with systems based on the ÉlanSC400 and ÉlanSC410 microcontrollers are power management and PC/AT keyboard emulation, because complete hardware support for both of these features is integrated directly into the ÉlanSC400 and ÉlanSC410 microcontrollers.

Power management is a good example of something that has both hardware-specific and operating-system-specific components. Basic power management can be performed completely transparently to the operating system with hardware support. This is possible because the operating system knows nothing about SMM. The power management unit (PMU) can cause a System Management Interrupt (SMI) to occur based on various PMU activities (see Chapter 5 for details). The operating system knows nothing about the SMI, which causes the transition to SMM. Code in the SMM handler (usually provided by the BIOS) will respond to the activity and cause a power management state transition, and then return from the SMI with a resume (RSM) instruction.

The matrix keyboard controller can also generate SMIs. With the hardware support provided by the ÉlanSC400 and ÉlanSC410 microcontrollers, an SMI handler can let the matrix keyboard controller emulate a PC/AT keyboard, also completely transparently to the operating system. See Chapter 16 for details.

3.5.2 SMM Requirements

The ability of SMM to operate completely transparently to any operating system places several requirements on SMM implementation:

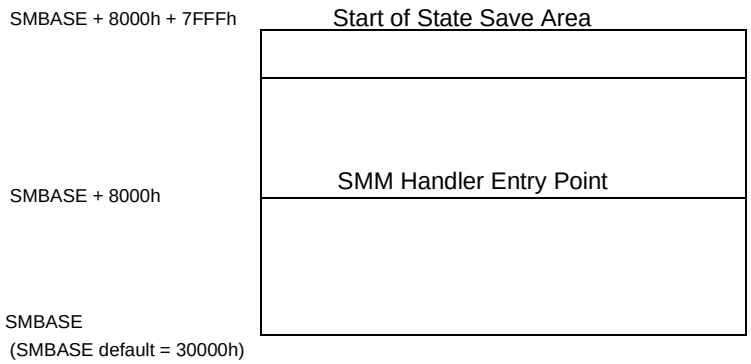
- An area of memory the O/S is not aware of must be available to store the complete state of the CPU on SMM entry. This area is called the State Save Map and is a part of the SMRAM (System Management Random Access Memory).
- Code that the O/S is not aware of must be available to execute the SMM task. This code is also stored in SMRAM.
- The effect on the cache of using this data and code space that the O/S is not aware of must be carefully considered. The ÉlanSC400 and ÉlanSC410 microcontrollers offer several options for managing the cache during SMM execution.
- The SMM code itself must not execute for too long, or the O/S will notice the increased interrupt latency (e.g., by losing characters coming in from a UART).

3.5.3 System Management Random Access Memory (SMRAM)

As noted above, SMM requires an area of memory independent of the O/S to store system state when SMM is entered and to store the code that runs during SMM. This memory is called SMRAM. Because there is no way to inform most legacy operating systems to leave a particular area of RAM alone, the ÉlanSC400 and ÉlanSC410 microcontrollers have the ability to “hide” SMRAM “underneath” other resources, such as ROM or ISA memory space. This effectively makes SMRAM invisible to the operating system. This hiding is accomplished by changing the value of SMBASE, a CPU register that defines the start of SMRAM. Historically, SMRAM is 64 Kbytes in length, but in the ÉlanSC400 and ÉlanSC410 microcontrollers, it is only 32 Kbytes in length, occupying the highest addressed 32 Kbytes in the legacy 64-Kbyte SMRAM block.

Figure 3-1 illustrates the SMRAM address space. SMBASE defines the start of the historical 64-Kbyte SMRAM, and the 32-Kbyte portion of SMRAM actually implemented by the ÉlanSC400 and ÉlanSC410 microcontrollers starts at SMBASE + 8000h. This is the location of the SMM handler entry point. SMRAM ends at SMBASE+0FFFFh, and the save area occupies the highest 512 bytes of SMRAM, from SMBASE+0FE00h to SMBASE+0FFFFh.

Figure 3-1 SMRAM Organization



3.5.4 System Management Interrupt (SMI)

SMM is entered via an SMI, which is a type of non-maskable interrupt. SMI is the highest priority interrupt in the entire system. SMI generation is controlled by CSC indexed registers 90–9Dh, which are more fully described in Chapter 5. Typically, a hardware activity, such as a change on the SUS_RES pin, will be programmed to cause an SMI. An SMI may also be forced by setting bit 0 in the Miscellaneous SMI/NMI Enable Register (CSC index 90h[0]). An SMI can be driven into the microcontroller by an external device by configuring one of the GPIO pins as an external SMI input via the GPIO_XMI to GPIO_CS Map Register (CSC index B0h). No SMI will be propagated to the CPU core unless bit 0 (Master SMI Enable) in the XMI Control Register (CSC index 9Dh[0]) has been set.

The following activities occur when the ÉlanSC400 and ÉlanSC410 microcontrollers process an SMI:

1. The cache will be automatically flushed unless disabled by setting bit 5 in the Non-Cacheable Window 0 Address/Attributes/SMM Register (CSC index 11h[5]).
2. Caching while in SMM is disabled unless enabled by setting bit 6 in CSC index 11h. See Section 7.7.3.1 in this manual for a discussion about caching and SMM.
3. The memory management hardware will map an area in DRAM to use for SMRAM when the 32-Kbyte region starting at SMBASE+8000h overlaps the “upper memory area” or “high memory area” (memory between 00A0000h and 010FFFFh). In this case, during SMM, CPU accesses (but not DMA accesses) to this 32-Kbyte area are directed to system DRAM instead of ROM or the ISA bus. This special feature allows “hiding” SMRAM under ISA or ROM space. In addition to the ISA or ROM space, SMRAM can be hidden under any MMS window that has been opened in the upper memory area (00A0000h–00FFFFFh) or the high memory area (0100000–010FFFFh). For example, if MMS Window B (which starts at 10000h) is opened and not pointing to DRAM (starting at 0100000h), the SMBASE can be located in this region. SMM mode thus time-multiplexes this system address space resource between MMS and SMM functions. If there is no overlap between the SMRAM region and upper or high memory, no redirection occurs.
4. $\overline{\text{A20M}}$ is deasserted so that SMM code can access any address in the system.
5. The entire CPU core state is saved at the top of SMRAM, in the State Save Map, as shown in Table 3-3. State is stored one double word (DWORD) at a time, starting at SMRAM+FFFCh, and proceeding downward in a stack-like fashion.

6. Interrupts (including NMI) are disabled and registers are initialized as shown in Table 3-4. Recognition of CPU soft resets is disabled.
7. SMM Execution starts at SMBASE+8000h. See Section 3.5.5 for more information.
8. The SMM routine supplied by the customer or BIOS vendor executes and performs whatever tasks are necessary to deal with the SMI. At the end of execution, this routine must make sure that the SMI source has been cleared, usually by writing a 0 to the appropriate bit in CSC indexed registers 94–97h or 9B–9Ch. Then the routine must execute a RSM (resume) opcode (0Fh AAh) to return from System Management Mode. If the source of the SMI is not cleared, another SMI is issued immediately upon return from the current SMI. Note that the state save is for CPU core registers only. For example, none of the CSC indexed registers, PC/AT legacy registers, etc., are included. Since SMI is the highest priority interrupt, care must be taken to preserve certain system resources. Any indexed register is an example of this, but the CSC index register at 22h must absolutely be preserved to maintain a transparent SMM handler.
9. System registers, including processor mode and interrupt enable information, are restored from the State Save Map. If the SMM handler has stored invalid information here, such as setting SMBASE to a value that is not 32-Kbyte-aligned, or setting illegal bits in the saved CR0 register image, a shutdown mode is entered.
10. The override of $\overline{A20}$ is removed.
11. The SMRAM memory mapping override is removed.
12. Caching is restored to its original state.
13. If a soft CPU reset has been requested, it will be issued and the CPU SRESET signal will be pulsed.

3.5.4.1 State Save Map

When an SMI occurs, the entire state of the CPU, including internal registers not normally visible to the programmer, is automatically saved to SMRAM so that, when the SMI processing is finished, the CPU core state can be transparently restored by the RSM instruction. The area of SMRAM where the state is stored is called the State Save Map. Table 3-3 shows the format of the State Save Map.

Many SMI handlers will have no interest in the format of the State Save Map, except for the location of SMBASE, because the goal of the handler is complete transparency to other code running on the machine.

Some SMI handlers are required to communicate with other code running on the machine. A typical example of this might be an implementation of Advanced Power Management (APM). Operating systems may make BIOS calls to communicate APM information. The BIOS will typically force an SMI to occur to exchange information with the SMI handler. In this case, the SMI handler requires knowledge of the format of the State Save Map, so that it can examine or store register values.

Although the entire state of the CPU is written out to the State Save Map, the format of some of the internal registers is subject to change, and is not documented. These areas in the map are marked “No access” in the table. Some registers, such as EAX, may be altered by the SMI handler before returning. These areas in the map are marked “Read/Write”. Other areas in the map can be read by the SMI handler, but should not be altered because alteration would leave the CPU in an undefined state. For example, the segment selector registers such as DS, CS, etc., can be read, but should not be written because the internal hidden descriptor would no longer match the selector value. These map areas are marked “Read-Only” in the table.

Table 3-3 SRAM State Save Map

Offset from SMBASE	Length in Bytes	Map Contents	Permitted Accesses
0FFFCh	4	CR0 Register	Read-only
0FFF8h	4	CR3 Register	Read-only
0FFF4h	4	EFLAGS Register	Read/Write
0FFF0h	4	EIP Register	Read/Write
0FFECh	4	EDI Register	Read/Write
0FFE8h	4	ESI Register	Read/Write
0FFE4h	4	EBP Register	Read/Write
0FFE0h	4	ESP Register	Read/Write
0FFDCh	4	EBX Register	Read/Write
0FFD8h	4	EDX Register	Read/Write
0FFD4h	4	ECX Register	Read/Write
0FFD0h	4	EAX Register	Read/Write
0FFCCh	4	DR6 Register	Read-only
0FFC8h	4	DR7 Register	Read-only
0FFC4h	4	TR (lower two bytes)	Read-only
0FFC0h	4	LDTR (lower two bytes)	Read-only
0FFBCh	4	GS Selector (lower two bytes)	Read-only
0FFB8h	4	FS Selector (lower two bytes)	Read-only
0FFB4h	4	DS Selector (lower two bytes)	Read-only
0FFB0h	4	SS Selector (lower two bytes)	Read-only
0FFACh	4	CS Selector (lower two bytes)	Read-only
0FFA8h	4	ES Selector (lower two bytes)	Read-only
0FF08h	160	Internal Registers	No access
0FF06h	2	I/O Trap Address	Read-only
0FF04h	2	I/O Trapped (bit 1) and Read/$\overline{\text{Write}}$ (bit 0)	Read-only
0FF02h	2	Halt Auto Restart (Bit 0 = 1)	Read/Write
0FF00h	2	I/O Trap Restart in lower byte (if = FFh)	Read/Write
0FEFCh	4	SMM Revision Identifier	Read/Write
0FEF8h	4	SMBASE	Read/Write
0FE00h	248	Internal Registers	No access

Table 3-4 SMM Initial Register Values

Register or Feature	SMM Initial State
EAX, EBX, ECX, EDX, ESI, EDI, EBP, ESP, GDTR, LDTR, IDTR, TSSR	Unmodified (contain values from interrupted program)
EFLAGS	0000 0002h
CR0	Bits 0, 2, 3, and 31 (PE, EM, TS, and PG) cleared; rest unmodified
DR6	Unpredictable state
DR7	0000 0400h
CS	Selector = 3000h[1], Base = SMBASE (Default value 30000h), Attributes = 16-bit / Expand Up, Limit = 4 Gbytes
EIP	0000 8000h
DS, ES, FS, GS, SS	Selector = 0, Base = 0, Attributes = 16 bit / Expand Up, Limit = 4 Gbytes
NMI	Non-maskable interrupts are disabled on entry. To enable NMIs, execute an IRET from with SMI handler.

Note:

1.The CS Selector value remains at 3000h, even if SMBASE is changed.

3.5.5 SMM Execution Environment

Table 3-4 shows the state of the CPU on entry to SMM mode. The following is a summary of key features in the SMM environment:

- Real-mode-style address calculation
- 4-Gbyte address limit checking
- IF flag is cleared and NMI is disabled
- TF flag in EFLAGS is cleared and single step traps are disabled
- DR7 is cleared and debug traps are disabled
- The RSM instruction no longer generates an invalid opcode exception
- Opcodes, register, and stack default to 16-bit usage

The processor begins execution of the SMI handler at offset 8000h in SMBASE. SMBASE defaults to 30000h, but may be moved from within an SMI handler (See Section 3.5.9 for details on relocating SMBASE). As Table 3-4 shows, the CS Selector value is 3000h. This is true even if SMBASE has been relocated, so care should be taken when reloading CS, or if attempting to load CS to another segment register, because the base value will not match the selector.

When the SMI handler is invoked, the CPU's PE and PG bits in CR0 are reset to 0 to disable paging. The processor is in an environment similar to Real mode, but without the 64-Kbyte limit checking. However, the default operand size and the default address size are set to 16 bits. The EM bit is cleared so that no exceptions are generated.

Because the segment bases (other than CS) are cleared to 0 and the segment limits are set to 4 Gbytes, the address space may be treated as a single flat 4-Gbyte linear space that is unsegmented. The CPU is still in Real mode, and when a segment selector is loaded with a 16-bit value, that value is then shifted left by 4 bits and loaded into the Segment Base Register. Loading a selector does not alter the limit or attributes in the hidden part of the descriptor.

In SMM, the CPU can access or jump anywhere within the 4-Gbyte physical address space. However, because the CPU is in a mode similar to Real mode, the following restrictions apply:

- Address prefix overrides are required to reach any address greater than 1 Mbyte. Because segment addresses are simply the selector value shifted left 4 bits, only the first 1 Mbyte may be addressed without an override, both for data accesses and for control transfers.
- If SMBASE has been relocated, reloading CS with 3000h (e.g., via a far return or IRET) will not store the proper value in the CS Base. If interrupts are to be enabled or exceptions may occur, the SMM handler should perform a far jump to itself at its actual location. For example, if SMBASE has been relocated to A0000h, the following code sequence could be performed.

```
      push 0A000h    ; new segment selector (A000h * 16 = A0000h)
      push offset ReturnLocation
      retf           ; far return to self
   ReturnLocation:
```

- Any jump, call, or return that does not have an operand-size override prefix, and any interrupt or exception, will truncate both the new EIP and the return address (if any) to the 16 low-order bits. If the SMM handler will be executing any code above 1 Mbyte, interrupts should not be enabled, and exceptions should not be allowed to occur.
- SMMBASE is not reset as a result of typical reset conditions, e.g., triple fault, Port 0092[0], etc., unless an SMI is pending or active, in which case a hard reset will occur.

3.5.6 Exceptions and Interrupts

When the CPU enters SMM, it disables INTR interrupts, debug, and single-step traps by clearing the EFLAGS, DR6, and DR7 registers. This prevents a debug application from accidentally breaking into an SMI handler. This is necessary because the SMI handler operates from a distinct address space (SMRAM), and the debug trap does not represent the normal system memory space.

For an SMI handler to use the debug trap feature of the processor to debug SMI handler code, it must first ensure that an SMM-compliant debug handler is available. The SMI handler must also ensure DR3–DR0 are saved to be restored later. The debug registers DR3–DR0 and DR7 must then be initialized with the appropriate values.

For the software to use the single-step feature, it must ensure that an SMM-compliant single-step handler is available and then set the trap flag in the EFLAGS Register. If the system design requires the processor to respond to hardware INTR requests while in SMM, it must ensure than an SMM-compliant interrupt handler is available, and then set the interrupt flag in the EFLAGS Register (using the STI instruction). Software interrupts are not blocked on entry to SMM, and the system software designer must provide an SMM-compliant interrupt handler before attempting to execute any software interrupt instructions. Note that in SMM mode, the interrupt vector table has the same properties and location as the Real-mode vector table.

NMI interrupts are blocked on entry to the SMI handler. If an NMI request occurs during the SMI handler, it is latched and serviced after the processor exits SMM. Only one NMI request is latched during the SMI handler. If an NMI request is pending when the processor executes the RSM instruction, the NMI is serviced before the next instruction of the interrupted code sequence.

Although NMI requests are blocked when the CPU enters SMM, they may be enabled through software by executing an IRET instruction. If the SMI handler requires the use of NMI interrupts, it should invoke a dummy interrupt service routine to execute an IRET instruction. When an IRET instruction is executed, NMI interrupt requests are serviced in the same Real-mode manner in which they are handled outside of SMM.

3.5.7 Auto Halt Restart

In some power managed systems, the Halt (HLT) instruction can be used to halt execution when there is no work to be done. Typically, HLT is executed with interrupts enabled, and an interrupt request brings the CPU out of halt state. After the interrupt is serviced, main line execution resumes with the instruction after the Halt instruction.

When an SMI occurs while the CPU is halted, by default, the Halt instruction is restarted upon exit from SMM. This will cause the CPU to re-enter the halt state after having executed the SMI. This feature is called “Auto Halt Restart.” The SMI handler may choose to disable this feature (on a per-SMI basis). This causes the CPU to resume with the instruction after the HLT upon exit from SMM, just as it does when a regular interrupt handler exits. In this case, the SMI causes the CPU to leave the halt state to continue executing main-line code after the SMI handler finishes.

Bit 0 of the word at SMBASE+0FF02h is the Auto Halt Restart bit. It will be set to 1 upon SMM entry if and only if the interrupted instruction was a HLT. When the SMI handler resets this bit to 0, execution after the RSM continues with the instruction after the HLT; otherwise the HLT is re-executed. The SMI handler should never set this bit—doing so causes unexpected behavior when the interrupted instruction is not a halt.

3.5.8 I/O Trapping

3.5.8.1 Restarting I/O Instructions

An I/O instruction is said to be “trapped” if address decode logic external to the CPU core asserts the SMI input to the CPU during an I/O cycle. The ÉlanSC400 and ÉlanSC410 microcontrollers have several programmable sources for enabling SMI generation based on certain I/O address cycles being decoded. When any of these is enabled and the specified I/O access occurs, SMM will be entered as a result of an I/O trap. The I/O Trap Restart feature allows a trapped I/O instruction to be restarted. This feature is very useful for power-managed systems.

For example, consider a system with a floppy disk controller that may be shut off to conserve power. The operating system knows nothing of this power management, so the power management must be completely transparent to the O/S. If the power management firmware decides that the floppy should be turned off (perhaps because of a PMU timer time-out), it can turn off the floppy controller, and then can turn on I/O trapping for floppy disk accesses by setting bit 0 in the I/O Access SMI Enable Register B (CSC index 9Ah[0]).

When the O/S next attempts to read from or write to a floppy controller I/O address, the instruction will be trapped and the SMI handler will be entered. The hardware will set bit 0 of the I/O Access SMI Status Register B (CSC index 9Ch[0]) to indicate the SMI was caused by trapping a floppy disk controller access.

When the SMI handler notices that bit 0 is set, the handler should take the following actions:

- Reset this bit (by writing 0FEh to CSC index 9Ch).
- Power up the floppy disk controller (this action is system-implementation-dependent).
- Restore all floppy disk controller registers to valid states.
- Make the RSM instruction restart the trapped I/O instruction by setting the word at SMBASE+0FF00h (the I/O Instruction Restart Slot) to 00FFh.
- Execute the RSM instruction to allow the floppy access to proceed.

Note that, if one of these I/O trap bits (in CSC index 9B or 9C) is set upon entry to SMI, the condition should be dealt with before exiting SMM. Restarting an I/O instruction from a subsequent back-to-back SMI request is not legal. I/O traps should be prioritized ahead of other SMI causes in the SMI dispatcher.

3.5.8.2 Emulating I/O Instructions

Trapped I/O instructions can also be emulated and then discarded, rather than restarted. When a valid I/O instruction has been trapped, bit 1 of the word at SMBASE+0FF04H is set. When this bit is set, bit 0 of the same word will be 1 if the interrupted instruction was attempting an I/O read, or 0 for a write, and the word at SMBASE+0FF06h will contain the I/O address of the access.

This information can be used to emulate the I/O access. An example is to emulate a standard PC/AT floppy controller when a non-standard one is being used.

This information can also be used to determine what I/O address caused the trap when using the GPIO trap feature, which will generate a trap for up to 16 consecutive addresses. See the register descriptions for CSC index B4–B7h.

Emulation is performed by examining the instruction opcode to determine the exact instruction, and then using the register information in the State Save Map (i.e., the address of the trapped I/O) to determine exactly what to do. In the simplest case, the value of the AL Register in the State Save Map (e.g., the lowest byte of the EAX Register) is used to output, or is updated for an input. If an instruction is emulated, no special action is needed to cause the CPU to continue with the next instruction after the RSM.

If the SMI did not occur as a result of a trapped I/O instruction, bit 1 of the word at SMBASE+0FF04h will be zero, and the value of bit 0 in this word will be unpredictable, as will the value of the word at SMBASE+0FF06h. In this case, the word at SMBASE+0FF00h (the I/O Instruction Restart Slot) should not be written to because the results will be unpredictable.

3.5.9 SMM Base Relocation Example

As discussed previously, the default value for SMBASE is 30000h. This legacy value is not suitable for many operating systems because it does not allow transparent SMM operation (the RAM at 30000h is visible to the host operating system). The value of SMBASE can be changed, but only from within an SMI handler.

The solution is to force an SMI to occur and change the SMBASE value from within the handler before the O/S gets control. This is exactly how the BIOS power management code does it.

The following simplified program shows how to move an SMI handler to A8000 (behind the ISA VGA graphics space). The program assumes the following:

- SMM features of the currently running BIOS (such as power management) have been shut off to keep SMM from being relocated by the BIOS. (SMBASE is at its default 30000h value.)
- The program is running from DOS, and there are few enough TSRs and drivers so that the default SMRAM area (38000–3FFFFh) is free for use.
- The display is a VGA card in a normal text mode (80x25 screen at B8000h).
- The area at B0000h is free for use by the program, e.g., the internal graphics controller on the ÉlanSC400 microcontroller is disabled, no monochrome card is attached, and EMM/QEMM/etc. have not appropriated the area. (This area is where the MMS A memory mapping window is located.)

Given the above assumptions, the code that follows is a fully functional program. It contains a code fragment that is moved to the default SMRAM location, and another code fragment that is moved to the target SMRAM location, via use of MMS (because the DRAM at the target SRAM location of A8000h is not visible during normal system operation). The code fragment moved to the default SMRAM location changes SMBASE and performs an RSM instruction. Since the cause of the SMI has not been removed, another SMI occurs immediately, but using the relocated SMBASE. The other code fragment removes the cause of the SMM (the force SMM bit) and performs an RSM instruction. Both code fragments update the VGA display to show that the SMI occurred.

```
; This program was assembled with TASM, and linked with TLINK into a
; tiny model (.COM) file.
; It assumes that there are not so many TSRs and drivers loaded that
; it loads too high -- CS should be well below 3000h when the
; program runs.

code segment para public use16 'CODE'
.386

assume cs: code, ds: code, es: nothing, fs: nothing,gs:nothing

org 100h
Go:
         jmp     short PastTheData

; Data for moves. We are moving one code fragment into 3000:8000
; (assuming that that does not interfere with the location of this
; program) and another fragment into A000:8000, via the MMS window
; at B000:0000.

CodeDst1 LABEL DWORD
         dw      8000h,3000h

CodeSrc1 DW     CodeFrag1

CodeDst2 LABEL DWORD
         dw      0000h,0B000h

CodeSrc2 DW     CodeFrag2

PastTheData:
         in      al,22h
         push    ax
```

```
; Use MMS Window 5 to map CPU address B000:0 to RAM address A000:8000
        mov     ax,(0A800h SHR (15-4)) * 100h + 32h
        out     22h,ax
        mov     ax,0C833h
        out     22h,ax

; Move both the code fragments
        les     di,CodeDst1
        mov     si,CodeSrc1
        mov     cx,CodeLen1
        cld
        rep     movs byte ptr es:[di],byte ptr ds:[si]

        les     di,CodeDst2
        mov     si,CodeSrc2
        mov     cx,CodeLen2
        cld
        rep     movs byte ptr es:[di],byte ptr ds:[si]

; Disable the MMS window
        mov     ax,033h
        out     22h,ax

; Enable SMI and force it a few times, to prove that it works
        mov     ax,019Dh     ;Enable SMI at index 9D
        out     22h,ax

        ; Force SMI. This first force will actually generate 2 SMIs.
        ; This is an (expected in this case) side effect of not clearing
        ; the force smi bit in the primary SMM handler at 38000. SMIs
        ; will continue to occur until the force smi bit is cleared as
        ; is done in the relocated SMM handler at B0000h.

        ; Note that the 2nd time you run this, only 1 SMI will occur
        ; because the primary handler at 38000 will not be called. Also
        ; note that in order to start from scratch in terms of SMI handlers,
        ; you have to power cycle the system, or hit the hard reset
        ; (resetdrv) button. CTL-ALT-DEL will not reset the SMMBASE.

        mov     ax,0190h
        out     22h,ax

        mov     ax,0090h     ;Disable force smi
        out     22h,ax

; Exit back to DOS
        int     20h          ;Return to DOS

;-----------------------------------------------------------------------

;----------< SMI handler for power on reset default SMM Base >-----------

;-----------------------------------------------------------------------

; This code fragment is the initial SMI handler that gets copied to the
; default SMI location at 3000:8000 to handle the first SMI. Inside the
; default handler the SMMBASE is moved to the less intrusive location of
; A000:8000.

CodeFrag1:

; Set new state base
        mov     dword ptr cs:[0FEF8h],0A0000h
```

```
; Write sign on message to the VGA screen.
        mov     ax,0B800h    ;Source and dest segments are the
        mov     es,ax        ;display buffer
        mov     ds,ax
        cld

        mov     si,80*2      ;Scroll everything up 1 line
        mov     di,0
        mov     cx,80*24
        rep     movsw

        mov     di,80*24*2   ;Init the (new) bottom line to spaces
        mov     ax,0720h
        mov     cx,80
        rep     stosw

        ;-----------< Now write the signon message >--------------

        mov     di,80*24*2   ;Init the destination to start of last line


        ; Remember, the code fragments, including the signon message are
        ; being loaded into memory 38000h and a8000h manually by this
        ; utility. So you can't just use the .asm offset directive to
        ; find the start of the string like you normally would. Since
        ; only codefrag1 is copied into the 38000 area, the signon message
        ; is relative to the segment (which is hard coded to be CS), to
        ; codefrag1 (which is the start of the code), and to the size of
        ; codefrag1 (which is SMI3000Happens-CodeFrag1).

        mov     bx,(SMI3000Happens-CodeFrag1) + 8000h
        mov     ah,07h             ;Use light gray attribute

WriteLoop1:
        mov     al,cs:[bx]         ;Attribute is in ah, char is in al
        inc     bx                 ;Next char
        or      al,al              ;Check for sentinel (0)
        jz      short ExitWrite1   ;if sentinel, bail
        stosw                      ;else write to screen memory
        jmp     WriteLoop1         ;
ExitWrite1:

; Exit the handler. Another SMI will happen immediately because we haven't
; and cleared the forcesmi bit. This time, the SMBASE has changed, so we
; will start executing from the A000:8000 location.

        db     0Fh,0AAh            ; return from SMI (Resume instruction)

SMI3000Happens db     "SMI handler installed & working. SMM base relocated
to system DRAM at A0000h.",0

CodeLen1        EQU $ - CodeFrag1

;-------------------------------------------------------------------------

;--------------< SMI handler for relocated SMM Base >--------------------

;-------------------------------------------------------------------------

; This code fragment is the SMI handler for the 2nd SMI and beyond. It gets
; copied to the (somewhat arbitrary) location of A000:8000.
```

```
CodeFrag2:

;-------------------------------------------------------------------------

;------< Click the speaker for an audible indication of SMI activity >--

;-------------------------------------------------------------------------

         mov    bx,4300             ;frequency of click
         mov    ax,34DDh
         mov    dx,0012h
         cmp    dx,bx
         jnb    ExitClick
         div    bx
         mov    bx,ax
         in     al,61h
         test   al,03
         jne    SpkrEnabled
         or     al,03
         out    61h,al
         mov    al,0B6h
         out    43h,al

SpkrEnabled:
         mov    al,bl
         out    42h,al
         mov    al,bh
         out    42h,al

; short delay while the speaker is putting out the click
         mov    cx,08000h
         loop   $

; Don't bother to put back timer count or speaker gate value,
; this is just a test utility.in     al,61h
         and    al,0FCh       ;Turn off the speaker gate
         out    61h,al
ExitClick:

; Clear all SMI status bits or another SMI can result. Any SMM status port
; that has an SMI status bit set will be written to port 680H, and port
; 80 candisplay the value read back. The last port found with any bits
; set is what will be displayed in ports 680/80.

         in      al,22h       ;Save index 22h for later restoration so SMI
         mov     bl,al        ;does not change system state

         mov     al,0
         out     80h,al       ;Leave 0 at port 80 to indicate no smi event
         mov     dx,680h      ;happened

Try94:

         mov     al,94h
         out     22h,al
         in      al,23h
         cmp     al,0
         je      Try95
         out     80h,al
         mov     al,0
         out     23h,al
```

```
            mov     al,94h
            out     dx,al

Try95:

            mov     al,95h
            out     22h,al
            in      al,23h
            cmp     al,0
            je      Try96
            out     80h,al
            mov     al,0
            out     23h,al
            mov     al,95h
            out     dx,al

if 0   ;----< Uncomment this block when working with XT Keyboard SMIs >-----

            You would think this is required, but it doesn't seem to be. Test
            this with smi_xt.pas in the tech\kbd directory.
            in      al,60h       ;This should clear the interrupt so
                                 ;another can occur

            in      al,64h       ;some test code to see what port 64h looked
            mov     dx,3ffh      ;like when smm occurred due to xt kb smi.
                                 ;(It reads 0Ah).
            out     dx,al        ;Store in a global for display.

            ; The following toggle must be done or you only get 1 SMI,
            ; and then no more.

            in      al,61h       ;And this toggling of 61h[7] should clear
            or      al,0C0h      ;the xt shift register so you don't get
            out     61h,al       ;false smis when the next byte is shifted
                                 ;in (and the existing data is shifted out
                                 ;to the IRQ signal!!

            ; This delay is required since you are "acking" the XT KB which is
            ; running relatively slow microcode. Failure to do this can cause
            ; the XT KB to generate a continuous stream of SMIs.

            mov     cx,0ffffh ;Short delay
            loop    $

            and     al,7fh    ;Enable the XT kb interface again.
            out     61h,al

endif   ;----------<****************************************>-------

Try96:

            mov     al,96h
            out     22h,al
            in      al,23h
            cmp     al,0
            je      Try97
            out     80h,al
            mov     al,0
            out     23h,al
            mov     al,96h
            out     dx,al
```

```
Try97:

        mov     al,97h
        out     22h,al
        in      al,23h
        cmp     al,0
        je      Try9B
        out     80h,al
        mov     al,0
        out     23h,al
        mov     al,97h
        out     dx,al

Try9B:

        mov     al,9Bh
        out     22h,al
        in      al,23h
        cmp     al,0
        je      Try9C
        out     80h,al
        mov     al,0
        out     23h,al
        mov     al,9Bh
        out     dx,al

Try9C:

        mov     al,9Ch
        out     22h,al
        in      al,23h
        cmp     al,0
        je      ExitSmm
        out     80h,al
        mov     al,0
        out     23h,al
        mov     al,9Ch
        out     dx,al

ExitSmm:

        mov     al,bl               ;restore index 22h
        out     22h,al

        db      0Fh,0AAh            ;return from SMI (Resume instruction)

CodeLen2        EQU $ - CodeFrag2

code ends

end go
```

3.5.10 SMM Interaction With SRESET

The Am486 CPU NMI and $\overline{\text{SMI}}$ input signals are edge-triggered. The Am486 CPU core clears all internal NMI and SMI events upon receipt of the SRESET signal. Internal to the ÉlanSC400 and ÉlanSC410 microcontrollers, the NMI and $\overline{\text{SMI}}$ signals are asserted once and are then held in the asserted state until the source for the interrupt is cleared. Therefore, an SRESET event that is subsequent to or concurrent with the assertion of one of these interrupts clears the interrupt internal to the CPU, even though the external PMU logic is asserting the $\overline{\text{SMI}}$ or NMI signal. As a result, the interrupt handler is never called to clear

the PMU logic, and no new edge is ever generated to the CPU on these signals. Consequently, no further interrupt ever occurs from these sources.

To avoid this situation, the boot code (which is invoked as a result of the SRESET) should force the NMI and $\overline{\text{SMI}}$ signals to be deasserted via their enable bits and then re-enable them. This will cause a new edge to be asserted to the CPU for the NMI and SMI events if any events were pending. SMIs can be disabled via CSC index 9Dh[0]. NMIs can be disabled via Port 0070h[7].

Note that SRESET is normally the result of either setting Port 0092h[0], reading Port 00EFh, sending a CPU reset command to the keyboard controller, or experiencing a CPU triple-fault. All of these means have been used by older software to switch the CPU from Protected mode back to Real mode.

3.6 CPU CORE IDENTIFICATION USING THE CPUID INSTRUCTION

Information about the integrated Am486 CPU core is available by reading the DX Register after a system reset (see reset information in Chapter 4), and also by using the CPUID instruction at any time. The CPUID instruction is available on later model 32-bit processors from all leading x86 vendors and allows programs to determine information about the CPU, including the manufacturer, cache type, and availability of an FPU.

The ÉlanSC400 and ÉlanSC410 microcontrollers are the first members of a new family of embedded devices. The CPUID instruction can be used to identify a processor as belonging to this family, and then the ÉlanSC400 Microcontroller Revision ID Register (CSC index FFh) can be used to identify which silicon revision software is running on.

A user-modifiable bit in the EFLAGS Register indicates support of the CPUID instruction. This bit (bit 21) is referred to as the EFLAGS.ID bit and is reset to 0 at CPU reset (RESET or SRESET) for compatibility with existing processor designs.

Using the CPUID instruction the microcontroller can be done with the following steps, as shown in the code sample in Section 3.6.3:

- Ensure that the CPU is capable of executing an “invalid opcode” exception if it does not recognize the CPUID instruction, and install a trap at the exception vector.
- Execute the CPUID instruction twice, once to get the manufacturer name and once to get the device description.
- Make sure the manufacturer name is “AuthenticAMD”.
- Make sure the device is described as a 486 SX1 with a write-back cache.

The Am486 CPU core in the ÉlanSC400 and ÉlanSC410 microcontrollers is the first CPU AMD has made with a write-back cache and no FPU, so these tests should be sufficient to uniquely identify the family. For consistency, the results reported by CPUID are constant. Even though cache accesses can be set to write-back or write-through and the CPU speed can be clock-doubled or clock-tripled, changing these parameters through software does not alter the CPUID results.

3.6.1 CPUID Timing

CPUID execution timing depends on the selected EAX parameter values, as shown in Table 3-5.

Table 3-5 CPUID Instruction Description

OP Code	Instruction	EAX Input Value	CPU Core Clocks	Description
0F A2	CPUID	0	41	AMD ASCII String
		1	14	CPU ID Register
		>1	9	Null Registers

3.6.2 CPUID Operation

The CPUID instruction requires the user to pass an input parameter to the CPU in the EAX Register. The CPU response is returned to the user in registers EAX, EBX, ECX, and EDX.

- When the parameter passed in EAX is 0, the register values returned upon instruction execution are:

```
EAX[31:0] = 00000001h
EBX[31:0] = 68747541h
ECX[31:0] = 444D4163h
EDX[31:0] = 69746E65h
```

The values in EBX, ECX, and EDX contain an ASCII string that spells out

```
'AuthenticAMD'
```

- When the parameter passed in EAX is 1, the register values returned are:

```
EAX[3:0] = Stepping ID
EAX[7:4] = Model:
          AH = enhanced Am486 SX1 write back mode
EAX[11:8] = Family
           4H = Am486 CPU
EAX[15:12] = 0000b
EAX[31:16] = RESERVED
EBX[31:0] = 00000000h
ECX[31:0] = 00000000h
EDX[31:0] = 00000000h
```

The 0 in bit 0 of EDX[31:0] indicates that the FPU is not present

Note: *Please send e-mail to the LPD Technical Support Center for stepping ID details. Use this e-mail address: LPD@amd.com*

The value returned in EAX after executing the CPUID instruction is identical to the value loaded into EDX upon CPU reset. Software must avoid any dependency upon the state of reserved processor bits.

- When the parameter passed in EAX is greater than 1, the register values returned upon instruction execution are:

```
EAX[31:0] = 00000000h
EBX[31:0] = 00000000h
ECX[31:0] = 00000000h
EDX[31:0] = 00000000h
```

Flags Affected: None
Exceptions: None

3.6.3 CPUID Example

Using the CPUID instruction from 32-bit assembly language is relatively easy; using the CPU ID instruction is more difficult from 16-bit C code. The following C code fragment shows how to positively identify ÉlanSC400 microcontroller (and derivative) CPUs from 16-bit Microsoft C.

```
//////////////////////////////////////////////////////////////////////
// Exception and MyInt6 are used by IsE4 to install a longjmp handler
// at the illegal opcode exception vector.

static jmp_buf Exception;

void MyInt6(void)
{
// Reenable interrupts, and make the setjmp return a '1', showing that
// the exception occurred

_enable();
longjmp(Exception,1);
}

//////////////////////////////////////////////////////////////////////

// The goal of IsE4 is to return TRUE if the CPU is an
// ÉlanSC400 microcontroller or derivative, by verifying the following:

//   - The CPU was made by AMD "AuthenticAMD"
//   - The CPU has no FPU
//   - The CPU is capable of write-back caching

// Because of limitations with 16-bit code, the upper words of the data
// are not verified, but the verification is still relatively secure.

BOOL IsE4(void)
{
typedef void (_far * LPFUNC)(void);
typedef LPFUNC _far *LPLPFUNC;

   LPLPFUNC Int6;
   LPFUNC OldInt6;

// Save the old int6 vector, and install our exception handler

   Int6 = MK_FP(0,6*4);
   OldInt6 = *Int6;
   *Int6 = MyInt6;

// 8088/8086 CPUs don't have exception handling, but 8088-80186 CPUs push a
// different value when pushing SP than the 286 and above.

   _asm {
   push   sp
   pop   ax
   sub   ax,sp
   jnz   NotMine   // Jump if 8088/8086 or 80188/80186
}

// setjmp will only return true if we encountered the 'illegal exception'
// opcode.

// In this case, clean up by restoring the interrupt vector, and return
// FALSE.
```

```
   if (setjmp(Exception))
   {

    // If we ever vector to "NotMine", we'll clean up and return FALSE.

   _asm {
         NotMine:
         }
   *Int6 = OldInt6;
   return FALSE;
}

// All set up, ready to perform the test. The 16-bit compiler doesn't
// understand 32-bit instructions, so we manually code them.

_asm{
   _emit 0x66  // XOR EAX,EAX  -- a 286 should vector to int 6 here
   _emit 0x33
   _emit 0xC0

   _emit 0x0F  // CPUID   -- 386s, older 486s should vector to int 6 here
   _emit 0xA2

   // Test for fragments of the "AuthenticAMD" string
   // This checks every other word of the string (ignores high-order words)

   cmp   ax,1           -- Make sure EAX changed
   jnz   NotMine
   cmp   bx,07541h      -- Check low order string portions
   jnz   NotMine
   cmp   cx,04163h
   jnz   NotMine
   cmp   dx,06E65h
   jnz   NotMine

   // Check the stepping, that it has write-back cache, and that
   // it has no FPU. EAX should already contain a 1 from previous
   // CPUID instruction

   _emit 0x0F  // CPUID
   _emit 0xA2

   or   bx,cx
   or   bx,dx
   jnz   NotMine   // Jump if FPU or other feature present

   mov   bx,ax
   and   bx,0Fh
   xor   ax,bx
   cmp   bx,4    // Check for stepping 4 or greater of core
   jb   NotMine
   cmp   ax,04A0h  // Check features
   jnz   NotMine
   }

   // Passed all the tests. Must be an ÉlanSC400 microcontroller or
   // derivative. Clean up and return TRUE.

   *Int6 = OldInt6;
   return TRUE;
}
```

CHAPTER

4 SYSTEM INTERFACES

4.1 INITIALIZATION

The microcontroller is in an indeterminate state when power is first applied. Power-on reset places the microcontroller into a defined state, as described in this section. Other types of reset defined below are used to control the state of specific parts of the microcontroller.

4.1.1 Types of Reset

The ÉlanSC400 and ÉlanSC410 microcontrollers employ five different types of reset, which are summarized in Table 4-1.

- **Power-On Reset**—This master hardware is generated by the $\overline{\text{RESET}}$ input. $\overline{\text{RESET}}$ is an asynchronous input equivalent to POWERGOOD in the PC/AT system architecture.
- **RTC-Only Reset**—This internal reset uses the BBATSEN signal to sense the Real-Time Clock's back-up battery voltage during a power-on reset.
- **CPU Reset**—Also called soft reset, this is equivalent to the SRESET function on the Am486 microprocessor. This reset is a synchronized reset to the CPU only.
- **ISA System Reset**—The RSTDRV output is used to reset all external devices connected to the ISA bus.
- **VESA Local (VL) Bus Reset**— The $\overline{\text{VL_RST}}$ output is used to reset all external devices connected to the VL-bus.

Table 4-1 Types of Reset

Types of Reset	Also Called	Cause	Effect
Power-On Reset	Reset System Reset Master Reset Cold Reset Internal Master Reset Hardware Reset	Asserting and deasserting the $\overline{\text{RESET}}$ input	Resets the entire microcontroller except for the Real-Time Clock. All configuration registers are reset. The CPU core is reset. (The CPU's RESET input is driven active.) The microcontroller enters High-Speed Power-Management mode. See Table 4-2 for more detail.
RTC-Only Reset		The BBATSEN input being sampled below 2.4 V during a power-on reset BBATSEN also provides an internal reset signal to the RTC when an external back-up battery is applied for the first time.	Only the RTC is reset. Resets bit 7 (VRT) of Register D (RTC index 0Ch) to 0. An initial read to this register will then set the bit back to 1.
CPU Reset	Soft Reset Fast Reset Hot Reset CPU Core Reset SRESET Slow Reset	Reading the Alternate CPU Reset Control Register (Port 00EFh) Setting bit 0 of the System Control Port A Register (Port 0092h) "Slow reset" command sequences that are intended for an external SCP are trapped and decoded internally Shutdown cycle issued by the CPU	Pulses the internal CPU SRESET signal. Only the CPU is reset. The Am486 cache state and SMBASE are not affected. No effect on configuration registers
ISA System Reset	Signal Name: RSTDRV System Reset ISA Reset	Asserting the $\overline{\text{RESET}}$ input	Re-initializes all devices connected to the ISA bus to their reset state
VL-Bus Reset	Signal Name: $\overline{\text{VL_RST}}$ VESA Reset	Setting bit 4 in the Cache and VL Miscellaneous Register (CSC index 14h) asserts $\overline{\text{VL_RST}}$	Re-initializes the VL-bus target to its reset state. After enabling the VL-bus interface, $\overline{\text{VL_RST}}$ should be asserted and deasserted before using the VL-bus.

4.1.1.1 Power-On Reset

Power-on reset is invoked by asserting the $\overline{\text{RESET}}$ input. Power-on reset can be asserted at any point during operation. Power-on reset configures the microcontroller as follows:

- Instruction execution is suspended.
- Instruction fetching is suspended.
- Any interrupt or trap conditions are ignored.
- Except as previously noted, the contents of all configuration registers are reset to their listed default power-on reset states.
- The PLLs are disabled.

Power-on reset mode is exited when the $\overline{\text{RESET}}$ input is deasserted. At this point,

- The configuration pins CFG3-CFG0 are sampled.
- CPU begins fetching instructions from the reset vector of 3FFFFF0h in $\overline{\text{ROMCS0}}$ space when $\overline{\text{RESET}}$ is deasserted.

The state of CFG1–CFG0 pin straps determines the width of the ROM0 data bus (as described in Section 4.4). These pin straps are used to select between 8-, 16-, or 32-bit data bus widths for the physical device that is connected to the $\overline{\text{ROMCS0}}$ pin for the linear address decode. At power-on reset, the 64-Kbyte segment between 00F0000h and 00FFFFFh is enabled by default for $\overline{\text{ROMCS0}}$ decode. 3FF0000–3FFFFFFh is enabled for decode (CSC index 21h),and in many systems this will alias to 00F0000–00FFFFFh. (Setting the characteristics of the ROM address spaces is described in Chapter 8.)

The CFG2 pin strap selects whether or not the system will boot from the device attached to $\overline{\text{ROMCS0}}$ or from the PC Card Socket A memory card.

The CFG3 pin strap is used for selecting between the GPIO_CSx I/O pins and the SD bus buffer control signals: $\overline{\text{DBUFOE}}$, $\overline{\text{DBUFRDL}}$, and $\overline{\text{DBUFRDH}}$. When the buffer control signal configuration is selected using the CFG3 pin, the $\overline{\text{DBUFOE}}$, $\overline{\text{DBUFRDL}}$, and $\overline{\text{DBUFRDH}}$ signals will be driven from boot time on for all accesses to the peripheral data bus. These signals are used to control external transceivers on the system data bus.

A power-on reset configures the internal cores and peripherals of the ÉlanSC400 and ÉlanSC410 microcontrollers as shown in Table 4-2. After the deassertion of $\overline{\text{RESET}}$, the configuration registers should be initialized with the information required for the system, and interrupts should be re-enabled. See Section 4.4.1 for more detail on configuration pin usage.

Table 4-2 Internal Core States Immediately Following Power-On Reset

Internal Core	State	Comments
Internal Am486 CPU	Enabled	
Power-Management Unit	Enabled	High-Speed mode, 8 MHz
ISA Bus Controller	Enabled	Not all pins available until programmed
VL-Bus Controller	Disabled	
ROM/Flash Controller	Enabled	Pin straps are used to set the ROM width for $\overline{\text{ROMCS0}}$ and device from which to fetch (ROM/PC Card)
DRAM Controller	Disabled	
DMA Controllers	Enabled	
Programmable Interrupt Controllers	Enabled	Although the PIC address decode enable control is affected by power-on reset, the internal state of the PICs is not reset until the PICs receive ICW1
Programmable Interval Timer	Enabled	
Real-Time Clock	Enabled	Not reset by a power-on reset
Parallel Port	Disabled	
Serial Port	Disabled	
Matrix Keyboard Controller	Disabled	
XT Keyboard Controller	Disabled	
GPIOs	Enabled	

Table 4-2 Internal Core States Immediately Following Power-On Reset (continued)

Internal Core	State	Comments
Infrared Port	Disabled	
PC Card Controller	Disabled	V_{CC} to cards is enabled to support using CFG2 to cause reset vector to point to PC Card Socket A. The PC Card controller is not supported on the ÉlanSC410 microcontroller.
Graphics Controller	Disabled	The graphics controller is not supported on the ÉlanSC410 microcontroller.

4.1.1.2 Am486 CPU DX Register at CPU Reset

The DX register always contains a component identifier at the conclusion of the CPU reset process. The upper byte of DX(DH) contains 04h and the lower byte of DX(DL) contains a CPU type/stepping identifier. Table 4-3 shows the value in the DX register after CPU reset.

Table 4-3 CPU ID Codes

CPU Type and Cache Mode During CPU Reset	Component ID (DH)	Revision ID(DL)
SX1 in write-back mode	04h	Axh

4.2 SIGNAL DESCRIPTIONS

The descriptions in Table 4-4 are organized in alphabetical order within the functional group listed here.

- System Interface
- Configuration Pins
- Memory Interface
- VL-Bus Interface
- Power Management
- Clocks
- Parallel Port
- Serial Port
- Keyboard Interfaces
- General-Purpose Input/Output
- Serial Infrared Port
- PC Card (ÉlanSC400 Microcontroller Only)
- LCD Graphics Controller (ÉlanSC400 Microcontroller Only)
- Boundary Scan Test Interface
- Reset and Power

Table 4-4 Signal Description Table

Signal	Type	Description
System Interface		
AEN	O	**DMA Address Enable** is used to indicate that the current address active on the SA25–SA0 address bus is a memory address, and that the current cycle is a DMA cycle. All I/O devices should use this signal in decoding their I/O addresses, and should not respond when this signal is asserted. When AEN is asserted, the $\overline{\text{PDACK1}}$– $\overline{\text{PDACK0}}$ signals are used to select the appropriate I/O device for the DMA transfer. AEN is also asserted when a DMA cycle is occurring internal to the chip AEN is also asserted for all accesses to the PC Card I/O space to prevent ISA devices from responding to the $\overline{\text{IOR}}$/$\overline{\text{IOW}}$ signal assertions, since these signals are shared between the PC Card and ISA interfaces.
BALE	O	**Bus Address Latch Enable** is driven at the beginning of an ISA bus cycle with valid address. This signal can be used by external devices to latch the address for the current cycle. BALE is also asserted for all accesses to the PC Card interfaces (memory or I/O) and all DMA cycles. This prevents an ISA device from responding to a cycle based on a previously latched address.
$\overline{\text{DBUFOE}}$	O	**Data Buffer Output Enable** is used to control the output enable on the external transceiver required to drive the peripheral data bus in local bus and 32-bit DRAM modes.
$\overline{\text{DBUFRDH}}$	O	**High Byte Data Buffer Direction Control** controls direction of data flow through the external transceiver required to drive the peripheral data bus in local bus and 32-bit DRAM mode. This is the control signal for the upper 8 bits of the data bus.
$\overline{\text{DBUFRDL}}$	O	**Low Byte Data Buffer Direction Control** controls direction of data flow through the external transceiver required to drive the peripheral data bus in local bus and 32-bit DRAM mode. This is the control signal for the lower 8 bits of the data bus.

Table 4-4 Signal Description Table (continued)

Signal	Type	Description
IOCHRDY	STI PU	**I/O Channel Ready** should be driven by open-drain devices. When pulled Low during an ISA access, wait states are inserted in the current cycle. This pin has an internal weak pull-up that should be supplemented by a stronger external pull-up (usually 4.7 or 1 Kilohm) for faster rise time.
$\overline{\text{IOCS16}}$	I	**I/O Chip Select 16:** The targeted I/O device drives this signal active early in the cycle to request a 16-bit transfer.
$\overline{\text{IOR}}$	O	**I/O Read Command** indicates that the current cycle is a read from the currently addressed I/O device. When this signal is asserted, the selected I/O device may drive data onto the data bus. This signal is also shared with the PC Card interface.
$\overline{\text{IOW}}$	O	**I/O Write Command** indicates that the current cycle is a write to the currently addressed I/O device. When this signal is asserted, the selected I/O device may latch data from the data bus. This signal is also shared with the PC Card interface.
$\overline{\text{MCS16}}$	I	**Memory Chip Select** 16-bit is used to signal to the ISA control logic that the targeted memory device is a 16-bit device.
$\overline{\text{MEMR}}$	O	**Memory Read Command** indicates that the current cycle is a read of the currently addressed memory device. When this signal is asserted, the memory device may drive data onto the data bus.
$\overline{\text{MEMW}}$	O	**Memory Write Command** indicates that the current cycle is a write of the currently addressed memory device. When this signal is asserted, the memory device may latch data from the data bus.
$\overline{\text{PDACK1}}$–$\overline{\text{PDACK0}}$	O	**Programmable DMA Acknowledge** signals may each be mapped to one of the seven available DMA channels. They are driven active (Low) back to the DMA initiator to acknowledge the corresponding DMA requests.
PDRQ1–PDRQ0	I	**Programmable DMA Requests** may each be mapped to one of the seven available DMA channels. They are asserted active (High) by a DMA initiator to request DMA service from the DMA controller.
PIRQ7–PIRQ0	I	**Programmable Interrupt Requests** may each be mapped to one of the available 8259 interrupt channels. They are asserted when a peripheral requires interrupt service. (Rising Edge/Active High Trigger)
RSTDRV	O	**System Reset** is the ISA bus reset signal. When this signal is asserted, all connected devices re-initialize to their reset state. This signal should not be confused with the internal CPU RESET and SRESET signals.
SA25–SA0	O	**System Address Bus** outputs the physical memory or I/O port latched addresses. It is used by all external peripheral devices other than main system DRAM. In addition, this is the local address bus in local bus mode.
$\overline{\text{SBHE}}$	O	**System Byte High Enable** is driven active when the high data byte is to be transferred on the upper 8 bits of the ISA data bus.
SD15–SD0	B	**System Data Bus** is shared between ISA, 8- or 16-bit ROM/Flash, and PC Card peripherals and can be directly connected to all of these devices. In addition, these signals are the upper word of the local data bus, the 32-bit DRAM interface, and the 32-bit ROM interface. In these modes, the system data bus can be generated via an external buffer connected to the SD bus and controlled by the buffer control signals provided.
SPKR	O	**Speaker, Digital Audio Output** controls an external speaker driver. It is generated from the internal 8254-compatible timer Channel 2 output “ANDed” with I/O Port 0061h[1] (Speaker Data Enable); the PC Card speaker signals are “exclusively-ORed” with each other and the speaker control function of the timer to generate the SPKR signal.
TC	O	**Terminal Count** is driven from the DMA controller pair to indicate that the transfer count for the currently active DMA channel has reached zero, and that the current DMA cycle is the last transfer.
Configuration Pins		
BNDSCN_EN	I	**Boundary Scan Enable** enables the boundary scan pin functions. When this pin is High, the boundary scan interface is enabled. When this pin is Low, the boundary scan pin functions are disabled and the pins are configured to their default functions.

Table 4-4 Signal Description Table (continued)

Signal	Type	Description
CFG3	I	**Configuration Pin 3** enables the SD buffer control signals, DBUFOE, DBUFRDH, and DBUFRDL. This pin is sampled at the deassertion of RESET.
CFG2	I	**Configuration Pin 2** selects whether or not the system will boot from PC Card Socket A memory card or from the device attached to ROMCS0. This pin is sampled at the deassertion of RESET. This pin is not supported on the ÉlanSC410 microcontroller.
CFG1–CFG0	I	**Configuration Pins 1–0** select the data bus width for the physical device(s) selected by the ROMCS0 pin (i.e., 8-, 16-, or 32-bit). These pins are sampled at the deassertion of RESET.
Memory Interface		
CASH3–CASH0	O	**Column Address Strobe High** indicates to the DRAM devices that a valid column address is asserted on the MA lines. These CAS signals are for the odd banks (Banks 1 and 3); CASH3–CASH2 are for the high word; and CASH1–CASH0 is for the low word.
CASL3–CASL0	O	**Column Address Strobe Low** indicates to the DRAM devices that a valid column address is asserted on the MA lines. These CAS signals are for the even banks (Banks 0 and 2); CASL1–CASL0 are for the low word; CASL3–CASL2 are for the high word.
D31–D0	B	**Data Bus** is used for DRAM and local bus cycles. This bus is also used when interfacing to 32-bit ROMs.
MA12–MA0	O	**Memory Address:** The DRAM row and column addresses are multiplexed onto this bus. Row addresses are driven onto this bus and are valid upon the falling edge of RAS. Column addresses are driven onto this bus and are valid upon the falling edge of CAS.
MWE	O	**Write Enable** indicates an active write cycle to the DRAM devices. This signal is also used to three-state EDO DRAMs at the end of EDO read cycles.
RAS3–RAS0	O	**Row Address Strobe** indicates to the DRAM devices that a valid row address is asserted on the MA lines.
ROMCS2–ROMCS0	O	**ROM Chip Selects** are active Low outputs that provide the chip select for the BIOS ROM and/or the ROM/Flash array. After power-on reset, the ROMCS0 chip select will go active for accesses into the 64K segment that contains the boot vector, at address 3FF0000h to 3FFFFFFh. ROMCS0 can be driven active during a linear (direct) address decode of certain addresses in the high memory (00A0000–00FFFFFh) region. By default, direct-mapped accesses to the 64-Kbyte region from 00FFFF0h to 00FFFFFh are enabled to support legacy PC/AT BIOS. This area is known as the aliased boot vector. It can also be activated by accessing a Memory Management System (MMS) page that points to the ROM0 address space. ROMCS1 is activated only when accessing an MMS page that points to it. A third, MMS-mappable ROMCS2 signal is available by reconfiguring one of the chip's General Purpose Input Output (GPIO) pins for this function and also requires the use of MMS to access devices connected to it.
ROMRD	O	**ROM Read** indicates that the current cycle is a read of the currently selected ROM device. When this signal is asserted, the selected ROM device may drive data onto the data bus.
ROMWR	O	**ROM Write** indicates that the current cycle is a write of the currently selected ROM device. When this signal is asserted, the selected ROM device may latch data from the data bus.
R32BFOE	O	**ROM 32-Bit Buffer Output Enable** provides the buffer enable signal for the external transceivers on the low word of the ROM interface. This signal is automatically provided when the ROMCS0 interface is configured as 32-bit (the configuration can be done using either CFG1–CFG0 or CSC index 20h[1–0]). Once ROMCS0 is configured as 32-bit, all accesses to 32-bit ROM devices on ROMCS2–ROMCS0 will result in the assertion of the R32BFOE signal.
VL-Bus Interface		
VL_ADS	O	**Local Bus Address Strobe** is asserted to indicate the start of a VL-bus cycle. It is always strobed Low for one clock period. The address and status lines will be valid on the rising edge of VL_LCLK which samples this signal Low.
VL_BE3–VL_BE0	O	**Local Bus Byte Enables** indicate which byte lanes of the 32-bit data bus are involved with the current VL-bus transfer.

Table 4-4 Signal Description Table (continued)

Signal	Type	Description
VL_BLAST	O	**Local Bus Burst Last** is asserted to indicate that the next VL_BRDY assertion will terminate the current VL-bus transfer.
VL_BRDY	I	**Local Bus Burst Ready** is asserted by the VL-bus target to indicate that it is terminating the current burst transfer. The chip samples this signal on the rising edge of VL_LCLK. VL_BRDY should be asserted for one VL_LCLK period per burst transfer. If VL_LRDY is asserted at the same time as VL_BRDY, VL_BRDY will be ignored and the VL-bus transfer will be terminated.
VL_D/C VL_M/IO VL_W/R	O O O	**Local Bus Data/Code Status** is driven Low to indicate that code is being transferred. A High on this signal indicates that data is being transferred. **Local Bus Memory/I/O Status** is driven Low to indicate an I/O transfer. A High on this signal indicates a memory transfer. **Local Bus Write/Read Status** is driven Low to indicate a read transfer. A High on this signal indicates a write.
VL_LCLK	O	**Local Bus Clock** is the VL-bus clock. It is used by the VL-bus target for all timing references. This signal is in phase with the internal CPU's clock input. (Rising Edge Active)
VL_LDEV	I	**Local Bus Device Select** is asserted by the VL-bus target to indicate that it is accepting the current transfer as indicated by the address and status lines. The VL-bus target will assert this signal as a function of the address and status presented on the bus. VL_LDEV may be qualified with VL_ADS by the local bus device.
VL_LRDY	I	**Local Bus Ready** is asserted by the VL-bus target to indicate that it is terminating the current bus cycle. This signal is sampled by the chip on the rising edge of VL_LCLK.
VL_RST	O	**Local Bus Reset** is the VL-bus master reset. It is controlled with CSC index 14h[4].
Power Management		
ACIN	I	**AC Supply Active** can be used to indicate to the system that it is being powered from an AC source. When asserted, this signal may disable power management functions (if configured to do so).
BL2–BL0	I	**Battery Low Detects** are used to indicate to the chip the current status of the system's primary battery pack. BL0–BL2 can indicate various conditions of the battery as conditions change. These inputs may be used to force the system into one of the power saving modes when activated. (Low-Going Edge)
LBL2	O	**Latched Battery Low Detect 2** may be driven Low and latched on the low going edge of the BL2 input to indicate to the system that the chip has been forced into the Suspend mode by a battery dead indication from the BL2 signal. It is cleared by one of the "all clear" indicators that allow the system to resume after a battery dead indication.
SUS_RES	I	**Suspend/Resume Operation:** When the chip is in Hyper-Speed, High-Speed, Low-Speed, or Standby mode, a software-configurable edge on this pin may cause the internal logic to enter Suspend mode. When in Suspend, a software-configurable edge on this pin may cause the chip to enter the High-Speed or Low-Speed mode. The choice of edge is configured using the SUS_RES Pin Configuration Register at CSC index 50h.

Bus Cycle Initiated	VL_M/IO	VL_D/C	VL_W/R
Interrupt Acknowledge	0	0	0
Halt/Special Cycle	0	0	1
I/O Read	0	1	0
I/O Write	0	1	1
Code Read	1	0	0
Reserved	1	0	1
Memory Read	1	1	0
Memory Write	1	1	1

Table 4-4 Signal Description Table (continued)

Signal	Type	Description
Clocks		
CLK_IO	I/O	**Clock Input/Output** can be used as an input to drive the integrated 8254 timer with a 1.19318 mHz clock signal from an external source, or it can be used as an output to bring out certain internal clock sources to drive external devices.
LF_INT, LF_LS, LF_VID, LF_HS	A	**Loop Filters** are used to connect external RC loop filters required by the internal PLLs. LF_VID is not supported on the ÉlanSC410 microcontroller.
32KXTAL1 32KXTAL2		**32.768 KHz Crystal Interface Signals** are used for the 32.768 KHz crystal. This is the main clock source for the chip and is used to drive the internal Phase-Locked Loops (PLLs) that generate all other clock frequencies needed in the system.
Parallel Port ***(Note: The names in parentheses in this section are those used in EPP mode.)***		
$\overline{\text{ACK}}$ (INTR)	I	**Printer Acknowledge:** In standard mode, this signal is driven by the parallel port device with the state of the printer acknowledge signal. In EPP Mode, this signal is used to indicate to the chip that the parallel port device has generated an interrupt request.
$\overline{\text{AFDT}}$ ($\overline{\text{DSTRB}}$)	O	**Auto Line Feed Detect:** In standard mode, this signal is driven by the chip indicating to the parallel port device to insert a line feed at the end of every line. In EPP mode, this signal is driven active by the chip during reads or writes to the EPP data registers.
BUSY ($\overline{\text{WAIT}}$)	I	**Printer Busy:** In standard mode, this signal is driven by the parallel port device with the state of the printer busy signal. In EPP mode, this signal is used to add wait states to the current cycle.
$\overline{\text{ERROR}}$	I	**Error:** The printer asserts the Error signal to inform the parallel port of a deselect condition, paper end (PE) or other error condition.
$\overline{\text{INIT}}$	O	**Initialize Printer:** This signals the printer to begin an initialization routine.
PE	I	**Paper End:** The printer asserts this signal when it is out of paper.
$\overline{\text{PPDWE}}$	O	**Parallel Port Write Enable** controls an external 374 type latch in a unidirectional parallel port design. This device is used to latch the SD7–SD0 bus onto the parallel port data bus. To implement a bidirectional parallel port, this pin is reconfigured to act as an address decode for the parallel port data port. It may then be externally gated with $\overline{\text{IOR}}$ and $\overline{\text{IOW}}$ to provide the Parallel Port Data Read and Write Strobes, respectively.
$\overline{\text{PPOEN}}$	O	**Parallel Port Output Buffer Enable** supports a bidirectional parallel port design. $\overline{\text{PPOEN}}$ is used to control the output enable of the external Parallel Port Output Buffer (373 octal D-type transparent latch).
SLCT	I	**Printer Select** is returned by a printer upon receipt of $\overline{\text{SLCTIN}}$
$\overline{\text{SLCTIN}}$ ($\overline{\text{ASTRB}}$)	O	**Printer Selected:** In Standard mode, this signal is driven by the chip to select the parallel port device. In EPP mode, this signal is driven active by the chip during reads or writes to the EPP address register.
$\overline{\text{STRB}}$ ($\overline{\text{WRITE}}$)	O	**Strobe:** In Standard mode, this signal is used to indicate to the parallel port device to latch the data on the parallel port data bus. In EPP mode, this signal is driven active during writes to the EPP data or the EPP address register.
Serial Port		
$\overline{\text{CTS}}$	I	**Clear To Send** is driven back to the serial port to indicate that the external data carrier equipment (DCE) is ready to accept data.
$\overline{\text{DCD}}$	I	**Data Carrier Detect** is driven back to the serial port from a piece of data carrier equipment when it has detected a carrier signal from a communications target.
$\overline{\text{DSR}}$	I	**Data Set Ready** indicates that the external DCE is ready to establish a communication link with the internal serial port controller.
$\overline{\text{DTR}}$	O	**Data Terminal Ready** indicates to the external DCE that the internal serial port controller is ready to communicate.
$\overline{\text{RIN}}$	I	**Ring Indicate** is used by an external modem to inform the serial port that a ring signal was detected. A change in state on this signal by the external modem may be configured to cause a modem status interrupt. This signal may be used to cause the chip to resume from a Suspend state.

Table 4-4 Signal Description Table (continued)

Signal	Type	Description
$\overline{\text{RTS}}$	O	**Request To Send** indicates to the external DCE that the internal serial port controller is ready to send data.
SIN	I	**Serial Data In** is used to receive the serial data from the external serial device or DCE into the internal serial port controller.
SOUT	O	**Serial Data Out** is used to transmit the serial data from the internal serial port controller to the external serial device or DCE.
Keyboard Interfaces		
KBD_COL7–KBD_COL0	O	**Matrix-Scanned Keyboard Column Outputs** drive the matrix keyboard column lines. (Open Collector Output with programmable termination)
KBD_ROW14–KBD_ROW0	STI	**Matrix-Scanned Keyboard Row Inputs** samples the row lines on the matrix keyboard.
XT_CLK	I/O	**XT Keyboard Clock** is the clock signal for an external XT keyboard interface. (Open Collector Output)
XT_DATA	I/O	**XT Keyboard Data** is the data signal for an external XT keyboard interface. (Open Collector Output)
General-Purpose Input/Output		
GPIO31–GPIO15 GPIO_CS14–GPIO_CS0	B	**General Purpose I/Os and Programmable Chip Selects** Each of the GPIOs can be programmed to be an input or an output. As outputs, all of the GPIOs can be programmed to be High or Low. Some of the GPIOs can be programmed to be High or Low for each of the power management modes. Also as outputs, some of these pins can be individually programmed as chip selects for other external peripheral devices. These can be configured as direct memory address decodes or I/O decodes qualified or non-qualified by the ISA bus command signals. Any one of the GPIO_CSx signals can be configured as $\overline{\text{ROMCS2}}$. As inputs, all the GPIOs can be read back with a register bit. Some of these pins can be individually programmed to act as activity triggers, wake up sources, or SMIs.
Serial Infrared Port		
SIRIN	I	**Infrared Serial Input** is the digital input for the serial infrared interface.
SIROUT	O	**Infrared Serial Output** is the digital output for the serial infrared interface.
PC Card Controller (ÉlanSC400 Microcontroller Only) ***(Note: The names in parentheses in this section are those used in PC Card Memory and I/O mode.)***		
BVD1_A ($\overline{\text{STSCHG_A}}$)–BVD1_B ($\overline{\text{STSCHG_B}}$)	I	**Battery Voltage Detect** is driven Low by a PC Card when its on-board battery is dead. When the PC Card interface is configured for I/O, this signal can be driven by the card to indicate a card status change. It is typically used to generate a system IRQ in this mode. These pins are not supported on the ÉlanSC410 microcontroller.
BVD2_A ($\overline{\text{SPKR_A}}$) (DRQ_A)–BVD2_B ($\overline{\text{SPKR_B}}$) (DRQ_B)	I	**Battery Voltage Detect** is driven Low by a PC Card when its on-board battery is weak. When the PC Card interface is configured for I/O, this signal can be driven by the card's speaker output. When enabled, this signal can drive the chip SPKR output. When PC Card DMA is enabled, the DMA request from the PC Card can be programmed to appear on this signal. See also the description for WP_A ($\overline{\text{IOIS16_A}}$) (DRQ_A) and WP_B ($\overline{\text{IOIS16_B}}$) (DRQ_B); the DMA request can also be programmed to appear on these pins. These pins are not supported on the ÉlanSC410 microcontroller.
$\overline{\text{CD_A}}$–$\overline{\text{CD_B}}$ $\overline{\text{CD_A2}}$	I	**Card Detect** indicates that the card is properly inserted. Socket A is capable of being configured to use two card detect inputs and socket B is only provided with one. If only one card detect is to be used for a socket, the input signals should be driven from a logical AND (digital OR) of the CD1 and CD2 signals from their respective card interfaces. These pins are not supported on the ÉlanSC410 microcontroller.

Table 4-4 Signal Description Table (continued)

Signal	Type	Description
ICDIR	O	**Card Data Direction** controls the direction of the card data buffers or voltage translators. It works in conjunction with the $\overline{\text{MCEL}}$ and $\overline{\text{MCEH}}$ card enable signals to control data buffers on the card interface. When this signal is High, the data flow is from the chip to the card socket, indicating a data write cycle. When this signal is Low, the data flow is from the card socket into the chip, indicating a read cycle. This pin is not supported on the ÉlanSC410 microcontroller.
$\overline{\text{OE}}$	O	**PC Card Output Enable:** This is the PC Card memory read signal. This pin is not supported on the ÉlanSC410 microcontroller.
$\overline{\text{MCEH_A}}$, $\overline{\text{MCEH_B}}$	O	**Card Enables, High Byte** enables a PC Card's high data bus byte transceivers for the respective card interfaces. These pins are not supported on the ÉlanSC410 microcontroller.
$\overline{\text{MCEL_A}}$, $\overline{\text{MCEL_B}}$	O	**Card Enables, Low Byte** enables a PC Card's low data bus byte transceivers for the respective card interfaces. These pins are not supported on the ÉlanSC410 microcontroller.
$\overline{\text{PCMA_VCC}}$	O	**PC Card Socket A V_{CC} Enable** can be used to control the V_{CC} to socket A. This pin is not supported on the ÉlanSC410 microcontroller.
$\overline{\text{PCMB_VCC}}$	O	**PC Card Socket B V_{CC} Enable** can be used to control the V_{CC} to socket B. This pin is not supported on the ÉlanSC410 microcontroller.
PCMA_VPP2–PCMA_VPP1	O	**PC Card Socket A VPP Selects** can be used to control the VPP to socket A. These pins are not supported on the ÉlanSC410 microcontroller.
PCMB_VPP2–PCMB_VPP1	O	**PC Card Socket B VPP Selects** can be used to control the VPP to socket B. These pins are not supported on the ÉlanSC410 microcontroller.
RDY_A ($\overline{\text{IREQ_A}}$), RDY_B ($\overline{\text{IREQ_B}}$)	I	**Card Ready** indicates that the respective card is ready to accept a new data transfer command. When the card interface is configured as an I/O interface, this signal is used as the card Interrupt Request input into the chip. These pins are not supported on the ÉlanSC410 microcontroller.
$\overline{\text{REG_A}}$ ($\overline{\text{DACK_A}}$), $\overline{\text{REG_B}}$ ($\overline{\text{DACK_B}}$)	O	**Attribute Memory Select** signals are driven inactive (High) for accesses to a PC Card's Common Memory, and asserted (Low) for accesses to a PC Card's Attribute Memory and I/O space for their respective card interfaces. When PC Card DMA is enabled, the DMA acknowledge to the PC Card will appear on this signal. These pins are not supported on the ÉlanSC410 microcontroller.
RST_A, RST_B	O	**Card Reset** signals are the reset for their respective cards. When active, this signal clears the Interrupt and General Control Register (PC Card index 03h and 43h), thus placing a card in an unconfigured (Memory-Only mode) state. It also indicates the beginning of any additional card initialization. These pins are not supported on the ÉlanSC410 microcontroller.
$\overline{\text{WAIT_AB}}$	I	**Extend Bus Cycle** delays the completion of the memory access or I/O access that is currently in progress. When this signal is asserted (Low), wait states are inserted into the cycle in progress. Only one $\overline{\text{WAIT}}$ input is provided on the chip. External logic is required for a two-socket implementation to logically AND (digitally OR) each card's $\overline{\text{WAIT}}$ signal together. This pin is not supported on the ÉlanSC410 microcontroller.
$\overline{\text{WE}}$ (TC)	O	**PC Card Write Enable** is the PC Card memory write signal. Data will be transferred from the chip to the PC Card. When PC Card DMA is enabled, the DMA Terminal Count to the PC Card will appear on this signal. This pin is not supported on the ÉlanSC410 microcontroller.
WP_A ($\overline{\text{IOIS16_A}}$) (DRQ_A), WP_B ($\overline{\text{IOIS16_B}}$) (DRQ_B)	I	**Write Protect** indicates the status of the respective card's Write Protect switch. When the respective card is configured for an I/O interface, this signal is used by the card to indicate back to the chip that the currently accessed port is 16 bits wide. When PC Card DMA is enabled, the DMA request from the PC Card can be programmed to appear on this signal. See also the description for BVD2_A (SPKR_A) (DRQ_A) and BVD2_B (SPKR_B) (DRQ_B); the DMA request can also be programmed to appear on these pins. These pins are not supported on the ÉlanSC410 microcontroller.
LCD Graphics Controller (ÉlanSC400 Microcontroller Only)		
FRM	O	**LCD Panel Line Frame Start** is asserted by the chip at the start of every frame to indicate to the LCD panel that the next data clocked out is intended for the start of the first scan line on the panel. Some panels refer to this signal as FLM or S (scan start up). This pin is not supported on the ÉlanSC410 microcontroller.

Table 4-4 Signal Description Table (continued)

Signal	Type	Description
LC	O	**LCD Panel Line Clock** is activated at the start of every pixel line. Commonly referred to by LCD data sheets as CL1 or CP1. This pin is not supported on the ÉlanSC410 microcontroller.
LCDD7–LCDD0	O	**LCD Panel Data bits:** LCDD7–LCDD0 are data bits for the LCD panel interface. When driving 4-bit single-scan panels, bits 3–0 form a nibble-wide LCD data interface. In dual-scan panel mode, LCDD3–LCDD0 are the data bits for the top half of the LCD, and LCDD7–LCDD4 are the data bits for the bottom half of the LCD. When driving 8-bit single-scan panels (monochrome or color STN), these bits are the 8-bit data interface. These pins are not supported on the ÉlanSC410 microcontroller.
$\overline{\text{LVDD}}$	O	**LCD Panel VDD Voltage Control** is used to control the assertion of the LCD's VDD voltage. This is provided to be part of the solution in sequencing the panel's VDD, DATA, and VEE in the proper order during panel power up and power down to prevent damage to the panel from CMOS driver latch up. VDD is used to power the LCD logic and is usually +5 V or +3 V DC. This pin is not supported on the ÉlanSC410 microcontroller.
$\overline{\text{LVEE}}$	O	**LCD Panel VEE Voltage Control** is used to control the assertion of the LCD's VEE voltage. This is provided to be part of the solution in sequencing the panel's VDD, DATA, and VEE in the proper order during panel power up and power down to prevent damage to the panel from CMOS driver latch up. VEE is the LCD contrast voltage and is either positive or negative with an amplitude of 15–30 V DC.This pin is not supported on the ÉlanSC410 microcontroller.
M	O	**LCD Panel AC Modulation** is the AC modulation signal for the LCD. AC modulation causes the LCD panel drivers to reverse polarity to prevent an internal DC bias from forming on the panel. This pin is not supported on the ÉlanSC410 microcontroller.
SCK	O	**LCD Panel Shift Clock** is the nibble/byte strobe used by the LCD panel to latch a nibble or byte of incoming data. Commonly referred to by LCD panels as CL2 or CP2. This pin is not supported on the ÉlanSC410 microcontroller.
Boundary Scan Test Interface		
BNDSCN_TCK	I	**Test Clock** is the boundary-scan input clock that is used to shift serial data patterns in from BNDSCN_TDI.
BNDSCN_TDI	I	**Test Data Input** is the serial input stream for boundary-scan input data. This pin has a weak internal pull-up resistor. It is sampled on the rising edge of BNDSCN_TCK. If not driven, this input is sampled High internally.
BNDSCN_TDO	O TS	**Test Data Output** is the serial output stream for boundary-scan result data. It is in the high impedance state except when scanning is in progress.
BNDSCN_TMS	I	**Test Mode Select** is an input for controlling the test access port. This pin has a weak internal pull-up resistor. If it is not driven, it is sampled High internally.
Reset and Power		
BBATSEN	I	**Backup Battery Sense:** RTC (Real Time Clock) backup battery voltage is sampled on this pin each time the AVCC pin has power applied to it followed by a chip master reset. If this samples below 2.4 V, the VRT bit (RTC index 0Dh) will be cleared until read one time. At this time, the VRT bit will be set until BBATSEN is sampled again. BBATSEN also provides a power-on-reset signal for the RTC when an RTC backup battery is applied for the first time.
GND		**Ground Pins**
$\overline{\text{RESET}}$	I	**Reset Input** is an asynchronous hardware reset input equivalent to POWERGOOD in the AT system architecture.
V_{CC}		**3.3 V DC Supply Pins** provide power to the core.
V_{CC}_ANALOG		**3.3 V Supply Pins** provide power to the analog section of the chip, including the internal PLLs and integrated oscillator circuit. Extreme care should be taken that this supply voltage is isolated properly to provide a clean, noise free voltage to the PLLs.
V_{CC}_BUS		**3.3 V DC Supply Pins** provide power to the SD bus I/O signals.
V_{CC}_CPU		**3.3 V DC Supply Pins** provide power to the internal CPU.
V_{CC}_LCD or V_{CC}_VL		**3.3 V DC Supply Pins** provide power to the LCD panel/VL-bus control signals on the ÉlanSC400 microcontroller. These pins are called V_{CC}_VL on the ÉlanSC410 microcontroller.

Table 4-4 Signal Description Table (continued)

Signal	Type	Description
V_{CC}_MEM		**3.3 V DC Supply Pins** provide power to the system memory I/O signals.
V_{CC}_PCM or V_{CC}_PP		**3.3 V DC Supply Pin** provides power to the PC Card Socket A control signals on the ÉlanSC400 microcontroller. This pin is called V_{CC}_PP on the ÉlanSC410 microcontroller.
V_{CC}_PCM2 or V_{CC}_PP		**3.3 V DC Supply Pin** provides power to the parallel port/PC Card slot B control signals on the ÉlanSC400 microcontroller. This pin is called V_{CC}_PP on the ÉlanSC410 microcontroller.
V_{CC}_RTC		**3.3 V Supply Pin** provides power to the internal real time clock and on-board static/ configuration RAM. This pin may be driven independently of all other power pins.
V_{CC}_SER		**3.3 V DC Supply Pins** provide power to the serial port I/O signals
V_{CC}_SYS		**3.3 V DC Supply Pins** provide power to the ISA bus control signals

4.3 PIN CHANGES FOR THE ÉLANSC410 MICROCONTROLLER

The following signals supported on the ÉlanSC400 microcontroller are not available on the ÉlanSC410 microcontroller.

- Configuration pin: CFG2
- PC Card controller signals: $\overline{\text{MCEL_A}}$, $\overline{\text{MCEL_B}}$, $\overline{\text{MCEH_A}}$, $\overline{\text{MCEH_B}}$, RST_A, RST_B, $\overline{\text{REG_A}}$, $\overline{\text{REG_B}}$, $\overline{\text{CD_A}}$, $\overline{\text{CD_B}}$, $\overline{\text{CD_A2}}$, $\overline{\text{RDY_A}}$, $\overline{\text{RDY_B}}$, BVD1_A, BVD1_B, BVD2_A, BVD2_B, WP_A, WP_B, $\overline{\text{WAIT_AB}}$, $\overline{\text{OE}}$, $\overline{\text{WE}}$, ICDIR, $\overline{\text{PCMA_VCC}}$, PCMA_VPP1, PCMA_VPP2, $\overline{\text{PCMB_VCC}}$, PCMB_VPP1, PCMB_VPP2
- Graphics controller signals: LCDD7–LCDD0, M, LC, SCK, FRM, $\overline{\text{LVEE}}$, $\overline{\text{LVDD}}$
- Loop filter signal: LF_VID

The following power pins are renamed on the ÉlanSC410 microcontroller:

- The two V_{CC}_LCD pins are called V_{CC}_VL on the ÉlanSC410 microcontroller.
- V_{CC}_PCM and V_{CC}_PCM2 are both called V_{CC}_PP on the ÉlanSC410 microcontroller.

4.4 MULTIPLEXED PIN FUNCTION OPTIONS

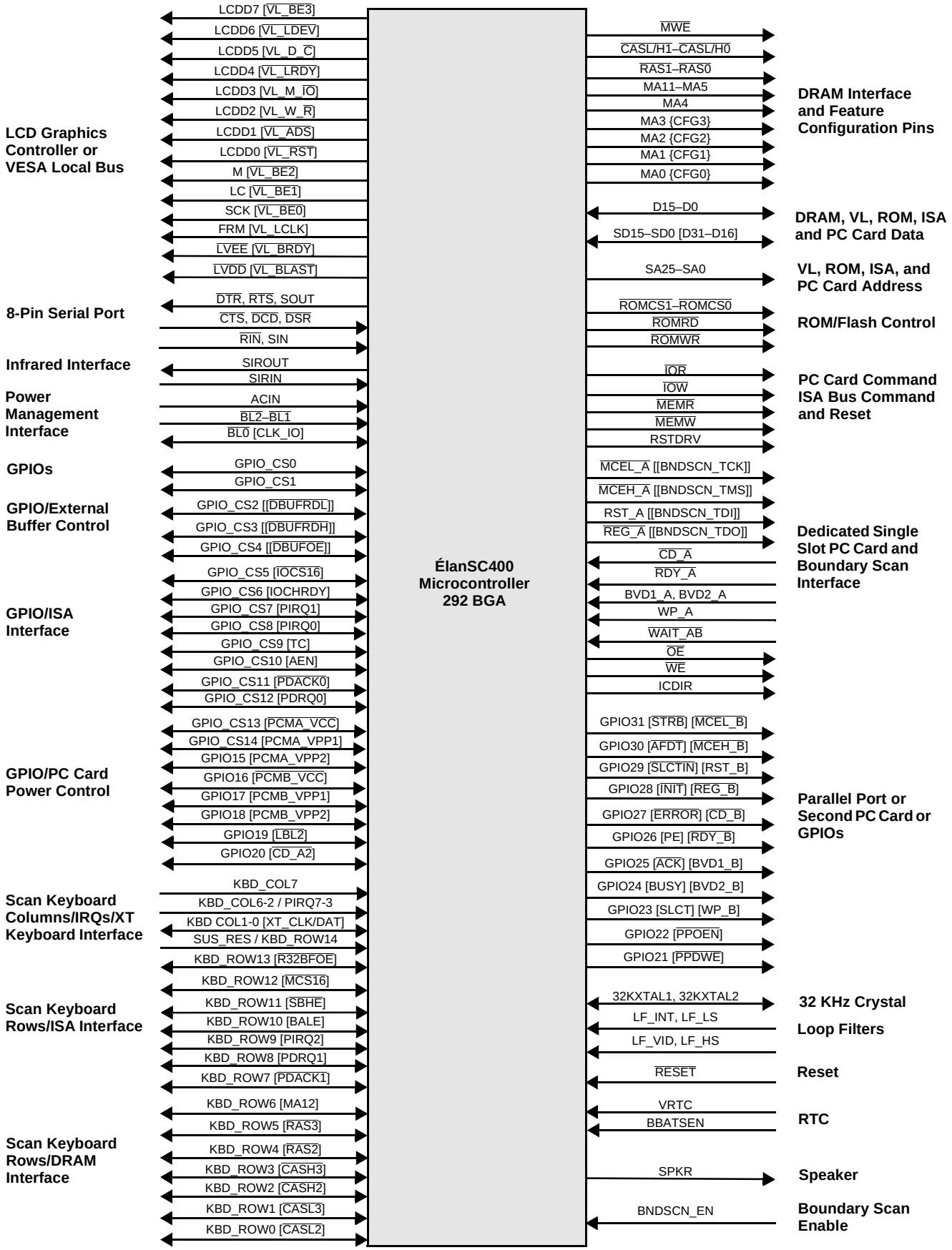
Many pins on the ÉlanSC400 and ÉlanSC410 microcontrollers have more than one function. Figure 4-1 and Figure 4-2 show the multiplexing of pins by function for each microcontroller.

Pins with multiplexed functions have their functions selected in one of two ways:

- By configuration pins that are latched during reset
- By firmware via programmed configuration registers

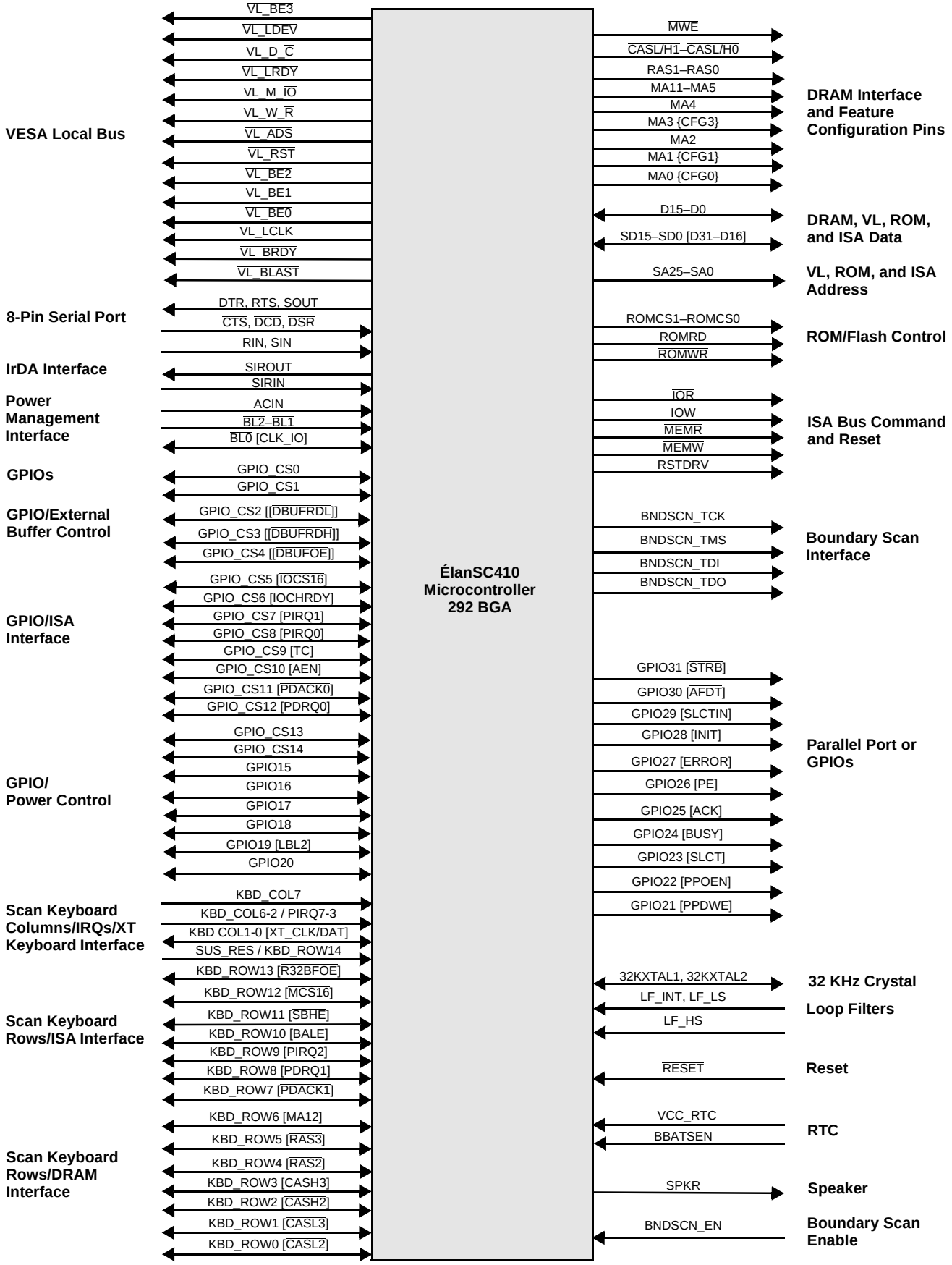
Reference tables showing which configuration registers are used to select pin functions are included in Appendix A of this manual.

Figure 4-1 Multiplexed Pins on the ÉlanSC400 Microcontroller



Note: */ =Two functions available on the pin at the same time. { } = Function during hardware reset.* [ ] *= Alternative function selected by firmware configuration.* [[ ]] *= Alternate function selected by a hardware configuration pin state at power-on reset.*

Figure 4-2 Multiplexed Pins on the ÉlanSC410 Microcontroller



Note: */ =Two functions available on the pin at the same time.* { } *= Function during hardware reset.* [ ] *= Alternative function selected by firmware configuration.* [[ ]] *= Alternate function selected by a hardware configuration pin state at power-on reset.*

4.4.1 Using the Configuration Pins to Select Pin Functions

The configuration pins are used only for those functions that must be selected at reset, prior to firmware execution. All other I/O functions are selected using configuration registers.

Table 4-5 provides an overview of the configuration pin functions. All of the CFG pins have weak internal pull-down resistors that select the default function. External pull-up resistors are required to select an alternative function.

Table 4-5 Pin Strap Bus Buffer Options

CFG3	CFG1	CFG0	$\overline{\text{ROMCS0}}$ Data Width	$\overline{\text{DBUFOE}}$ $\overline{\text{DBUFRDL}}$ $\overline{\text{DBUFRDH}}$	$\overline{\text{R32BFOE}}$
0	0	0	8-bit	Disabled	Disabled
0	0	1	Reserved	Reserved	Reserved
0	1	0	16-bit	Disabled	Disabled
0	1	1	32-bit	Disabled	Enabled
1	0	0	8-bit	Enabled	Disabled
1	0	1	Reserved	Reserved	Reserved
1	1	0	16-bit	Enabled	Disabled
1	1	1	32-bit	Enabled	Enabled

Notes:

1. *In the table above, CFG3 is defined as the enable/disable for the $\overline{\text{DBUFOE}}$, $\overline{\text{DBUFRDL}}$, and $\overline{\text{DBUFRDH}}$ signals. They can be enabled independently of whether or not a 32-bit D bus is selected via the firmware to support the VL local bus or 32-bit DRAM interface.*
2. *The 32-bit ROM option must be selected on $\overline{\text{ROMCS0}}$ for the $\overline{\text{R32BFOE}}$ signal to be enabled. The selection of the $\overline{\text{DBUFOE}}$, $\overline{\text{DBUFRDL}}$, and $\overline{\text{DBUFRDH}}$ signals is still dependent only on the CFG3 signal.*

4.4.1.1 CFG0 and CFG1 Pins

These pins (shown in Table 4-6) configure the data bus width (8-, 16-, or 32-bit) of the ROM interface that is selected by the $\overline{\text{ROMCS0}}$ pin. When a 32-bit ROM is selected, these pins also enable the $\overline{\text{R32BFOE}}$. Once $\overline{\text{ROMCS0}}$ is configured as 32-bit, all accesses to 32-bit ROM devices on $\overline{\text{ROMCS2}}$–$\overline{\text{ROMCS0}}$ will result in the assertion of the $\overline{\text{R32BFOE}}$ signal.

Note: *The data bus width for the $\overline{\text{ROMCS0}}$ interface can also be changed through programming. However, this is not recommended. The programming feature was implemented mainly for testing.*

Table 4-6 CFG0 and CFG1 Configuration

CFG1	CFG0	Configuration
0	0	8-bit $\overline{\text{ROMCS0}}$ ROM interface
0	1	Reserved
1	0	16-bit $\overline{\text{ROMCS0}}$ ROM interface
1	1	32-bit $\overline{\text{ROMCS0}}$ ROM interface

4.4.1.2 CFG2 Pin

On the ÉlanSC400 microcontroller, this configuration pin (see Table 4-7) is used for selecting the $\overline{\text{ROMCS0}}$ steering at system boot time. CFG2 is not supported on the ÉlanSC410 microcontroller.

The boot ROM chip select ($\overline{\text{ROMCS0}}$) can either be enabled to drive the $\overline{\text{ROMCS0}}$ pin or can be rerouted to drive the PC Card (socket A only) interface chip selects. The CFG0 and CFG1 pins are still used to select the data bus width for the $\overline{\text{ROMCS0}}$ decode, regardless of the CFG2 configuration. The PC Card $\overline{\text{ROMCS0}}$ redirection should not be selected when the CFG0 and CFG1 configuration pins are set to select a 32-bit ROM interface. See Section 7.6.4.2 for more information on redirecting $\overline{\text{ROMCS0}}$ to PC Card Socket A.

When the ROM chip select decode has been redirected to PC Card socket A, all of the normal PC Card controller features can still be used to drive the PC Card Socket A interface. The ROM chip select and decode remapping to the PC Card socket can be enabled and disabled using firmware at any time.

Table 4-7 CFG2 Configuration

CFG2	Configuration
0	Enables the $\overline{\text{ROMCS0}}$ decode on the $\overline{\text{ROMCS0}}$ pin
1	Enables the $\overline{\text{ROMCS0}}$ decode to access PC Card socket A

4.4.1.3 CFG3 Pin

This configuration pin is used for selecting between the GPIO_CS4–GPIO_CS2 I/O pins and the SD bus buffer control signals: $\overline{\text{DBUFOE}}$, $\overline{\text{DBUFRDL}}$, and $\overline{\text{DBUFRDH}}$. When the buffer control signal configuration is selected using the CFG3 pin, the $\overline{\text{DBUFOE}}$, $\overline{\text{DBUFRDL}}$, and $\overline{\text{DBUFRDH}}$ are driven from boot time on for all accesses to the peripheral data bus. These three signals are to be used for the external system bus transceiver control. See Table 4-8 for the CFG3 configuration definitions.

Table 4-8 CFG3 Configuration

CFG3	Configuration
0	Enables the GPIO_CS4–GPIO_CS2 signals on the I/O pins
1	Enables the SD bus buffer control signals $\overline{\text{DBUFOE}}$, $\overline{\text{DBUFRDL}}$, and $\overline{\text{DBUFRDH}}$ on the I/O pins

4.4.1.4 BNDSCN_EN Pin

The BNDSCN_EN configuration pin (see Table 4-9) is used to enable the boundary scan function I/O pins. The following pins are configured for their boundary scan function when BNDSCN_EN is asserted:

- BNDSCN_TCK
- BNDSCN_TMS
- BNDSCN_TDI
- BNDSCN_TDO

Table 4-9 Boundary Scan Function Configuration

BNDSCN_EN	Configuration
0	Enables the PC Card function
1	Enables the boundary scan function

4.5 DATA AND ADDRESS BUSES

4.5.1 Data Buses

The ÉlanSC400 and ÉlanSC410 microcontrollers provide 32 bits of data that are divided into two separate 16-bit buses.

- **System Data (SD) Bus**—The system (or peripheral) data bus (SD15-SD0) is always 16 bits wide and is shared between ISA, 8- or 16-bit ROM/Flash, and, on the ÉlanSC400 microcontroller, the PC Card peripherals. The system data bus can be directly connected to all of these devices. In addition, these signals are the upper word of the VESA local (VL) data bus, the 32-bit DRAM interface, and the 32-bit ROM interface.
- **Data (D) Bus**—The D15–D0 data bus is used during 16-bit DRAM cycles. For 32-bit DRAM, VL-bus, and ROM cycles, this bus is combined with the system data bus. In other words, the data bus pins D31–D16 are shared with the system data bus pins SD15–SD0.

The ÉlanSC400 and ÉlanSC410 microcontrollers support the data bus configurations listed below. External transceivers or buffers are required in some bus configurations to isolate the buses and to provide proper data steering.

- **Configuration A**—16-bit DRAM bus, 8/16-bit ROM, 32-bit VL-bus disabled, internal graphics controller enabled/disabled, matrix keyboard interface enabled/disabled
- **Configuration B**—16/32-bit DRAM bus, 8/16-bit ROM, 32-bit VL-bus enabled/disabled, internal graphics controller disabled, matrix keyboard interface disabled
- **Configuration C**—16/32-bit DRAM bus, 32-bit ROM, 32-bit VL-bus enabled/disabled, internal graphics controller disabled, matrix keyboard interface disabled

The ÉlanSC400 and ÉlanSC410 microcontrollers offer flexibility in configuring the ROM and DRAM data buses for different widths.The ROM widths (8/16/32 bits) are programmed during power up through two pin straps, CFG0 and CFG1.

- When DRAM is configured for 16 bits and the VL-bus is disabled, the pins SD15–SD0/ D31–D16 are dedicated for the system (SD) bus. This results in Configuration A.
- When DRAM is configured for 32 bits or the VL-bus is enabled, the pins SD15–SD0/ D31–D16 are shared between the SD bus and the DRAM/VL-bus. This corresponds to Configuration B or Configuration C. Control signals are available to control an external SD buffer when necessary to isolate the (variable) system data bus loading (ISA, PC Card, etc.) from the local data bus or to level-shift voltages. Devices on the D-bus side connected to the microcontroller are the DRAM and the VL-bus target; on the SD-buffer side (away from the microcontroller) are the ISA, ROM, and PC Card devices.

The DRAM widths (16/32 bits) as well as the VL-bus enabling/disabling are programmed through configuration registers. When enabled, the VL-bus is always 32 bits wide. The graphics controller on the ÉlanSC400 microcontroller is enabled/disabled through a configuration register. Up to four 16- or 32-bit banks of DRAM are supported.

The ÉlanSC400 and ÉlanSC410 microcontrollers contain a total of 4 data byte lanes, which are referred to as: V3, V2, V1, and V0. The functionality of these four data byte lanes depends on the bus configuration chosen, as shown in Figure 4-3, Figure 4-4, and Figure 4-5, beginning on page 4-21. The byte lanes map to the microcontroller's pins as shown in Table 4-10.

Table 4-10 Byte Lanes

Byte Lane	Pins
V0	D7–D0
V1	D15–D8
V2	SD7–SD0/D23–D16
V3	SD15–SD8/D31–D24

4.5.1.1 Configuration A: 16-Bit DRAM Bus and 16-Bit SD Bus

In this configuration (shown in Figure 4-3), byte lanes V1 and V0 form the DRAM data bus byte lanes D15–D8 and D7–D0 respectively. Bytes lanes V3 and V2 form the SD data bus byte lanes SD15–SD8 and SD7–SD0 respectively. No external buffers or transceivers are required to provide isolation between local and system data buses in this mode. The internal graphics controller on the ÉlanSC400 microcontroller may be enabled or disabled. The VL-bus is always disabled in this mode. The ROM and PC Card targets reside on the SD bus and may be programmed to be 8 or 16 bits wide. The matrix keyboard may be enabled or disabled in this mode. Note that the $\overline{\text{RAS}}$ and $\overline{\text{CAS}}$ signals for DRAM banks 2 and 3 are traded for keyboard row signals.

4.5.1.2 Configuration B: 32-Bit DRAM Bus and 16-Bit SD Bus

This configuration (Figure 4-4) differs from Configuration A in that either the DRAM interface is programmed to be 32 bits wide and/or the VL-bus is enabled. This configuration uses byte lanes V3 and V2 for the upper word of the DRAM bus and/or the VL-bus. The SD system bus is formed by buffering byte lanes V3 and V2 through external transceivers to create SD15–SD8 and SD7–SD0. These external transceivers might be required to reduce SD bus loading on the high word of the VL-bus/32-bit DRAM bus. $\overline{\text{DBUFOE}}$ is the enable signal for these two transceivers while $\overline{\text{DBUFRDL}}$ and $\overline{\text{DBUFRDH}}$ are the direction control signals for the low and high bytes of the SD bus.

The internal graphics controller on the ÉlanSC400 microcontroller must always be disabled in this mode. The VL-bus may be enabled or disabled. As in Configuration A, the ROM and PC Card targets reside on the system bus and may be programmed to be 8 or 16 bits wide.

The matrix keyboard interface is not available in Configuration B.

4.5.1.3 Configuration C: 32-Bit DRAM Bus, 16-Bit SD Bus, and 32-Bit ROM Bus

Configuration C (Figure 4-5) is identical to Configuration B except for the ROM interface, which supports 32-bit wide ROM interface. Byte lanes V1 and V0 are buffered through two external 8-bit transceivers or buffers to generate the lower sixteen bits of the 32-bit ROM data bus.

It is important to note that 32-bit ROM operation is only supported in Fast-ROM mode. Once $\overline{\text{ROMCS0}}$ is configured as 32-bit, all accesses to 32-bit ROM devices on $\overline{\text{ROMCS2}}$–$\overline{\text{ROMCS0}}$ will result in the assertion of the $\overline{\text{R32BFOE}}$ signal. $\overline{\text{R32BFOE}}$ provides the buffer enable signal for the external transceivers on the low word of the ROM interface. $\overline{\text{ROMRD}}$ is used as the direction control signal for both bytes of the high ROM word. The use of

$\overline{\text{R32BFOE}}$ and associated buffers is at the discretion of the system designer. It is only required if loading on the ROM interface is heavy enough to impact the VL/DRAM data bus operation or if a 5-V ROM device needs voltage translation to the 3.3-V VL/DRAM bus level.

The matrix keyboard interface is not available in Configuration C.

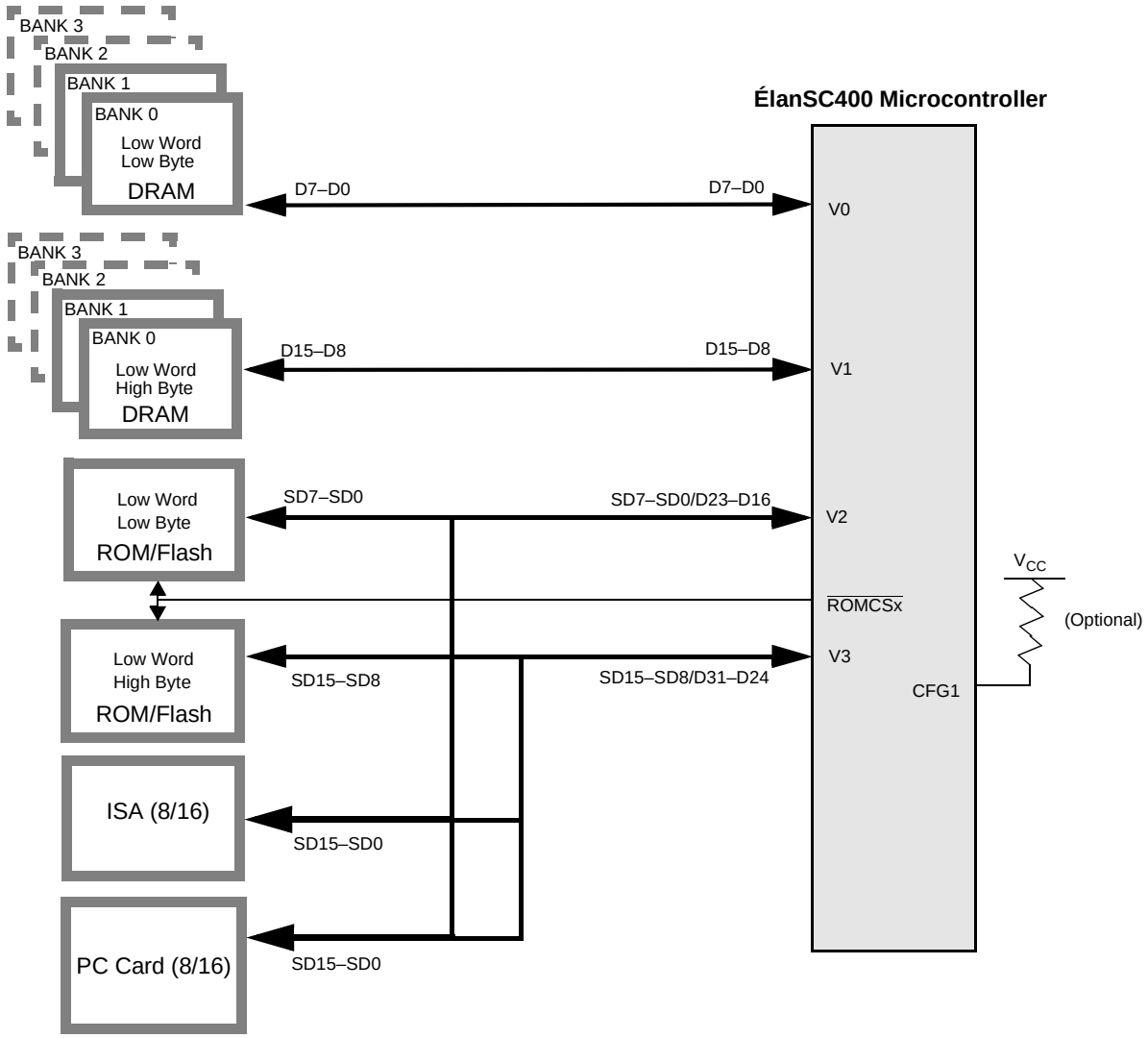
4.5.1.4 Data Paths

Table 4-11 shows the external signals used for all permitted CPU-initiated data transfers.

Table 4-11 Byte Lanes by Access Target and Type

Target	Access Type	Byte 3 (V3)	Byte 2 (V2)	Byte 1 (V1)	Byte 0 (V0)
32-Bit DRAM or VL-Bus double word	Read/Write	D31–D24 (SD15–SD8)	D23–D16 (SD7–SD0)	D15–D8	D7–D0
16-Bit DRAM	Read/Write	D15–D8	D7–D0	D15–D8	D7–D0
32-Bit ROM/Flash	Read/Write	D31–D24 (SD15–SD8)	D23–D16 (SD7–SD0)	D15–D8	D7–D0
16-Bit ROM/Flash, PC Card, or ISA Slave	Read/Write	SD15–SD8	SD7–SD0	SD15–SD8	SD7–SD0
8-Bit ROM/Flash, PC Card, or ISA Slave	Read/Write	SD7–SD0	SD7–SD0	SD7–SD0	SD7–SD0
Parallel Port	Read/Write	SD7–SD0	SD7–SD0	SD7–SD0	SD7–SD0

Figure 4-3 Bus Configuration A: 16-Bit DRAM Bus and 16-Bit SD Bus



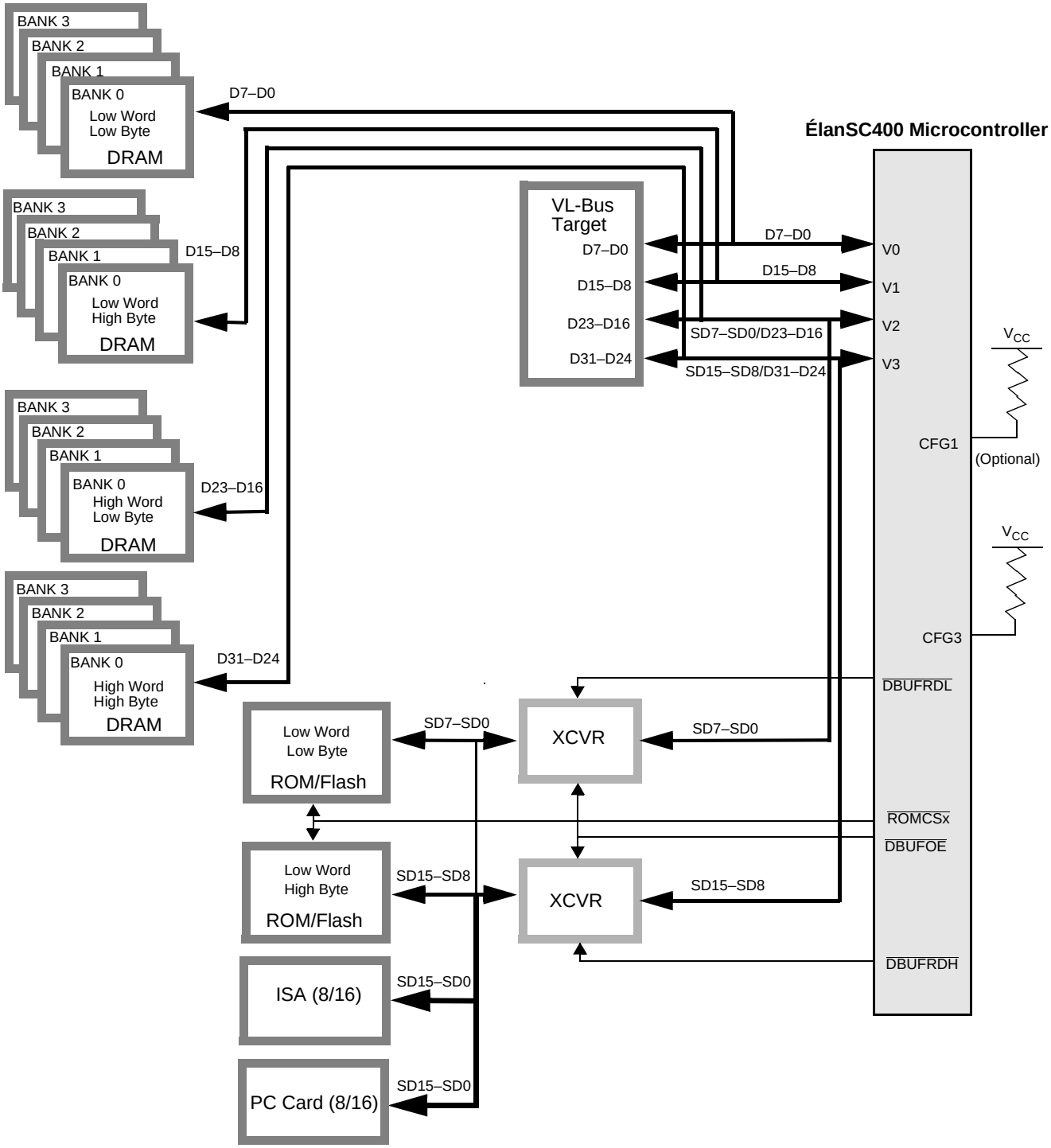
Notes:

The ÉlanSC400 and ÉlanSC410 microcontrollers support a maximum of 4 banks of 32-bit DRAM, but because the $\overline{RAS}$ and $\overline{CAS}$ signals for the high word and for banks 2 and 3 are traded for keyboard row signals, the minimum system would have one or two banks of DRAM—either Bank 0 or Bank 1 populated with 16-bit DRAMs. See Section 1.3 for a complete description of which features can be traded for others. See Figure 4-1 and Figure 4-2 for a summary of multiplexed pin options.

In this configuration, $\overline{ROMCSx}$ can be either $\overline{ROMCS0}$, $\overline{ROMCS1}$, or $\overline{ROMCS2}$.

When used, the CFG1 pin-strap enables a 16-bit ROM/Flash interface. When the CFG1 pin-strap pull-up is not used, an 8-bit ROM/Flash interface results. See Section 4.4.1.1 for information on using the CFG1–CFG0 configuration pins (which are always used together).

Figure 4-4 Bus Configuration B: 32-Bit DRAM Bus and 16-Bit SD Bus



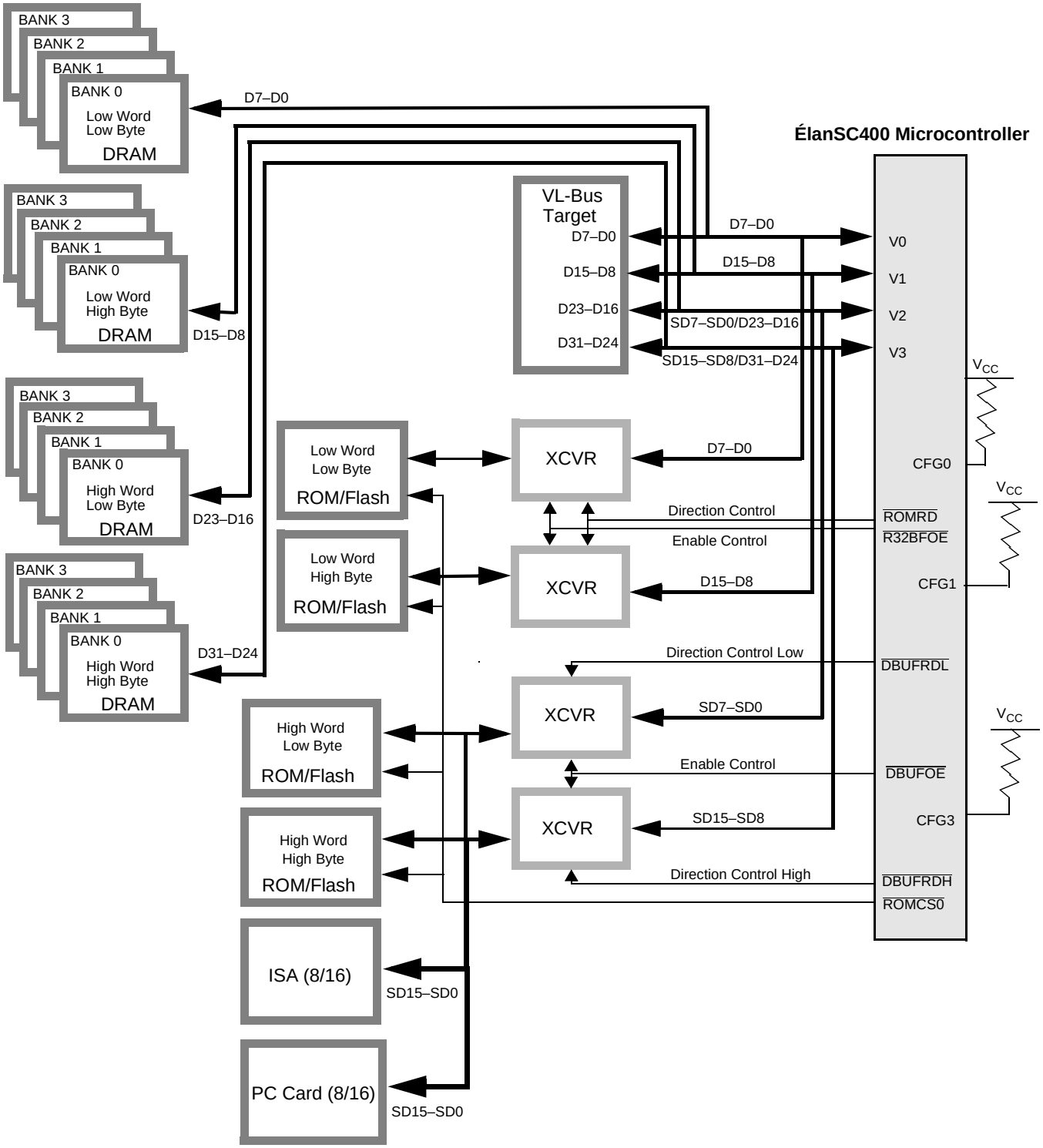
Notes:

Anytime the interface (DRAM, VL-bus, or ROM) is programmed for 32 bits, the matrix keyboard interface is not available. See Section 1.3 for a complete description of which features can be traded for others. See Figure 4-1 and Figure 4-2 for a summary of multiplexed pin options.

In this configuration, $\overline{ROMCSx}$ can be either $\overline{ROMCS0}$, $\overline{ROMCS1}$, or $\overline{ROMCS2}$.

When used, the CFG1 pin-strap enables a 16-bit ROM/Flash interface. When the CFG1 pin-strap pull-up is not used, an 8-bit ROM/Flash interface results. See Section 4.4.1.1 for information on using the CFG1–CFG0 configuration pins (which are always used together).

Figure 4-5 Bus Configuration C: 32-Bit DRAM Bus, 16-Bit SD Bus, and 32-Bit ROM



Notes:

Anytime the interface (DRAM, VL-bus, or ROM) is programmed for 32 bits, the matrix keyboard interface is not available. See Section 1.3 for a complete description of which features can be traded for others. See Figure 4-1 and Figure 4-2 for a summary of multiplexed pin options.

In this configuration, all of the ROM chip selects are available. $\overline{ROMCS0}$ must be configured as 32-bit to provide access to the $\overline{R32BFOE}$ signal. Once $\overline{ROMCS0}$ is configured as 32-bit, all accesses to 32-bit ROM devices on $\overline{ROMCS2}$–$\overline{ROMCS0}$ will result in the assertion of the $\overline{R32BFOE}$ signal. Mixed ROM sizes can be supported. Once any ROM is buffered (High or Low), all ROMs connected to that word must be buffered.

4.5.2 Address Buses

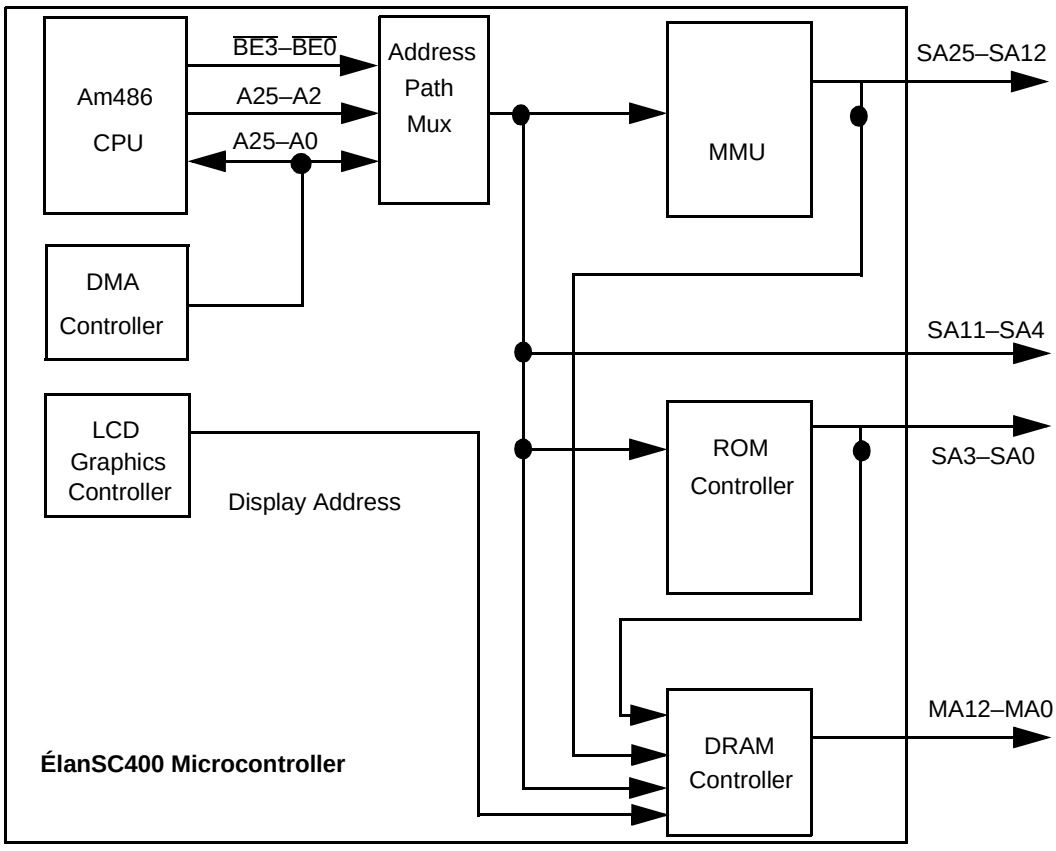
Address generation on the ÉlanSC400 and ÉlanSC410 microcontrollers is shown in Figure 4-6. There are two address buses on the ÉlanSC400 and ÉlanSC410 microcontrollers.

- **System Address Bus**—The SA25–SA0 system address bus outputs the physical memory or I/O port latched addresses. These addresses are used by all external peripheral devices other than main system DRAM, including ISA services, the ROM/Flash interface, and, on the ÉlanSC400 microcontroller, the PC Card controller. In addition, this is the local address bus in VL-bus mode.
- **Memory Address Bus**—DRAM row and column addresses are multiplexed onto the memory address bus (MA12–MA0). Valid row addresses are driven onto this bus by the falling edge of $\overline{RAS}$. Valid column addresses are driven onto this bus by the falling edge of $\overline{CAS}$.

The SA bus is shared between the ISA bus, the VL-bus, the ROM/Flash interface, and, on the ÉlanSC400 microcontroller, the PC Card controller. The ÉlanSC400 and ÉlanSC410 microcontrollers provide programmable drive strengths in the I/O buffers to accommodate loading for various system configurations.

On the ÉlanSC400 microcontroller, the DRAM controller multiplexes between using the system address (SA25–SA0) or the address generated by the internal LCD graphics controller, depending on which system is accessing DRAM. The DRAM controller then generates a separate DRAM address on the MA12–MA0 bus. The separate DRAM address is a multiplexed row/column address required by DRAM devices. This use of dual address buses feeding the DRAM controller frees up the system address bus to allow CPU accesses to other peripherals during graphics controller DRAM fetches.

Figure 4-6 Address Generation



4.6 SYSTEM INTERFACES

The following system interfaces are described in separate chapters of this book:

- ROM interface (Chapter 8)
- DRAM interface (Chapter 9)
- Parallel port interface (Chapter 14)
- Serial port interface (Chapter 15)
- Keyboard interfaces (Chapter 16)
- Infrared port interface (Chapter 18)
- PC Card interface (ÉlanSC400 microcontroller only) (Chapter 19)
- Graphics interface (ÉlanSC400 microcontroller only) (Chapter 20)

4.7 ISA BUS INTERFACE

4.7.1 Overview

The ISA interface consists of a subset of ISA-compatible bus signals, allowing for the connection of 8- or 16-bit devices supporting ISA-compatible I/O, memory, and DMA cycles. The following features are supported:

- 8.2944 MHz maximum bus clock speed
- Programmable DMA clock speed up to 16 MHz
- 8-bit and 16-bit ISA I/O and memory cycles (ISA memory is non-cacheable)
- Direct connection to 3- or 5-volt peripherals

Eight programmable IRQ (PIRQ7–PIRQ0) input pins are available. These interrupts may be routed via software to any available PC/AT-compatible interrupt channel. Interrupts on the ÉlanSC400 and ÉlanSC410 microcontrollers are described in Chapter 11.

Two programmable DMA channels are available for external DMA peripherals. These DMA channels may be routed via software to any available ISA DMA channel. DMA on the ÉlanSC400 and ÉlanSC410 microcontrollers is described in Chapter 10.

Note: *External ISA bus-mastering is not supported on the ÉlanSC400 and ÉlanSC410 microcontrollers.*

4.7.2 Registers

A summary listing of the chip setup and control (CSC) registers used to control the ISA interface is shown in Table 4-12. Complete register descriptions can be found in the *Élan™SC400 Microcontroller Register Set Reference Manual* (order #21032).

Table 4-12 ISA Interface Register Summary

Register	I/O Address	ISA Interface Function	Description in Register Set Manual
Linear ROM0/Shadow Register	22h/23h Index 21h	00F0000–00FFFFFh ROM0 decode disable, accesses directed to the ISA bus	page 3-26
Pin Mux Register A	22h/23h Index 38h	ISA signal enable: PIRQ0, PIRQ1, $\overline{\text{AEN}}$, TC, IOCHRDY, $\overline{\text{IOCS16}}$, PDRQ0, and $\overline{\text{PDACK0}}$	page 3-44

Table 4-12 ISA Interface Register Summary (continued)

Register	I/O Address	ISA Interface Function	Description in Register Set Manual
Pin Mux Register B	22h/23h Index 39h	ISA signal enable: $\overline{\text{MCS16}}$, $\overline{\text{SBHE}}$, BALE, PIRQ2, PDRQ1, and $\overline{\text{PDACK1}}$	page 3-45
Pin Mux Register C	22h/23h Index 3Ah	ISA signal enable: PIRQ7–PIRQ3, pin termination when the ISA interface is powered down in Suspend	page 3-46
GP_CSA/B IO Command Qualification Register	22h/23h Index B8h	Data bus width and timing for ISA I/O cycles on GP_CSA or GP_CSB	page 3-138
GP_CSC/D Memory Command Qualification Register	22h/23h Index BDh	Data bus width and timing for ISA memory cycles on GP_CSC or GP_CSD	page 3-144
Internal I/O Device Disable/Echo Z-Bus Configuration Register	22h/23h Index D0h	CSC register echo and direct-mapped register echo to ISA bus for debugging	page 3-164
Write-Protected System Memory (DRAM) Window/Overlapping ISA Window Enable Register	22h/23h Index E0h	Overlapping ISA window enable, CPU accesses generate an ISA cycle instead of a DRAM cycle	page 3-181
Overlapping ISA Window Start Address Register	22h/23h Index E1h	Start address for the overlapping ISA window	page 3-182
Overlapping ISA Window Size Register	22h/23h Index E2h	Window size for the overlapping ISA window	page 3-183
Suspend Pin State Register A	22h/23h Index E3h	Power control in Suspend mode for ISA bus interface	page 3-184
Suspend Mode Pin State Override Register	22h/23h Index E5h	Suspend mode override for ISA bus interface	page 3-186

4.7.3 Block Diagram

Block diagrams of the ISA interface are shown in Figure 4-7 and Figure 4-8. The ISA bus can be set up for either an 8-bit only configuration or an 8-/16-bit configuration, depending on the pin multiplexing options that are selected. The two programmable DMA channels can use any available 8- or 16-bit DMA channel.

- In the 8-bit only configuration (shown in Figure 4-7), all bus cycles, including DMA, are performed as 8-bit transfers on the lower half of the SD data bus. The single available DMA handshake pair can be routed to any available 8-bit channels.
- In the 8-/16-bit configuration (shown in Figure 4-8), 8- and 16-bit bus cycles can access 8- or 16-bit target devices.

Figure 4-7 8-Bit Minimal ISA Interface

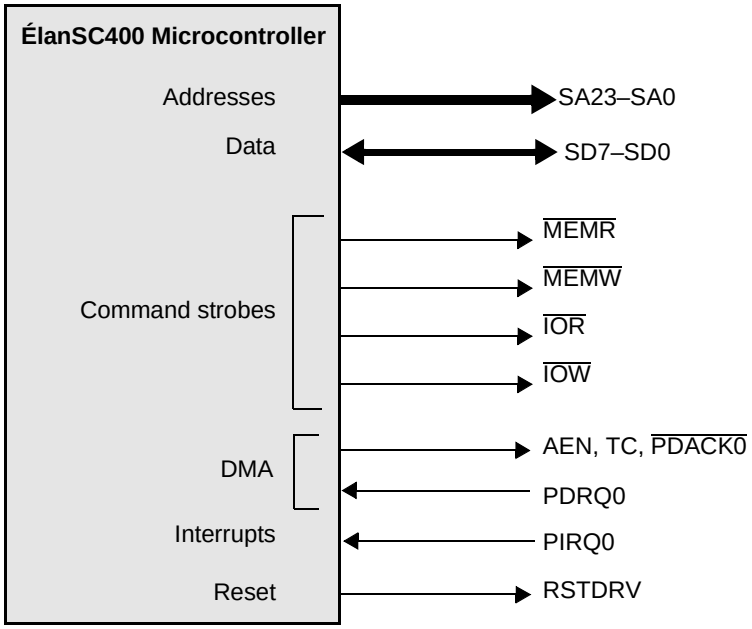
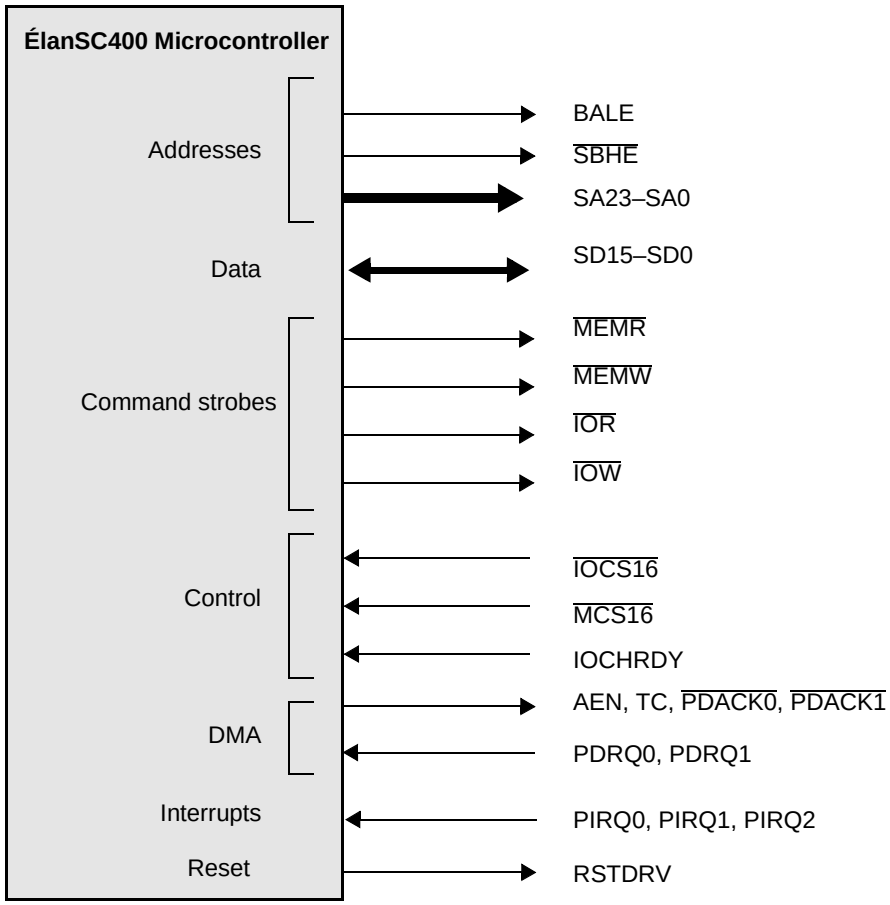


Figure 4-8 16-Bit Maximum ISA Interface



4.7.4 Supported ISA Signals

The ISA interface on the ÉlanSC400 and ÉlanSC410 microcontrollers uses the signals listed in Table 4-13. The ISA signals shown as optional in Table 4-13 are shared with other functions on the ÉlanSC400 and ÉlanSC410 microcontrollers. Table 4-14 lists the signals that are traded off for ISA signals. The signals are grouped by enable bit.

- ISA control signals IOCHRDY and $\overline{\text{IOCS16}}$, and $\overline{\text{MCS16}}$ are available via a programmable option.
- IOCHRDY can be deasserted to extend the length of ISA or ROM cycles.
- $\overline{\text{IOCS16}}$ and $\overline{\text{MCS16}}$ can be asserted on a cycle basis to generate 16-bit ISA I/O or memory transfers, respectively. $\overline{\text{IOCS16}}$ and $\overline{\text{MCS16}}$ are ignored during ROM, PC Card, or DRAM cycles. $\overline{\text{IOCS16}}$ and $\overline{\text{MCS16}}$ are also ignored for accesses to internal I/O devices and VL-bus cycles.

Signals not supported by the ISA interface include $\overline{\text{MASTER}}$, $\overline{\text{REFRESH}}$, $\overline{\text{IOCHCHK}}$, OSC (14.318 MHz), SYSCLK, and $\overline{\text{0WS}}$.

Table 4-13 ISA Interface Signals

Function	External Signals
Data Bus	SD15–SD0
Address Bus	SA23–SA0
Control Signals (Optional)	BALE, $\overline{\text{IOCS16}}$, $\overline{\text{MCS16}}$, $\overline{\text{SBHE}}$, IOCHRDY, $\overline{\text{DBUFRDL}}$, $\overline{\text{DBUFRDH}}$, $\overline{\text{DBUFOE}}$
Command Strobes (Dedicated)	$\overline{\text{IOR}}$, $\overline{\text{IOW}}$, $\overline{\text{MEMR}}$, $\overline{\text{MEMW}}$
Reset (Dedicated)	RSTDRV
DMA (Optional)	AEN, TC, PDRQ0, PDRQ1, $\overline{\text{PDACK1}}$, $\overline{\text{PDACK0}}$
Interrupts (Optional)	PIRQ7–PIRQ0

Table 4-14 Signals Shared with the ISA Interface

CSC Index [Bit]	Default Signals Enabled (Bit=0)	Additional ISA Signals (Bit=1)
38h[4]	GPIO_CS5	$\overline{\text{IOCS16}}$
38h[3]	GPIO_CS6	IOCHRDY
38h[2]	GPIO_CS7	PIRQ1
38h[1]	GPIO_CS8	PIRQ0
38h[0]	GPIO_CS12–GPIO_CS9	PDRQ0, $\overline{\text{PDACK0}}$, AEN, TC
39h[2]	KBD_ROW12–KBD_ROW7	$\overline{\text{MCS16}}$, $\overline{\text{SBHE}}$, BALE, PIRQ2, PDRQ1, $\overline{\text{PDACK1}}$
3Ah[1]	KBD_COL6–KBD_COL2	PIRQ7–PIRQ3

4.7.5 Operation

The ISA controller on the ÉlanSC400 and ÉlanSC410 microcontrollers generates all the required ISA bus command and control signals and ensures that the ISA timing specifications are met. These specifications are based on the IEEE's *Personal Computer Bus Standards P996*, with certain non-critical modifications.

4.7.5.1 Bus Speeds

The ISA bus runs at a maximum speed of 8.294 MHz while the microcontroller is in High-Speed mode. In Low-Speed or Temporary Low-Speed mode, the ISA bus speed is dictated by the CPU clock speed and can be programmed to be 8.924, 4.147, 2.074, or 1.037 MHz. In Standby and Suspend modes, the ISA bus is not functional.

The DMA controller clock can be programmed to 16, 8, 4, or 1 MHz when the microcontroller is in High-Speed mode. When in Low Speed or Temporary Low Speed mode, the DMA clock runs at either the programmed value or the CPU clock speed, whichever is lower; or it can be disabled. Timing compatible with legacy DMA is achieved when the DMA controller is configured to 4 MHz. Faster timings, however, are not anticipated to cause problems for modern DMA devices.

4.7.5.2 Addressing

All address signals on the ÉlanSC400 and ÉlanSC410 microcontrollers are internally latched, from SA23 through SA0. This differs from standard ISA, where address bits 23-17 are provided non-latched. The address-to-command setup time provided for SA23–SA17 is sufficiently fast that these signals may be connected to devices that decode ISA signals LA23–LA17 early in order to generate $\overline{\text{MCS16}}$ or $\overline{\text{IOCS16}}$. If a device has signal pins for standard ISA signals LA19–LA17 *and* SA19–SA17, the microcontroller's SA19–SA17 pins may be connected to both sets of corresponding device address pins. BALE is provided as a programmable option for compatibility purposes. $\overline{\text{SBHE}}$ is also available as a programmable option for external devices that require it.

Note that the microcontroller's address space extends to 64 Mbytes with the addition of address bits SA24 and SA25. ISA memory space is limited to a maximum 16 Mbytes, however. $\overline{\text{MEMR}}$ and $\overline{\text{MEMW}}$ will not be asserted for any accesses above the programmed limit, with the exception of the memory overlay window explained below.

The ISA memory overlay feature allows the "overlapping" of a single block of ISA memory space on top of system DRAM space. This block is in addition to the ISA memory region found in standard PC architecture between 640 Kbytes and 1 Mbyte. An ISA window of 64-Kbyte granularity and programmable start location may be defined using registers at CSC index E0–E2h. This window is fully locatable throughout the first 16-Mbytes of system memory space and can have a maximum size of 16 Mbytes. When this window is enabled and a memory access is detected in this region, the ÉlanSC400 and ÉlanSC410 microcontrollers will execute the cycle on the ISA bus and the DRAM interface will not be activated. This ISA window is not affected by the system DRAM write-protect controls. Any system DRAM that is located at the same address as this ISA window becomes invisible to the system, unless it is accessed through the MMS or video buffer relocation. The block is active for ISA memory even if the upper limit for other ISA accesses has been set to 1 Mbyte.

All ISA memory space is non-cacheable.

4.7.5.3 Command Strobes

The ISA command strobes $\overline{\text{MEMR}}$ and $\overline{\text{MEMW}}$ are asserted only for ISA cycles. The $\overline{\text{IOR}}$ and $\overline{\text{IOW}}$ command strobes are asserted for both ISA and PC Card cycles. Separate memory strobes are provided for accesses to ROM and PC Card memory. The ROM

interface uses dedicated ROMRD and ROMWR signals, while the PC Card sockets use MCEL_A, MCEH_A, MCEL_B, and MCEH_B. Table 4-15 shows the eight ISA DMA cycle types and the command strobes generated by each.

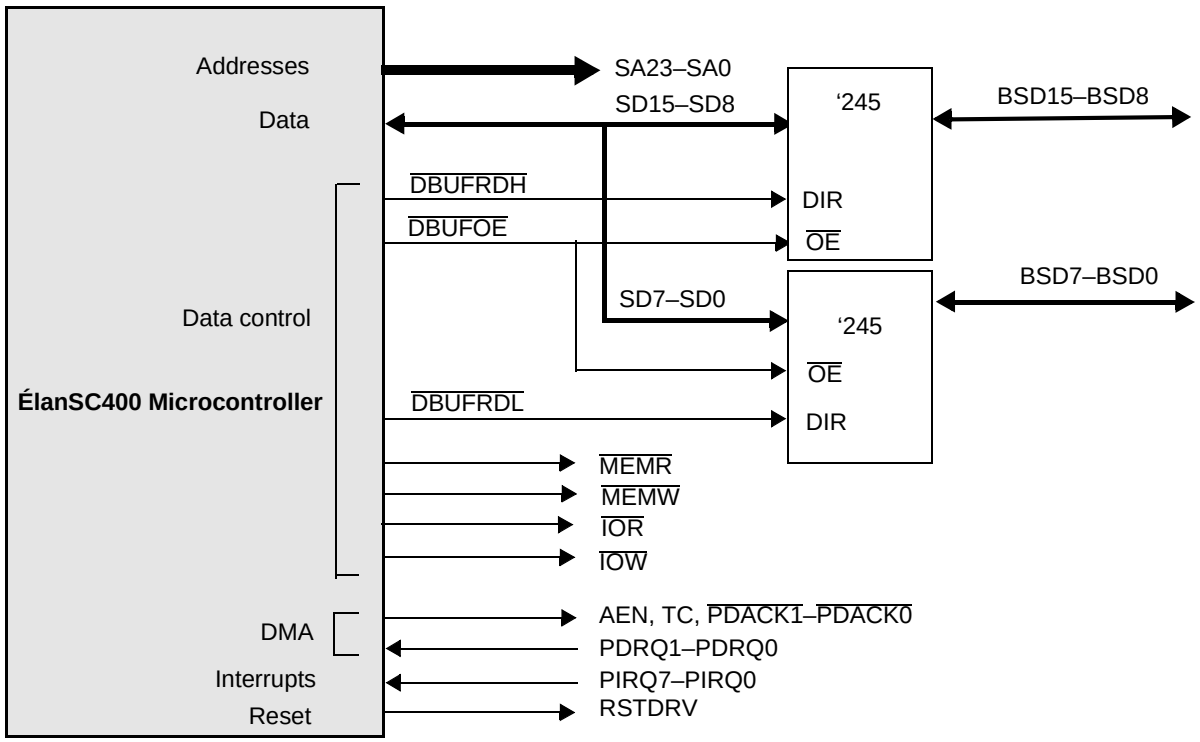
Table 4-15 ISA DMA Cycle Types

I/O Device Sits on this Bus (DMA Initiator)	Memory Device Sits on this Bus (DMA Target)	Data Transfer Direction (DMA Cycle Type)	ISA Command Strobes Generated
ISA	ISA	I/O to Memory (DMA Write)	MEMW, IOR
ISA	PC Card	I/O to Memory (DMA Write)	IOR
ISA	DRAM	I/O to Memory (DMA Write)	IOR
PC Card	ISA	I/O to Memory (DMA Write)	MEMW, IOR
ISA	ISA	Memory to I/O (DMA Read)	MEMR, IOW
PC Card	ISA	Memory to I/O (DMA Read)	MEMR, IOW
ISA	PC Card	Memory to I/O (DMA Read)	IOW
ISA	DRAM	Memory to I/O (DMA Read)	IOW

4.7.5.4 External Buffer Control Signals

When the ÉlanSC400 and ÉlanSC410 microcontrollers are configured for a 32-bit DRAM interface or are in local bus mode, it is necessary to use an external data bus buffer for the ISA bus. External buffers are also useful when the bus is heavily loaded. To provide buffering, three optional signals, DBUFOE, DBUFRDL, and DBUFRDH may be enabled. Figure 4-9 illustrates how external ‘245 transceivers could be connected to the microcontroller using these signals.

Figure 4-9 8-Bit ISA Bus with External Data Buffer



4.7.6 Using the ISA Bus for Debugging

Both direct-mapped and CSC indexed register accesses can be made to "echo" on the ISA bus for debugging purposes. This feature provides a data path for all register bits to be propagated to the pins of the chip. Setting bits 4 and 5 in the Internal I/O Device Disable/ Echo Z-Bus Configuration Register (CSC index D0h) allows all core register accesses, including PC/AT cores and CSC indexed registers, to be seen from the outside of the chip on the ISA bus.

- All non-echoed CSC indexed registers, PC Card indexed registers, and graphics indexed registers operate at CPU speeds.
- All other non-VL-bus, non-echoed I/O accesses use ISA timing.
- When programmed to echo on the ISA bus, direct-mapped and CSC indexed registers are accessed at ISA bus speeds.

The following paragraphs describe this debugging feature for direct-mapped and CSC indexed registers.

4.7.6.1 Echoing Direct-Mapped PC/AT Registers

Direct-mapped register accesses in the ÉlanSC400 and ÉlanSC410 microcontrollers can be echoed onto the external ISA bus by setting CSC index D0h[4]. This echo feature selection is disabled by default. This bit has no affect on the CSC indexed-register echo feature.

4.7.6.1.1 Direct-Mapped Register Writes

During an I/O write to a direct-mapped register when the echo feature is enabled, the following activity occurs on the external ISA bus:

- The I/O address is driven out onto the SA bus (SA23–SA0).
- $\overline{\text{SBHE}}$ is driven out (if enabled).
- BALE is driven out (if enabled).
- $\overline{\text{MCS16}}$ and $\overline{\text{IOCS16}}$ inputs are ignored (if enabled or disabled).
- AEN is asserted (if enabled).
- $\overline{\text{DBUFOE}}$ is deasserted (if enabled).
- $\overline{\text{DBUFRDH}}$ and $\overline{\text{DBUFRDL}}$ are static (if enabled).
- $\overline{\text{IOW}}$ is asserted.
- IOCHRDY input is ignored (if enabled or disabled).
- The write data is driven out onto SD7–SD0.

Note: *The annotation "if enabled" above refers to the fact that the pin(s) may or may not be configured for the ISA bus function.*

There are some direct-mapped registers that can be disabled when particular internal features are disabled, such as the following:

- Keyboard controller ports 0060h and 0064h
- PC Card controller ports 03E0h and 03E1h
- RTC ports 0070h, 0071h
- UART ports (COM1 at 03F8–03FFh and COM2 at 02F8–02FFh)
- Parallel port (LPT1 at 0378–037Fh and LPT2 at 0278–027Fh)

- Internal graphics controller ports

When these internal features are disabled, accesses to these registers (reads and writes) will be treated as standard ISA bus cycles whether or not direct-mapped register echoing is enabled.

Port 0070h is a special case. Writes to Port 0070h always go to Port 0070h, as well as to the ISA bus.

I/O ports 0080h, 0084–0086h, 0088h, and 008C–008Eh are also special cases. Because these I/O ports are both internal read/write registers and typically used as external writable ports for diagnostics, they must be handled differently. All I/O writes to these registers are run as ISA and internal cycles. In addition, AEN will not be asserted; and $\overline{\text{DBUFOE}}$, $\overline{\text{DBUFRDH}}$, and $\overline{\text{DBUFRDL}}$ will be asserted. This allows the ISA bus cycle to modify any external ISA bus register that may be present during a write cycle (i.e., a Port 0080h debug card).

All I/O write accesses that are not decoded as direct-mapped register accesses or CSC indexed register accesses will be driven onto the external ISA bus with all enabled ISA control signals available, assuming the cycle is not claimed by a device on the VL-bus. External cycles are first given to the VL-bus; if not claimed, they default to the ISA bus.

4.7.6.1.2 Direct-Mapped Register Reads

During an I/O read to a direct-mapped register when the echo feature is enabled, the following activity occurs on the external ISA bus:

- The I/O address is driven out onto the SA bus SA23–SA0.
- $\overline{\text{SBHE}}$ is driven out (if enabled).
- BALE is driven out (if enabled).
- $\overline{\text{MCS16}}$ and $\overline{\text{IOCS16}}$ inputs are ignored (if enabled or disabled).
- AEN is asserted (if enabled).
- $\overline{\text{DBUFOE}}$ is deasserted (if enabled).
- $\overline{\text{DBUFRDH}}$ and $\overline{\text{DBUFRDL}}$ are static (if enabled).
- $\overline{\text{IOR}}$ is asserted.
- IOCHRDY input is ignored (if enabled or disabled).
- SD7–SD0 *is driven* with the data that is present on the internal data bus.

There are some internal PC/AT Core registers that can be disabled when particular internal features are disabled such as the following:

- Keyboard controller ports 0060h and 0064h
- PC Card controller ports 03E0h and 03E1h
- RTC ports 0070h, 0071h
- UART ports (COM1 at 03F8–03FFh and COM2 at 02F8–02FFh)
- Parallel port (LPT1 at 0378–037Fh and LPT2 at 0278–027Fh)
- Internal graphics controller ports

When these features are disabled, accesses to these registers (reads and writes) will be treated as standard ISA bus cycles whether or not direct-mapped register echoing is enabled.

When the RTC is enabled, reads come from the internal register only. When the RTC is disabled, reads come from the ISA bus only.

All I/O read accesses that are not decoded as direct-mapped register accesses or CSC indexed register accesses will occur on the external ISA bus with all enabled ISA control signals available.

4.7.6.2 Echoing CSC Indexed Registers

CSC indexed register accesses can also be programmed to echo on the external ISA bus by setting CSC index D0h[5]. In order to eliminate any bus contention and/or cycle-to-cycle address conflicts on the external ISA bus, the microcontroller will always force the CSC indexed register accesses to run at the ISA bus speed when echoing is enabled. The CSC indexed-register echoing feature is totally independent of the direct-mapped register echoing feature.

4.7.6.2.1 CSC Indexed Register Writes

During an I/O write to a CSC indexed register, the following activity occurs on the external ISA bus when the CSC indexed-register echo feature is enabled.

- The I/O address is driven out onto SA23–SA0. For writes to the index register, this address is 22h. For writes to the actual CSC indexed register, the address is 23h.
- $\overline{\text{SBHE}}$ is driven out (if enabled).
- BALE is driven out (if enabled).
- $\overline{\text{MCS16}}$ and $\overline{\text{IOCS16}}$ inputs are ignored (if enabled or disabled).
- AEN is asserted (if enabled).
- $\overline{\text{DBUFOE}}$ is deasserted (if enabled).
- $\overline{\text{DBUFRDH}}$ and $\overline{\text{DBUFRDL}}$ are static (if enabled).
- $\overline{\text{IOW}}$ is asserted.
- IOCHRDY input is ignored (if enabled or disabled).
- The write data is driven out onto SD7–SD0.

All accesses are performed at ISA bus speeds when the CSC indexed-register echo feature is enabled. If a particular core feature is disabled, the individual CSC indexed registers associated with that core can still be accessed and, if the echo feature is enabled, will be echoed onto the ISA bus. The actual register bits may or may not be functional in this state.

4.7.6.2.2 CSC Indexed Register Reads

During an I/O read to a CSC indexed register, the following activity will occur on the external ISA bus when the CSC indexed-register echo feature is enabled.

- The I/O address is driven out onto SA23–SA0.
- $\overline{\text{SBHE}}$ is driven out (if enabled).
- BALE is driven out (if enabled).
- $\overline{\text{MCS16}}$ and $\overline{\text{IOCS16}}$ inputs are ignored (if enabled or disabled).
- AEN is asserted (if enabled).
- $\overline{\text{DBUFOE}}$ is deasserted (if enabled).
- $\overline{\text{DBUFRDH}}$ and $\overline{\text{DBUFRDL}}$ are static (if enabled).
- $\overline{\text{IOR}}$ is asserted.

- IOCHRDY input is ignored (if enabled or disabled).
- SD7–SD0 *is driven* with the data that is present on the internal data bus.

All accesses are performed at ISA bus speeds when the CSC indexed-register echoing feature is enabled. If a particular core feature is disabled, the individual CSC indexed registers associated with that core can still be accessed and, if the echo feature is enabled, will be echoed onto the ISA bus. The actual register bits may or may not be functional in this state.

Note that since $\overline{\text{DBUFOE}}$ is always deasserted in the above listed scenarios, echoed data will never be seen past the system data bus buffers (if any are used in the system).

4.7.7 Initialization

The ISA bus controller is enabled at power-on reset.

4.7.8 Power Management

The power management unit monitors the $\overline{\text{MEMR}}$ and $\overline{\text{MEMW}}$ signals for activity. The internal clock for the ISA bus controller is shut off when no ISA accesses are being performed.

Operation of the ISA bus controller is affected by the power-management functions shown in Table 4-16.

Table 4-16 Power Management in the ISA Bus Controller

ISA Bus Event	Description	Power Management Effect			
		Wake-Up	Activity	SMI	NMI
GPIO_CS14–GPIO_CS0	Triggered by the falling edge of the signal	Yes	Primary	Yes	Yes
GP_CSA–GP_CSD	Triggered by the falling edge of the signal qualified with the correct command		Programmable	Yes	Yes

4.8 VESA LOCAL (VL) BUS CONTROLLER

4.8.1 Overview

The VESA local (VL) bus controller provides the signals and associated timing necessary to support a single VL-bus target compliant with the Video Electronics Standards Association's (VESA) *VL-Bus Standard 2.0*.

The VL-bus controller includes the following features:

- 33 MHz operation at 3.3 V
- 32-bit data bus
- Burst-mode transfers
- Control of local bus reset through a CSC indexed register

VESA bus mastering and DMA transfers to and from the VL-bus target are not supported.

Note that, on the ÉlanSC400 microcontroller, the VL-bus is only available when the internal graphics controller is disabled in the Internal Graphics Control Register A (CSC index DDh[2]).

4.8.2 Registers

A summary listing of the chip setup and control (CSC) registers used to control the VL-bus is shown in Table 4-17. Complete register descriptions can be found in the *Élan™ SC400 Microcontroller Register Set Reference Manual* (order #21032).

The following CSC indexed registers are used to program the VL-bus interface.

- **Cache and VL Miscellaneous Register**–Setting bit 3 in this register enables the VL-bus. The VL-bus reset is also controlled in this register.
- **Activity Monitor Registers**–For power management, these registers report that any VL-bus cycle (memory or I/O) is the source of an activity.

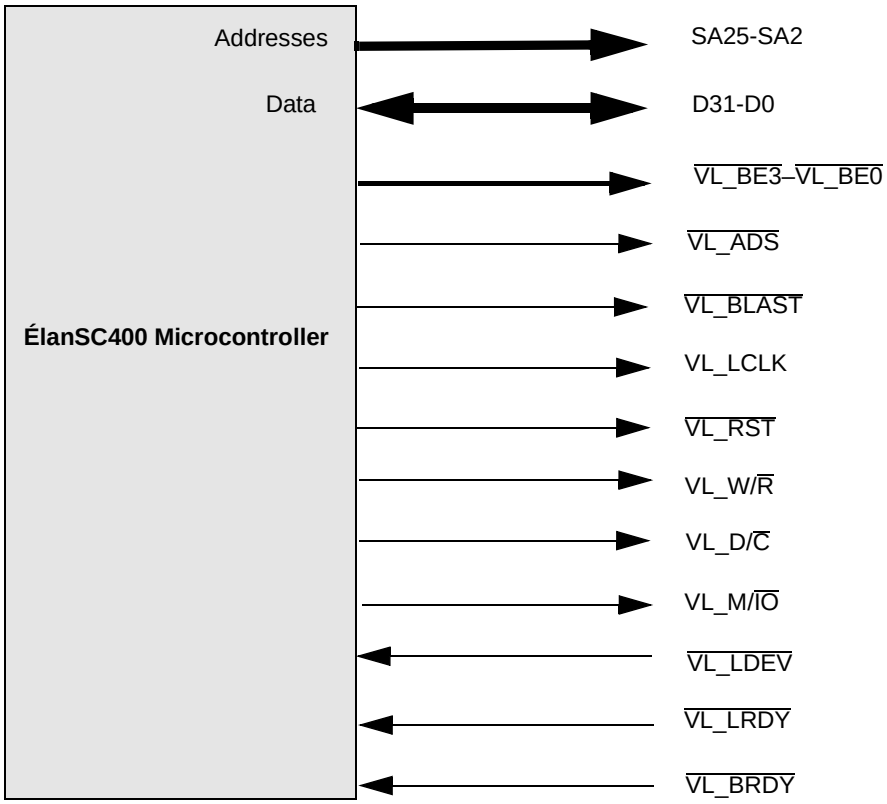
Table 4-17 VL-Bus Register Summary

Register	I/O Address	VL-Bus Function Keyword	Description in Register Set Manual
Cache and VL Miscellaneous Register	22h/23h Index 14h	VL-bus interface enable, VL-bus reset control	page 3-23
Activity Source Enable Register A	22h/23h Index 62h	Activity source enable: VL-bus cycle (memory or I/O)	page 3-71
Activity Source Status Register A	22h/23h Index 66h	Activity source status: VL-bus cycle (memory or I/O)	page 3-75
Activity Classification Register A	22h/23h Index 6Ah	Primary or secondary activity classification: VL-bus cycle (memory or I/O)	page 3-79
Suspend Pin State Register A	22h/23h Index E3h	Power control in Suspend mode for VL-bus interface	page 3-184

4.8.3 Block Diagram

Figure 4-10 is a simplified block diagram showing all the external signals used by the VL-bus. More complex examples showing how these signals are used in different configurations can be found in Figure 4-4 and Figure 4-5, starting on page 4-22.

Figure 4-10 VL-Bus Block Diagram



4.8.4 Operation

4.8.4.1 Address Interface

The VL-bus target connects to the microcontroller's SA25–SA2 address bus. The target's address bits 31 through 26 should be appropriately terminated at the target. The status outputs, VL_D/$\overline{C}$, VL_M/$\overline{IO}$, and VL_W/$\overline{R}$, and the byte enables $\overline{VL_BE3}$–$\overline{VL_BE0}$ are provided by the microcontroller and should be connected to the corresponding pins on the VL-bus target.

4.8.4.2 Data Interface

The ÉlanSC400 and ÉlanSC410 microcontrollers support a 32-bit data bus interface to the VL-bus target. The VESA data-sizing signal $\overline{LBS16}$ is not supported. The VL-bus data-bus byte-ordering for the ÉlanSC400 and ÉlanSC410 microcontrollers is shown in Table 4-18.

Due to loading requirements on the VL-bus data signals, an external buffer for the system data bus, SD15–SD0, might be required when configuring the ÉlanSC400 and ÉlanSC410 microcontrollers to use the local bus controller feature. A data transceiver enable, $\overline{DBUFOE}$, and two direction control signals, $\overline{DBUFRDL}$ and $\overline{DBUFRDH}$, are provided for this function. When using the external data buffers, the VL-bus target should be connected to the microcontroller's SD15–SD0 pins. The remaining system devices, except DRAM, should

be connected to the outputs of the external data transceiver. 32-bit DRAM should be connected to SD15–SD0, not to the buffered side.

Table 4-18 VL-Bus Data Bus Byte Ordering

Signals	VL-Bus Byte Lane	Byte Enable
D7–D0	Byte 0	$\overline{\text{VL_BE0}}$
D15–D8	Byte 1	$\overline{\text{VL_BE1}}$
D23–D16	Byte 2	$\overline{\text{VL_BE2}}$
D31–D24	Byte 3	$\overline{\text{VL_BE3}}$

4.8.4.3 Normal Bus Cycles

The VL-bus on the ÉlanSC400 and ÉlanSC410 microcontrollers supports single- and burst-mode transfers to and from the VL-bus target. There are five types of normal VL-bus cycles:

- Memory read, non-burst
- Memory read, burst
- Memory write, non-burst
- I/O read, non-burst
- I/O write, non-burst

The VL-bus controller is tightly coupled with the internal memory controller and address decode logic. The microcontroller drives the current CPU address onto the VL-bus and asserts $\overline{\text{VL_ADS}}$ when the cycle is not internally decoded as a DRAM, ROM, MMU hit, or I/O access to an internal core or register. $\overline{\text{VL_LDEV}}$ is then sampled at the next rising edge of the CPU clock. $\overline{\text{VL_BLAST}}$ is valid at the rising edge of VL_LCLK that samples $\overline{\text{VL_ADS}}$ asserted. Bus transfers are terminated by $\overline{\text{VL_LRDY}}$ and $\overline{\text{VL_LBRDY}}$. If no VL-bus device asserts $\overline{\text{VL_LDEV}}$, the cycle is then driven to the ISA bus.

VL-bus accesses are not cached. DRAM, ROM, and cycles that result in an MMS-windows access are of higher priority than VL-bus accesses.

4.8.4.4 Special Bus Cycles

The special bus cycles listed in Table 4-19 may also be visible on VL-bus accesses.

Note: *Technically, these special cycles are not considered VL-bus accesses on the ÉlanSC400 and ÉlanSC410 microcontrollers.* $\overline{\textit{VL_ADS}}$ *will not be asserted for these special cycles. It might be difficult for a system to determine that a special cycle has occurred, particularly when the CPU is in a Hold state and its output states for these signals are undefined.*

Table 4-19 Special Bus Cycles

SA4-SA2	VL_M/$\overline{IO}$	VL_D/$\overline{C}$	VL_W/$\overline{R}$	$\overline{VL_BE3}$–$\overline{VLBE0}$	Cycle Type	Cause
000	0	0	1	7h	Write-back	Completion of all write-backs in response to a WBINVD instruction.
000	0	0	1	Dh	Flush	Completion of a WBINVD or INVD instruction.
001	0	0	1	7h	Flush Acknowledge #1	Completion of all write-backs in response to the assertion of the internal CPU's $\overline{FLUSH}$ signal.
001	0	0	1	Dh	Flush Acknowledge #2	Completion of a cache flush in response to the assertion of the internal CPU's $\overline{FLUSH}$ signal.
100	0	0	1	Bh	Stop Grant	Assertion of internal CPU's STPCLK signal.
000	0	0	1	Bh	Halt	
xxx	0	0	1	Eh	Shutdown	

4.8.4.5 Unsupported VL-Bus Signal

Note that the microcontroller's VL-bus does not drive the VESA $\overline{RDYRTN}$ signal. The system designer is responsible for tying the VL-bus target's $\overline{LRDY}$ and $\overline{RDYRTN}$ signals together.

4.8.5 Initialization

The VL-bus controller is disabled at power-on reset. After enabling the VL-bus interface, $\overline{VL_RST}$ should be asserted and deasserted before using the VL-bus. The VL-bus reset control is located at CSC index 14h[4].

4.8.6 Power Management

The speed of the VL-bus changes with the CPU speed. VL-bus logic switching is disabled when the VL-bus interface is disabled.

Operation of the VL-bus is affected by the power-management functions shown in Table 4-20.

Table 4-20 Power Management in the VL-Bus Controller

VL-Bus Event	Description	Power Management Effect			
		Wake-Up	Activity	SMI	NMI
VL-bus cycle	Any VL-bus cycle (memory or I/O)		Programmable	Yes	Yes

4.9 PC/AT PORT LOGIC

4.9.1 Overview

The ÉlanSC400 and ÉlanSC410 microcontrollers provide all of the support functions found in the original IBM PC/AT. These include the Port B status and control bits, speaker control, SCP-based CPU-core reset, and A20 gate control, as well as extensions for fast CPU core reset and A20 gate control. In addition, a CPU shutdown cycle (e.g., as a result of a triple fault) will generate a CPU core reset. None of these resets will affect either on-board PC/AT legacy registers or CSC indexed registers specific to the ÉlanSC400 and ÉlanSC410 microcontrollers.

4.9.2 Registers

4.9.2.1 Direct-Mapped Registers

The following PC/AT features are supported using direct-mapped registers.

- **System Control Port B/NMI Status Register (Port 0061h)**—Port B is a PC/AT standard, miscellaneous feature, 8-bit, control register. The lower two bits of this register are read/write control bits that enable or disable sound generation features. The standard sound source on the PC/AT is the output of PIT Channel 2, which is fed to the system speaker via a driver. The PIT has several modes of operation that require software to have access to the PIT “gate” control. This gate control is provided by bit 0. In addition, software can enable or disable the PIT output data from reaching the system via bit 1.

  Bits 3 and 2 are reserved on the ÉlanSC400 and ÉlanSC410 microcontrollers. The legacy function of these bits was to enable and disable ISA bus I/O channel check or parity error Non-Maskable Interrupt (NMI) sources.

  Bits 5 and 4 of this register are read-only status bits that return the status of the SPKR output pin state and the DRAM refresh activity, respectively. The DRAM-refresh indicator bit toggles once each time the DRAM refresh cycle occurs. Although this rate was nominally 15.087 µs on a PC/AT, the refresh rate can be varied on the ÉlanSC400 and ÉlanSC410 microcontrollers if PIT Channel 1 is used as the DRAM refresh signal. By default, the system 32.768-KHz clock is used for DRAM refresh.

  The normal PC/AT functions performed by bits 7–6 (i.e., IOCHCK and Parity Error indication) are not supported on the ÉlanSC400 and ÉlanSC410 microcontrollers. These bits always read back a value of 0.

- **NMI Control**—The power management unit, keyboard scan timer, 8042 emulation logic, and the PC Card controller are the only possible sources for the generation of an NMI to the internal CPU. A master enable function inhibits any NMIs from reaching the CPU regardless of the state of the individual source enables. NMIs can be enabled by writing a 0 to the most significant bit at I/O address 0070h. Port 0070h is a write-only register, and bits 0–6 function as the RTC index address port.

- **System Control Port A Register (Port 0092h)**—Bit 0 of this register is used for fast CPU reset. A low-to-high transition on this bit will automatically reset the CPU. The reset pulse lasts for a period predetermined by the CPU reset pulse width timer. This bit is not automatically reset to ‘0b.’ To perform successive resets of the CPU core by software, this bit must be written to 0 and then back to ‘1b.’

  Bit 1 is used for A20 signal control. Setting this bit allows the CPU Address(20) to be propagated to the system logic; clearing this bit (default state) allows the CPU A20 signal to be driven Low as long as no other A20 gate control sources are forcing the CPU A20 signal to propagate. If any A20 gate control source is forcing A20 to propagate, then no other A20 gate control source will have any effect on A20. A20 signal propagation control

is an artifact of the PC/AT legacy architecture. The original purpose for the 80286 CPU (and later CPUs having greater than 20 address lines) was to support software applications that relied on the 8086/8088 address wrap.

Note:*This register causes the CPU's SRESET signal to be asserted for 16 CPU clock cycles.*

- **Alternate Gate A20 Control Register (Port 00EEh)**—A special 8-bit read/write control register provides a fast and reliable way to control the CPU A20 signal. A dummy read of this register returns a value of FFh and forces the CPU A20 to propagate to the core logic, while a dummy write to this register will cause the CPU A20 signal to be forced Low as long as no other A20 gate control sources are forcing the CPU A20 signal to propagate.
- **Alternate CPU Reset Control Register (Port 00EFh)**—A special 8-bit read-only control register provides a fast and reliable way to control the CPU Reset signal. A read of this register resets the CPU. This SRESET control mechanism together with both bit 0 of Port 0092 and KBD_SLOW_RC command sequence trapping (see Chapter 16) provide three different ways to generate SRESET control. Forcing these SRESET events while in SMM mode will cause the SRESET signal to be asserted after the SMM routine is exited.

CHAPTER

5 POWER MANAGEMENT

5.1 OVERVIEW

Power management on the ÉlanSC400 and ÉlanSC410 microcontrollers includes a dedicated power management unit (PMU) and additional power management features built into each integrated peripheral. Power management on the ÉlanSC400 and ÉlanSC410 microcontrollers provides a superset of APM 1.2 features. Seven modes of operation allow fine-tuning of power requirements for maximum battery life. The ÉlanSC400 and ÉlanSC410 microcontrollers can use the following techniques to conserve power:

- Slow down clocks when the system is not in active use
- Shut off clocks to parts of the microcontroller that are idle
- Switch off power to parts of the system that are idle
- Automatically reduce power use when batteries are low

The power management unit controls stopping and changing clocks, SMI (System Management Interrupt) generation, timers, activities, and battery-level monitoring. The PMU provides:

- Hyper-Speed, High-Speed, Low-Speed, Temporary Low-Speed, Standby, Suspend, and Critical Suspend modes
- Dynamically adjusted clock speeds for power reduction
- Programmable activity and wake-up monitoring
- General-purpose I/O pins to control external devices and external power management
- Battery low and AC power monitoring
- SMI/NMI synchronization and generation

5.1.1 PMU Terms

This document refers to activities, wake-ups, SMI/NMIs, battery controls, timer time-outs, and events. The following are the definitions:

- **Activities**—Indicate the system is doing something and needs to be operating. Activities can reset timers and cause mode changes to higher modes. Activities are only effective from Hyper-Speed, High-Speed, Low-Speed, Standby, and Temporary Low-Speed modes; they have no affect when the PMU is in Suspend mode. A primary activity is one that requires extensive CPU involvement and forces the PMU back to High-Speed mode from Low-Speed or Standby modes. A secondary activity does not require extensive CPU time to service it.
- **Wake-ups**—Actions that wake up the PMU from Suspend mode and take it back to an operating mode (Hyper-, High-, or Low-Speed). Wake-ups are only effective when the PMU is in Suspend mode.
- **SMI/NMIs**—Many things can be programmed to cause an SMI or Non-Maskable Interrupt (NMI) in the system. The only mode changes that occur for an SMI/NMI are changes to restart the clocks for interrupt servicing.

- **Battery control**—The ACIN, $\overline{BL2}$–$\overline{BL0}$ battery monitoring signals.
- **Timer time-out**—Each mode has a timer that allows the PMU to drop to the next mode (e.g., High-Speed drops to Low-Speed) when the timer times out.
- **Events**—A generic label to indicate any or all of the above terms.
- **PMUA, PMUB, PMUC, and PMUD**—Up to four GPIO_CS pins can be programmed to inform external hardware of internal PMU states. The internal signal names associated with this information are PMUA, PMUB, PMUC, and PMUD.

5.2 REGISTERS

A summary listing of the chip setup and control (CSC) registers used to control the PMU is shown in Table 5-1. Complete register descriptions can be found in the *Élan™ SC400 Microcontroller Register Set Reference Manual* (order #21032).

5.2.1 PMU Mode Control and Status Registers

CSC index registers 40–45h are used for mode control and status reporting. Important features of these registers include:

- A register for software to immediately program the PMU to any of the modes

  The PMU Force Mode Register (CSC index 40h) immediately takes the system to the programmed PMU mode. If the programmed mode is the mode the system is already in, the associated mode timer is reset.

- A register to read the present mode and the last mode the PMU was in

  The PMU Present and Last Mode Register (CSC index 41h) reflects the current mode and also the last mode the PMU was in. The following are special cases as far as mode changes are concerned.

  – In High-Speed mode, when a primary activity happens, the High-Speed mode timer is merely restarted. This is not a mode change; therefore the PMU Present and Last Mode Change Register remains unchanged.

  – In Temporary Low-Speed mode, when a secondary activity happens, the Temporary Low-Speed mode timer is merely restarted. This is not a mode change; therefore the PMU Present and Last Mode Change Register remains unchanged.

  – High-Speed, Low-Speed, or Temporary Low-Speed modes can be entered by programming the PMU Force Mode Register. While in the same mode, the PMU Present and Last Mode Register does not change because of this register write. The Present and Last Mode Register continues to reflect the real last state the PMU was in. The write to the PMU Force Mode Register restarts the mode's timer.

- A register (Clock Control Register at CSC index 82h[0]) to enable keeping the Phase-Locked Loops (PLLs) on during Suspend mode
- Registers (CSC index 42–44h) to set the timer value for each of the PMU modes
- A register bit (CSC index 40h[4]) to speed up all mode timers so that they time-out more quickly during debug

  This is beneficial in reducing the time it takes to go through diagnostic routines to check out the board, the microcontroller, and power management software. (The Temporary Low-Speed timer is not affected by this bit.)

- A register field (in the Wake-Up Pause/High-Speed Clock Timers Register at CSC index 45h [5–3]) to set the timer value for delaying starting up the High-Speed CPU clock when going to High-Speed mode from Suspend

Upon wake-up, the microcontroller goes into High-Speed mode at a reduced frequency (8.29 MHz) and delays running the clock up to the maximum programmed speed based on CSC index 45h[5–3].

If an SMI/NMI is serviced for the wake-up, the CPU-speed stepping-delay timer continues to count down during the interrupt service. If the timer times-out during the interrupt service routine, the CPU clock speeds up during the routine. This feature is useful for lowering the sudden current draw on the power supply when returning from Suspend. Software can determine if full operating speed has been reached by reading CSC index 40h[3]. This feature should not be disabled if the HS_COUNTING bit (CSC index 40h[3]) is set. (It should not be disabled when in use).

- A register field (CSC index 45h[2–0]) to set the timer value for delaying bringing the system out of Suspend, allowing time for the power planes to stabilize (if any have been turned off)
- A register bit (CSC index 40h[5]) to disable the LCD in Standby mode
- A register bit (CSC index 41h[6]) to immediately time out the active timer, allowing software to cause an immediate mode change

Note: *When EN_HYPER (CSC index 40h [6]) is set, any PMU Force Mode Register write that forces High-Speed goes to Hyper-Speed instead. With EN_HYPER set, High-Speed mode is not accessible through the PMU Force Mode Register. Also, after a wake-up from Suspend, the TIMEO_NOW bit (CSC index 41h[6]) cannot be written to for at least 30* µ*s.*

Table 5-1 PMU Controller Register Summary

Register	I/O Address	PMU Controller Function Keyword	Description in Register Set Manual
PMU Mode Control and Status			
PMU Force Mode Register	22h/23h Index 40h	PMU mode force, high-speed clock delay timer status, speed-up Suspend and Standby mode timer debug, LCD operation in Standby, Hyper-Speed mode enable, Low-Speed timer reset	page 3-51
PMU Present and Last Mode Register	22h/23h Index 41h	Read present and last PMU mode, time-out current mode timer in Hyper-Speed mode	page 3-53
Hyper/High-Speed Mode Timers Register	22h/23h Index 42h	Timer values for dropping down to High-Speed and Low-Speed modes from Hyper-and High-Speed	page 3-54
Low-Speed/Standby Mode Timers Register	22h/23h Index 43h	Timer values for dropping to Standby and Suspend modes from Low-Speed and Standby	page 3-55
Suspend/Temporary Low-Speed Mode Timers Register	22h/23h Index 44h	Timer values to count down in Temporary Low-Speed and Suspend modes, NMI/SMI service	page 3-56
Wake-Up Pause/High Speed Clock Timers Register	22h/23h Index 45h	Timer values for stabilizing power supplies and for switching the CPU clock to the programmed speed	page 3-57
PMU Wake-Up Control and Status			
SUS_RES Pin Configuration Register	22h/23h Index 50h	SUS_RES pin enable, pin trigger configuration	page 3-58

Table 5-1 PMU Controller Register Summary (continued)

Register	I/O Address	PMU Controller Function Keyword	Description in Register Set Manual
Wake-Up Source Enable Register A	22h/23h Index 52h	Wake-up source enable: RTC alarm, UART $\overline{\text{RIN}}$ and SIN pins, Suspend mode timer time-out, matrix key press	page 3-59
Wake-Up Source Enable Register B	22h/23h Index 53h	Wake-up source enable: $\overline{\text{BL0}}$, $\overline{\text{BL1}}$, $\overline{\text{BL2}}$, and ACIN	page 3-60
Wake-Up Source Enable Register C	22h/23h Index 54h	Wake-up source enable: PIRQ5–PIRQ0 and PDRQ1–PDRQ0	page 3-61
Wake-Up Source Enable Register D	22h/23h Index 55h	Wake-up source enable: Ring Indicate, Interrupt Request, Card Detect, and Status Change for PC Card pins	page 3-62
Wake-Up Source Status Register A	22h/23h Index 56h	Wake-up source status: SUS_RES, RTC alarm, UART $\overline{\text{RIN}}$ and SIN pins, Suspend mode timer time-out, matrix key press	page 3-63
Wake-Up Source Status Register B	22h/23h Index 57h	Wake-up source status: $\overline{\text{BL0}}$, $\overline{\text{BL1}}$, $\overline{\text{BL2}}$, and ACIN	page 3-64
Wake-Up Source Status Register C	22h/23h Index 58h	Wake-up source status: PIRQ5–PIRQ0 and PDRQ1–PDRQ0	page 3-65
Wake-Up Source Status Register D	22h/23h Index 59h	Wake-up source status: Ring Indicate, Interrupt Request, Card Detect, and Status Change for PC Card pins	page 3-66
GPIO as a Wake-Up or Activity Source Status Register A	22h/23h Index 5Ah	Wake-up or activity source status: GPIO_CS0–GPIO_CS7	page 3-67
GPIO as a Wake-Up or Activity Source Status Register B	22h/23h Index 5Bh	Wake-up or activity source status: GPIO_CS8–GPIO_CS14	page 3-68
PMU Activity Control and Status			
GP_CS Activity Enable Register	22h/23h Index 60h	Activity enable: GP_CSA–GP_CSD	page 3-69
GP_CS Activity Status Register	22h/23h Index 60h	Activity status: GP_CSA–GP_CSD	page 3-70
Activity Source Enable Register A	22h/23h Index 62h	Activity source enable: CPU access to UART, internal graphics I/O and memory, $\overline{\text{ROMCS2}}$–$\overline{\text{ROMCS0}}$, and any VL-bus cycle	page 3-71
Activity Source Enable Register B	22h/23h Index 63h	Activity source enable: CPU access to DRAM, matrix key pressed, timer tick interrupt, keyboard timer time-out, and keyboard registers	page 3-72
Activity Source Enable Register C	22h/23h Index 64h	Activity source enable: CPU access to external VGA controller I/O and memory, floppy controller registers, and IDE hard drive registers; DMA request, ACIN signal, UART $\overline{\text{RIN}}$ pin, and UART SIN pin	page 3-73

Table 5-1 PMU Controller Register Summary (continued)

Register	I/O Address	PMU Controller Function Keyword	Description in Register Set Manual
Activity Source Enable Register D	22h/23h Index 65h	Activity source enable: CPU access to parallel port, PC Card Socket A, PC Card Socket B, internal system registers; also enables PC Card Ring Indicate and PC Card INTR	page 3-74
Activity Source Status Register A	22h/23h Index 66h	Activity source status: CPU access to UART, internal graphics I/O and memory, $\overline{\text{ROMCS2}}$–$\overline{\text{ROMCS0}}$, and any VL-bus cycle	page 3-75
Activity Source Status Register B	22h/23h Index 67h	Activity source status: CPU access to DRAM, matrix key pressed, timer tick interrupt, keyboard timer time-out, and keyboard registers	page 3-76
Activity Source Status Register C	22h/23h Index 68h	Activity source status: CPU access to external VGA controller I/O and memory, floppy controller registers, and IDE hard drive registers; DMA request, ACIN signal, UART $\overline{\text{RIN}}$ pin, and UART SIN pin	page 3-77
Activity Source Status Register D	22h/23h Index 69h	Activity source status: CPU access to parallel port, PC Card Socket A, PC Card Socket B, internal system registers; also enables PC Card Ring Indicate and PC Card INTR	page 3-78
Activity Classification Register A	22h/23h Index 6Ah	Primary and secondary activity classification: CPU access to UART, internal graphics I/O and memory, $\overline{\text{ROMCS2}}$–$\overline{\text{ROMCS0}}$, and any VL-bus cycle	page 3-79
Activity Classification Register B	22h/23h Index 6Bh	Primary and secondary activity classification: CPU access to DRAM, matrix key pressed, timer tick interrupt, keyboard timer time-out, and keyboard registers	page 3-80
Activity Classification Register C	22h/23h Index 6Ch	Primary and secondary activity classification: CPU access to external VGA controller I/O and memory, floppy controller registers, and IDE hard drive registers; DMA request, ACIN signal, UART $\overline{\text{RIN}}$ pin, and UART SIN pin	page 3-81
Activity Classification Register D	22h/23h Index 6Dh	Primary and secondary activity classification: CPU access to parallel port, PC Card Socket A, PC Card Socket B, internal system registers; also enables PC Card Ring Indicate and PC Card INTR	page 3-82
Battery Level Pin Control and Status			
Battery/AC Pin Configuration Register A	22h/23h Index 70h	$\overline{\text{BLx}}$ pin configuration, force CPU clock and PMU mode, force software ACIN, and Suspend indications	page 3-83
Battery/AC Pin Configuration Register B	22h/23h Index 71h	Assert ACIN to disable PMU, $\overline{\text{BL2}}$ control to force PMU mode	page 3-85
Battery/AC Pin State Register	22h/23h Index 72h	$\overline{\text{BL0}}$–$\overline{\text{BL2}}$, ACIN, and SUS_RES states	page 3-86

Table 5-1 PMU Controller Register Summary (continued)

Register	I/O Address	PMU Controller Function Keyword	Description in Register Set Manual
Clock Control and Status			
CPU Clock Speed Register	22h/23h Index 80h	CPU clock speeds in Hyper-, High-, and Low-Speeds; present CPU clock speed	page 3-87
CPU Clock Auto Slowdown Register	22h/23h Index 81h	Fast and slow clock duration, auto slowdown enable	page 3-88
Clock Control Register	22h/23h Index 82h	PLL enable, restart delay time, 32-KHz clock state, DMA clock frequency	page 3-90
SMI/NMI Generation and Status			
Miscellaneous SMI/NMI Enable Register	22h/23h Index 90h	SMI/NMI enable: wake-up, SIN pin, $\overline{\text{RIN}}$ pin, RTC alarm, SUS_RES pin, force NMI or SMI	page 3-94
PC Card and Keyboard SMI/NMI Enable Register	22h/23h Index 91h	SMI/NMI enable: matrix keyboard key press, keyboard timer, and Input Buffer Written and Keyboard Output Buffer Read interrupts; PC Card interrupt, ring indicate, and card detects for PC Card Sockets A and B	page 3-95
Mode Timer SMI/NMI Enable Register	22h/23h Index 92h	SMI/NMI enable: time-outs for Suspend, Standby, Low-Speed, High-Speed, and Hyper-Speed mode timers	page 3-96
Battery Low and ACIN SMI/NMI Enable Register	22h/23h Index 93h	SMI/NMI enable: ACIN, $\overline{\text{BL2}}$–$\overline{\text{BL0}}$ pin edges	page 3-102
Miscellaneous SMI/NMI Status Register	22h/23h Index 94h	SMI/NMI status: wake-up, SIN pin, $\overline{\text{RIN}}$ pin, RTC alarm, SUS_RES pin, force NMI or SMI	page 3-99
PC Card and Keyboard SMI/NMI Status Register	22h/23h Index 95h	SMI/NMI status: matrix keyboard key press, keyboard timer, and Input Buffer Written and Keyboard Output Buffer Read interrupts; PC Card interrupt, ring indicate, and card detects for PC Card Sockets A and B	page 3-100
Mode Timer SMI/NMI Status Register	22h/23h Index 96h	SMI/NMI status: time-outs for Suspend, Standby, Low-Speed, High-Speed, and Hyper-Speed mode timers	page 3-101
Battery Low and ACIN SMI/NMI Status Register	22h/23h Index 97h	SMI/NMI status: ACIN, $\overline{\text{BL2}}$–$\overline{\text{BL0}}$ pin edges	page 3-102
SMI/NMI Select Register	22h/23h Index 98h	Select SMI or NMI: RTC alarm, $\overline{\text{RIN}}$ pin, SIN pin, PC Card interrupts, wake-ups, internal keyboard interrupts, SUS_RES pin, battery management (ACIN and $\overline{\text{BL2}}$–$\overline{\text{BL0}}$), and PMU mode timers	page 3-104
I/O Access SMI Enable Register A	22h/23h Index 99h	SMI enable for I/O access to keyboard, internal graphics, LPT1/LPT2 parallel port, UART COM1 and COM2	page 3-105
I/O Access SMI Enable Register B	22h/23h Index 9Ah	SMI enable for I/O access to GP_CSA, GP_CSB, PC Card Socket A, PC Card Socket B, IDE hard drive, and floppy controller	page 3-106

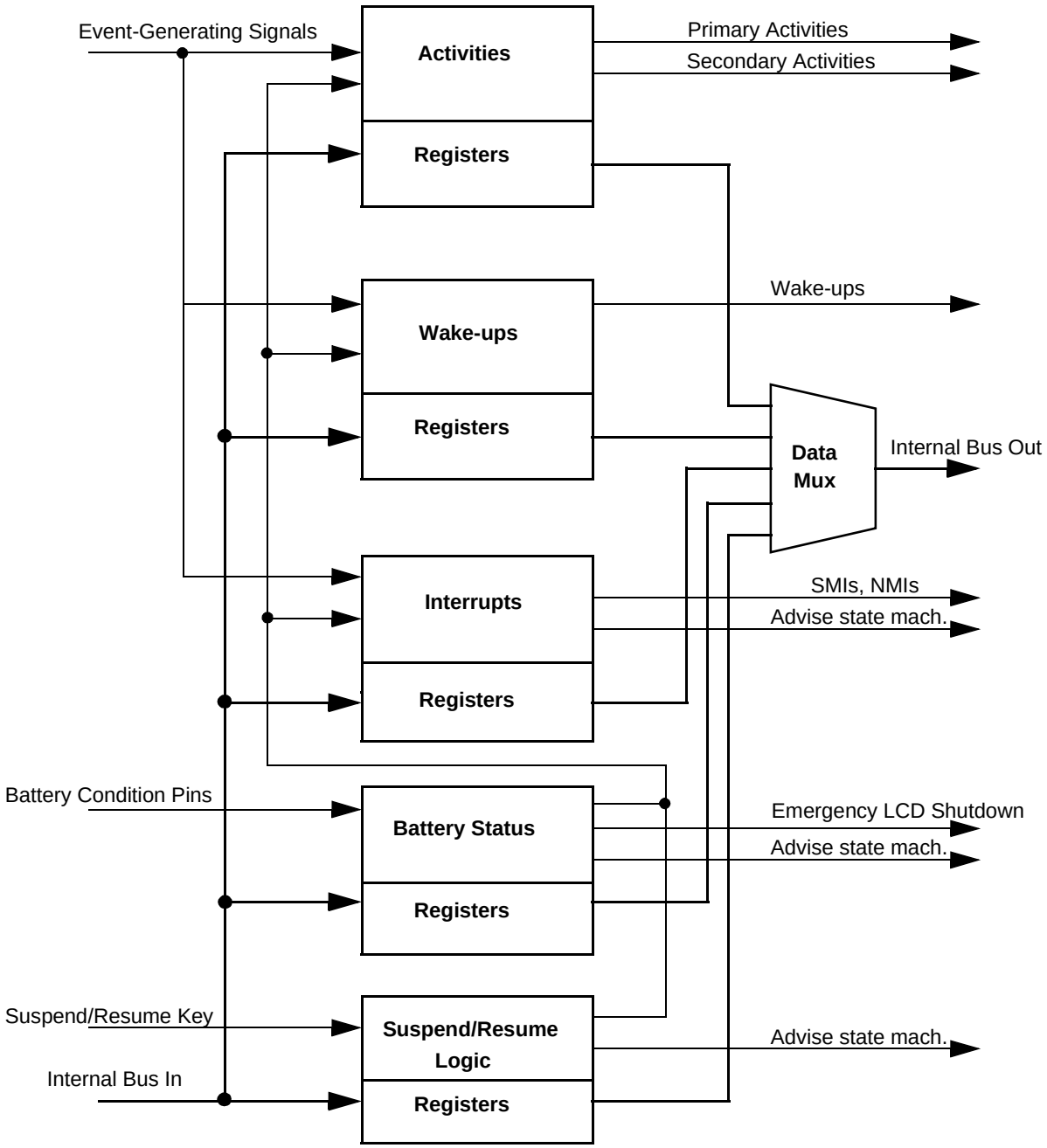
Table 5-1 PMU Controller Register Summary (continued)

Register	I/O Address	PMU Controller Function Keyword	Description in Register Set Manual
I/O Access SMI Status Register A	22h/23h Index 9Bh	SMI status for I/O access to keyboard, internal graphics, LPT1/LPT2 parallel port, UART COM1 and COM2	page 3-107
I/O Access SMI Status Register B	22h/23h Index 9Ch	SMI status for I/O access to GP_CSA, GP_CSB, PC Card Socket A, PC Card Socket B, IDE hard drive, and floppy controller	page 3-108
XMI Control Register	22h/23h Index 9Dh	Master SMI enable, NMI routine done	page 3-109
GPIO Pin Control, Status, Multiplexing			
GPIO_CS Function Select Register A	22h/23h Index A0h	GPIO_CS3–GPIO_CS0 as inputs, outputs, primary activities, or wake-ups	page 3-110
GPIO_CS Function Select Register B	22h/23h Index A1h	GPIO_CS7–GPIO_CS4 as inputs, outputs, primary activities, or wake-ups	page 3-111
GPIO_CS Function Select Register C	22h/23h Index A2h	GPIO_CS11–GPIO_CS8 as inputs, outputs, primary activities, or wake-ups	page 3-112
GPIO_CS Function Select Register D	22h/23h Index A3h	GPIO_CS14–GPIO_CS12 as inputs, outputs, primary activities, or wake-ups	page 3-113
GPIO_PMUA Mode Change Register	22h/23h Index AAh	Drive GPIO_PMUA signal with programmed value in PMU modes	page 3-120
GPIO_PMUB Mode Change Register	22h/23h Index ABh	Drive GPIO_PMUB signal with programmed value in PMU modes	page 3-122
GPIO_PMUC Mode Change Register	22h/23h Index ACh	Drive GPIO_PMUC signal with programmed value in PMU modes	page 3-124
GPIO_PMUD Mode Change Register	22h/23h Index ADh	Drive GPIO_PMUD signal with programmed value in PMU modes	page 3-126
GPIO_PMU to GPIO_CS Map Register A	22h/23h Index AEh	GPIO_PMUA and GPIO_PMUB mapping to GPIO_CSx pins	page 3-128
GPIO_PMU to GPIO_CS Map Register B	22h/23h Index AFh	GPIO_PMUC and GPIO_PMUD mapping to GPIO_CSx pins	page 3-129
GPIO_XMI to GPIO_CS Map Register	22h/23h Index B0h	GPIO_XMI mapping to GPIO_CS pins, SMI/ NMI selection	page 3-130
Suspend Control			
Suspend Mode Pin State Register A	22h/23h Index E3h	Power control in Suspend mode for PC Card sockets A and B, VL-bus, ISA bus, DRAM, and ROM interfaces	page 3-184
Suspend Mode Pin State Register B	22h/23h Index E4h	Power control in Suspend mode for $\overline{\text{DBUFOE}}$, $\overline{\text{R32BFOE}}$	page 3-185
Suspend Mode Pin State Override Register	22h/23h Index E5h	Suspend mode override for PC Card sockets A and B, $\overline{\text{DBUFOE}}$, $\overline{\text{R32FOE}}$, ISA bus, and ROM interface; pin termination latch command	page 3-186

5.3 BLOCK DIAGRAM

Figure 5-1 shows a block diagram of the power management unit.

Figure 5-1 Power Management Unit Block Diagram



5.4 OPERATION

The PMU on the ÉlanSC400 and ÉlanSC410 microcontrollers is designed to operate in either fully automatic mode, software-driven mode, or various combinations of the two.

- Fully automatic mode allows extensive power management operations to be performed completely transparently to software. In this mode, wake-ups and activities move the PMU to higher power/performance states, and time-outs without the presence of activities move the PMU to lower power/performance states.
- In software-driven modes, the PMU provides all of the resources required by a power management driver to implement almost any power management scheme, including a superset of APM 1.2. In addition, the PMU may be used in a role where it operates completely independently of any O/S, drive, or application software to provide intelligent power utilization at the system level.

For fully automatic mode operation, the BIOS/HAL initialization code must set up the PMU to define time-outs between the PMU states (modes) and also to define what events should be taken by the PMU as activities, wake-ups, etc. Once the operating system has loaded, the PMU requires no software intervention.

In a software-driven power management scheme, the PMU Force Mode Register is used by a software state machine to force the hardware into the desired power-consumption state. When no power management software is available, the hardware can be configured once at boot time by BIOS or system firmware to implement power management based on mode timers and power management events. After this has been done, the PMU hardware controls the system performance/power consumption state automatically and without action of any kind by software. More complex power management schemes can be devised which leverage intelligent power management software and automatic power management hardware in the same system.

A state sequencer on the ÉlanSC400 and ÉlanSC410 microcontrollers monitors the activity in the system and transitions from mode to mode based on built-in timers and the level of activity in the system. The actions that occur in each mode are programmable.

All clock switching is done at a “safe” time when transitions between modes will not harm system operation. Because the system implements hidden refresh, the PMU requests a CPU Hold before changing the CPU clock so that the CPU is inactive at the time the clock switches.

Changes in PMU modes affect the CPU clock primarily. Other clocks on the microcontroller may be limited by the speed of the CPU clock, but they are not otherwise altered by the mode changes. More detailed information on clock control and generation is found in Chapter 6.

The ACIN feature can be configured to disable most mode transitions and allow the system to run at maximum performance. Suspend mode can still be accessed. This feature is useful to get maximum non-driver-managed performance while connected to an AC wall adapter without completely reprogramming all mode timers, etc.

Each mode has a timer that, when it times-out, signals the PMU to step down to the next lower mode (see Figure 5-3). Each timer can be disabled to allow the PMU to remain in any mode, except for the Temporary Low-Speed timer. The PMU mode timers, when used in conjunction with activities and wake-ups, can provide power management control that is transparent to the operating system.

Temporary Low-Speed is a temporary mode. Its timer has a default minimum so that the PMU returns to the appropriate mode soon after the event that sent it to Temporary Low-

Speed mode is done. (The appropriate mode is dependent on entry conditions and other configurations; this can be determined by examining the flowcharts shown in Figure 5-3–Figure 5-8.) This timer is different than the other mode timers in that respect. The timer has no disable. It does not cause the PMU to stay in Temporary Low-Speed mode; it always continues on to another mode. This timer allows a system design that only goes as low as Standby mode but will still service secondary activities and then return to the low-power Standby mode (rather than getting stuck in Temporary Low-Speed mode). Again, this feature provides for "hardware-only" power management that automatically trades off processing performance with power consumption based on the real-time needs of the system.

5.4.1 Hyper-Speed Mode

Hyper-Speed mode is used when performance is much more valuable than battery life. Hyper-Speed mode utilizes the CPU's clock multiplying capability to run the CPU at 66 MHz (2x) or 100 MHz (3x).

For all PMU modes except Hyper-Speed mode, the CPU is clocked by the microcontroller-specific Phase-Locked-Loop (PLL) and clock-generation circuitry. However, when Hyper-Speed mode is used, the four microcontroller-specific PLLs are not used for CPU clock generation. In this case, the CPU core's own PLL is used.

When enabled, Hyper-Speed mode is entered from High-Speed mode. Any event that takes the microcontroller to High-Speed mode does so while the CPU-core PLL is brought up, then switches to Hyper-Speed mode. The exception to this is when the Hyper-Speed mode timer times out and drops to High-Speed mode. The PMU stays in High-Speed mode until a primary activity or ACIN forces a change back to Hyper-Speed mode (or until the High-Speed timer times out and PMU drops to Low-Speed mode).

While the CPU-core PLL is brought up, the CPU cannot operate in static clock mode. The CPU enters the Stop Grant state until the PLL stabilizes. Going to High-Speed mode while in the Stop Grant state allows any other device time to stabilize (e.g., power on an external device can be turned on by a GPIO).

The clock selection (66 MHz or 100 MHz) can be done at any time. If it is done while in Hyper-Speed mode, it will not take effect until the next time the PMU goes to Hyper-Speed mode. The system must do a CPU Stop Grant using the CPU's Stop Clock Interrupt before the clock switching can be done for entering and exiting Hyper-Speed mode.

This mode defaults to disabled. A bit must be set to enable the system to transition to Hyper-Speed mode.

5.4.1.1 Actions Taken During Hyper-Speed Mode

The following actions are taken on the ÉlanSC400 and ÉlanSC410 microcontrollers during Hyper-Speed mode:

- All parts of the system are clocked at full speed. (A summary of clock speeds per PMU mode is shown in Table 6-6.)
  - Because this mode uses the CPU-core PLL, there is a 1 ms delay in changing the CPU frequency (a CPU Stop Grant must be done using the CPU's Stop Clock Interrupt).
  - Automatic slowdown is available in this mode. When enabled via CSC index 81h, the automatic slowdown feature slows down the CPU clock at a programmed interval for a programmed amount of time. Although power is saved, the automatic slowdown feature reduces average system performance, because it slows down the CPU clock per a duty cycle that is software-controllable via CSC index 81h.

- The CPU clock is programmable to be 66 or 100 MHz. The bus clock remains at 33 MHz in Hyper-Speed mode. (Note that the CPU clock on the ÉlanSC400 and ÉlanSC410 microcontrollers does not switch dynamically per type of access cycle.)

5.4.1.2 Entering Hyper-Speed Mode

The system enters Hyper-Speed mode when Hyper-Speed Mode is enabled and either of the following occurs:

- The system goes to High-Speed mode.
  - After a 1 ms delay (for the CPU-core PLL to start up and stabilize), the system goes to Hyper-Speed mode unless High-Speed mode was entered by the Hyper-Speed timer time-out. Note that if Hyper-Speed mode is enabled, and a write to the PMU Force Mode Register (CSC index 40h) forced High-Speed mode, the system goes to Hyper-Speed mode.
- The system is in High-Speed mode and a primary activity happens.
  - The same PLL start-up time restrictions apply.

5.4.1.3 Leaving Hyper-Speed Mode

The system leaves Hyper-Speed mode when any of the following occurs:

- The Hyper-Speed mode timer times out.
  - The system drops to High-Speed mode.
- The system is programmed directly out with the PMU Force Mode Register.
  - The system can go to any other mode.
- The SUS_RES signal toggles.
  - If enabled, forces the system directly to Suspend mode
- $\overline{BL0}$, $\overline{BL1}$, or $\overline{BL2}$ go Low (programmable option using CSC index 70–71h).
  - $\overline{BL2}$ causes a mode change to Critical Suspend mode if enabled and ACIN is not active.
  - $\overline{BL0}$ or $\overline{BL1}$ causes a mode change to Low-Speed mode or High-Speed mode (8 MHz) if enabled and ACIN is not active.

5.4.2 High-Speed Mode

This mode is used when performance is more valuable than battery life. High-Speed mode does not use the CPU-core PLL for operation; it drives the enhanced Am486 CPU core in static clock mode.

High-Speed mode can be disabled by enabling and asserting the $\overline{BL2}$–$\overline{BL0}$ inputs (CSC index 70 and 71h). When this occurs, activities that normally caused a mode change to High-Speed go to Low-Speed instead. Only the PMU Force Mode Register (CSC index 40h) allows access to High-Speed mode.

5.4.2.1 Actions Taken During High-Speed Mode

The following actions are taken in the ÉlanSC400 and ÉlanSC410 microcontrollers during High-Speed mode:

- All parts of the system are clocked at full speed. (A summary of clock speeds per PMU mode is shown in Table 6-6.)
  - Automatic slowdown is available in this mode. When enabled via CSC index 81h, the automatic slowdown feature slows down the CPU clock at a programmed interval for a programmed amount of time. Although power is saved, the automatic slowdown feature reduces average system performance, because it slows down the CPU clock per a duty cycle that is software-controllable via CSC index 81h.
- The CPU clock is programmable to be 33 MHz, 16 MHz, or 8 MHz. (Note that the CPU clock on the ÉlanSC400 and ÉlanSC410 microcontrollers does not switch dynamically per type of access cycle.)

5.4.2.2 Entering High-Speed Mode

The system goes to High-Speed mode when High-Speed Mode is not disabled via $\overline{BL2}$ or $\overline{BL1}$ and any of the following occurs:

- Hardware reset (the CPU clock will default to 8 MHz)
- Hyper-Speed mode timer times out.
- A primary activity is detected and the microcontroller is not currently in Hyper-Speed mode.
- Resume or wake up from Suspend
- Programmed directly with the PMU Force Mode Register
- ACIN is enabled and the ACIN signal goes active or a bit in the Battery/AC Pin Configuration Register (CSC index 70h[5]) is set.

5.4.2.3 Leaving High-Speed Mode

The system leaves High-Speed mode when any one of the following occurs:

- A primary activity occurs and Hyper-Speed mode is enabled.
  - Goes to Hyper-Speed mode after the CPU-core PLL is stable.
  - If Hyper-Speed is enabled, the system stays in High-Speed mode for 1 ms only.
- The High-Speed mode timer times out.
  - Drops to Low-Speed mode
- Programmed directly out with the PMU Force Mode Register
  - Can go to any other mode
- The SUS_RES signal toggles.
  - If enabled, forces the system directly to Suspend mode
- $\overline{BL0}$, $\overline{BL1}$, or $\overline{BL2}$ are asserted (programmable option using CSC index 70–71h).
  - $\overline{BL2}$ causes a mode change to Critical Suspend mode if enabled and ACIN is not active.
  - — $\overline{BL0}$ or $\overline{BL1}$ causes a mode change to Low-Speed mode if enabled and ACIN is not active.

5.4.3 Low-Speed Mode

This mode is used when there is not a lot of CPU intensive activity in the microcontroller and the CPU clock can be slowed down for all CPU cycles.

5.4.3.1 Actions Taken During Low-Speed Mode

The following actions are taken in the ÉlanSC400 and ÉlanSC410 microcontrollers during Low-Speed mode:

- The CPU clock can be programmed to 8 MHz, 4 MHz, 2 MHz, or 1 MHz in this mode. (A summary of clock speeds per PMU mode is shown in Table 6-6.)
- The CPU clock is driven with the programmed frequency for all cycles.
  - — The CPU clock does not speed up to 8 MHz for ISA, PC Card, or ROM cycles. They happen at the programmed CPU clock speed. For example, if the CPU clock is programmed to 2 MHz, the ISA cycles will be approximately 4 times as long as normal, because the ISA clock is also 2 MHz.

5.4.3.2 Entering Low-Speed Mode

The system goes to Low-Speed mode when any one of the following occurs:

- The High-Speed mode timer times out.
- Programmed directly with the PMU Force Mode Register
- $\overline{\text{BL0}}$ or $\overline{\text{BL1}}$ goes Low (programmable option).
- A primary activity happens and the High-Speed mode is disabled via $\overline{\text{BL2}}$ or $\overline{\text{BL1}}$.
- Resume or wake up from Suspend mode when the High-Speed mode is disabled
- When a secondary activity occurs in Low-Speed mode the Timer may be reset (programming option); modes are not changed.

5.4.3.3 Leaving Low-Speed mode

The system leaves Low-Speed mode when any one of the following happens:

- The Low-Speed mode timer times out.
  - – Drops to Standby mode
- Programmed directly out with the PMU Force Mode Register
  - – Can go to any other mode
- A primary activity is detected and High-Speed mode is enabled.
  - – Goes back up to High-Speed mode
- $\overline{\text{BL2}}$ goes Low (programmable option using CSC index 70–71h).
  - – Cause a mode change to Critical Suspend mode if enabled and ACIN is not active
- The SUS_RES signal toggles.
  - — If enabled, forces the system to Suspend mode

5.4.4 Standby Mode

This mode is used when there is no activity in the microcontroller and many clocks can be shut down. When an enabled activity occurs, the PMU switches to the appropriate mode.

5.4.4.1 Actions Taken During Standby Mode

The following actions are taken in the ÉlanSC400 and ÉlanSC410 microcontrollers during Standby mode:

- The CPU clock is stopped. (A summary of clock speeds per PMU mode is shown in Table 6-6.)
- The internal LCD graphics controller can be programmed to be enabled or disabled.
- The High-Speed PLL can be shut off.

5.4.4.2 Entering Standby Mode

The system goes to Standby mode when any of the following occurs:

- The Low-Speed mode timer times out.
- Programmed directly with the PMU Force Mode Register
- Return from Temporary Low-Speed mode when the Temporary Low-Speed timer times out
  - — When Temporary Low-Speed mode was entered from Standby mode

5.4.4.3 Leaving Standby Mode

The system leaves Standby mode when any of the following occurs:

- The Standby mode timer times out.
  - – Drops to Suspend mode
- A primary activity is detected.
  - – Goes back up to High-Speed or Low-Speed Mode (based on $\overline{BL2}$ or $\overline{BL1}$)
- A secondary activity is detected.
  - – Goes to Temporary Low-Speed mode
  - – The Standby timer is paused while in Temporary Low-Speed mode. The count-down continues when Standby mode is re-entered. The timer is not reset by this mode change.
- $\overline{BL2}$ goes Low (programmable option using CSC index 70–71h).
  - – Cause a mode change to Critical Suspend mode if ACIN is not active
- The SUS_RES signal toggles.
  - – If enabled, forces the system to Suspend mode

5.4.5 Suspend Mode

Suspend mode is used when the system wants to enter a very low power mode, keeping the DRAM refreshed and saving the status of the microcontroller's internal wake-up or resume registers so it can return to the point it left off. If the system PLLs (the High-Speed, Low-Speed, Intermediate, and Graphics Dot Clock PLLs) are shut off, it will take longer to return, but Suspend power requirements will be reduced.

5.4.5.1 Actions Taken During Suspend Mode

The following actions are taken in the ÉlanSC400 and ÉlanSC410 microcontrollers during Suspend mode:

- All clocks are stopped (except the RTC and memory refresh, which are derived off the 32-KHz oscillator without the system PLL's involvement).
- The PLLs shut down (programmable option via CSC index 82h[0]). Note that clocks can be stopped (gated off) without shutting down the PLLs.
- The RTC is left running.
- The DRAM refresh (either $\overline{\text{CAS}}$-before-$\overline{\text{RAS}}$ or self-refresh) is programmable to be left active or turned off.
  - If $\overline{\text{CAS}}$-before-$\overline{\text{RAS}}$ refresh is left active, the refresh clock is switched from the timer counter to the 32-KHz oscillator.
- The pins on the microcontroller go to their predetermined state and stop toggling.

5.4.5.2 Entering Suspend Mode

The system goes to Suspend mode when any of the following occurs:

- The Standby mode timer times out.
- Programmed directly with the PMU Force Mode Register
- Critical Suspend mode is unlocked by ACIN, $\overline{\text{BL2}}$, and/or $\overline{\text{BL1}}$ and $\overline{\text{BL2}}$.
- The SUS_RES signal is enabled and changes.

5.4.5.3 Leaving Suspend Mode

The system leaves Suspend mode when any of the following occurs:

- The Suspend mode timer times out.
  - If an SMI/NMI is enabled, it goes to Temporary Low-Speed mode.
  - All the PLLs (except the CPU-core PLL) must be started back up to service the XMI in Temporary Low-Speed mode. The timing sequence is shown in the *Élan™SC400 and ÉlanSC410 Microcontrollers Data Sheet* (order #21028).
  - If enabled as a wake-up, it goes to High or Low-Speed mode based on either $\overline{\text{BL2}}$ or $\overline{\text{BL1}}$.
  - — If both the SMI/NMI and wake-up are enabled, it goes to High or Low-Speed mode before servicing the SMI/NMI, as opposed to servicing the SMI in Temporary Low-Speed mode.
- $\overline{\text{BL2}}$ is enabled and asserted.
  - — Goes to Critical Suspend mode

- A wake-up source is detected active, or the SUS_RES signal toggles.
  - — If enabled, forces the system to High-Speed or Low-Speed mode. The PLLs have to be started back up.

5.4.6 Critical Suspend Mode

Critical Suspend mode is used when a battery-dead indication comes in on $\overline{BL2}$, and the microcontroller must quickly go to a Suspend mode and stay there until an unlock event occurs. When an unlock event occurs in Critical Suspend mode, the system will do one of the following:

- Go to Suspend mode and wait for a wake-up.
- Wake up if the unlock event is also programmed as a wake-up.
- Wake up if a wake-up was sensed while the system was in Critical Suspend.

The unlock events that can be enabled are:

- ACIN is toggled.
- $\overline{BL2}$ goes inactive.
- $\overline{BL2}$ and $\overline{BL1}$ go inactive.

5.4.6.1 Actions Taken During Critical Suspend Mode

The following actions are taken in the ÉlanSC400 and ÉlanSC410 microcontrollers during Critical Suspend mode:

- Same as Suspend mode
- The system is locked in Critical Suspend mode as long as an unlock event does not occur.
- The LCD panel shutdown sequence is accelerated. The voltage and control signals to the panel will disable without regard to normal power-down sequencing, which is specified in graphics index 50–51h.
- PLLs shut down.

5.4.6.2 Entering Critical Suspend Mode

The system goes to Critical Suspend mode when:

- $\overline{BL2}$ goes Low (programmable option) and ACIN is not enabled or asserted.

5.4.6.3 Leaving Critical Suspend Mode

The system leaves Critical Suspend mode when either of the following occurs:

- An unlock occurs.
  - – Goes to Suspend mode
- An unlock that is enabled as a wake-up occurs.
  - — Forces the system to High-Speed or Low-Speed mode

5.4.7 Temporary Low-Speed Mode

Temporary Low-Speed mode is a PMU mode that the programmer can use to handle events that occur when the PMU is currently in a clock-off mode. This mode is used to service a secondary activity or an SMI/NMI from Standby mode and then return to Standby mode, or to service the Suspend timer time-out SMI/NMI and then return to Suspend mode.

Temporary Low-Speed mode may be entered when a secondary activity occurs. Secondary activities are invoked as a result of events that do not need extensive CPU time to service, so the PMU does not return to High-Speed mode for them. Instead, Temporary Low-Speed mode acts as a temporary low-speed mode that has its own timer and returns to Standby mode if it was entered by a secondary activity. A secondary activity that is received while in Temporary Low-Speed mode causes the system to restart the Temporary Low-Speed timer.

The Temporary Low-Speed mode timer works differently that other mode timers. When other mode timers time out, the PMU transitions to the next lower power/performance state. When the Temporary Low-Speed mode timer expires, the PMU returns to the clock-off state from which it was awakened to process the secondary activity in the first place.

When Temporary Low-Speed mode is entered from Standby mode, the Standby timer will be paused while in Temporary Low-Speed mode. The Standby timer then resumes its count down when it returns to Standby mode.

When Temporary Low-Speed mode is entered from Suspend, it acts like Suspend in that only a wake-up can change the mode to High- or Low-Speed (activities and ACIN do not change the mode). A force mode register write, however, can change to any other mode.

5.4.7.1 Actions Taken During Temporary Low-Speed Mode

The following actions are taken in the ÉlanSC400 and ÉlanSC410 microcontrollers during Temporary Low-Speed mode:

- CPU clock goes to the programmed Low-Speed mode rate. (A summary of clock speeds per PMU mode is shown in Table 6-6.)
- All other clocks go to the appropriate Low-Speed mode rate.
  - Except for LCD graphics, if it was disabled in the mode the PMU is coming from.
- Temporary Low-Speed mode timer is started.

5.4.7.2 Entering Temporary Low-Speed Mode

The system goes to Temporary Low-Speed mode when one of the following occurs:

- A secondary activity is received in Standby mode.
  - If a secondary activity happens in Temporary Low-Speed mode, the timer is restarted.
- An SMI/NMI is triggered while in the Standby mode, or by a Suspend timer time-out.
  - SMI/NMI in Suspend does not cause the PMU to go to Temporary Low-Speed unless it is caused by the Suspend timer time-out. The system goes to Temporary Low-Speed mode to service the SMI/NMI. During the interrupt service routine the PMU Force Mode Register can be used to change the PMU mode to any other mode rather than letting the system go back to Suspend or Standby mode.
- Programmed directly with the PMU Force Mode Register

5.4.7.3 Leaving Temporary Low-Speed Mode

The system leaves Temporary Low-Speed mode when one of the following occurs:

- Temporary Low-Speed mode timer times out.
  - If the last mode was Standby, the system returns to Standby; otherwise it goes to Suspend.
- Programmed directly out with the PMU Force Mode Register
  - Can go to any other mode
- The SUS_RES signal toggles.
  - If enabled and Temporary Low-Speed mode was called from Standby mode, forces the system to Suspend mode
  - If enabled and Temporary Low-Speed was entered as an SMI/NMI service routine from Suspend mode, the SUS_RES signal causes a transition to High-Speed (or Low-Speed) mode.
- A primary activity is detected (and Suspend was not the last mode).
  - Goes back up to High-Speed mode
- $\overline{\text{BL2}}$ goes Low (programmable option).
  - $\overline{\text{BL2}}$ causes a mode change to Critical Suspend mode if ACIN is not enabled and asserted.
- Wake-up detected
  - If Temporary Low-Speed mode was entered from Suspend, wake-ups can be detected and cause a mode change to High-Speed or Low-Speed mode.

5.4.8 PMU Flowcharts

The flowcharts in Figure 5-3–Figure 5-8 diagram the flow between modes for each of the major events: timers, activities, wake-ups/resume, ACIN, $\overline{BL0}$ and $\overline{BL1}$, and $\overline{BL2}$, with the SMI flows for each.

The following conventions apply to the flowcharts in this chapter.

- Clock speeds shown in boldface are the default speeds. Other speeds listed are programmable options.
- The solid arrows represent the default configurations.
- Dashed arrows show programmable options.
- An arrow leaving a mode at the same point where another arrow enters it represents what happens *after* the entering-arrow event happens. For example, in Figure 5-2, when the High-Speed mode timer times out and is programmed to cause an SMI/NMI, the SMI/NMI will happen while in High-Speed mode. After the interrupt is serviced, the system will then drop to Low-Speed Mode.
- SMI/NMI done—An SMI is done when the state restore from the SMI Return instruction is completed. An NMI is done when CSC index 9Dh[1] is written.

Figure 5-2 Interrupts in High-Speed Mode: Example

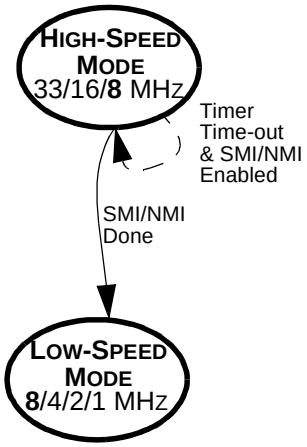
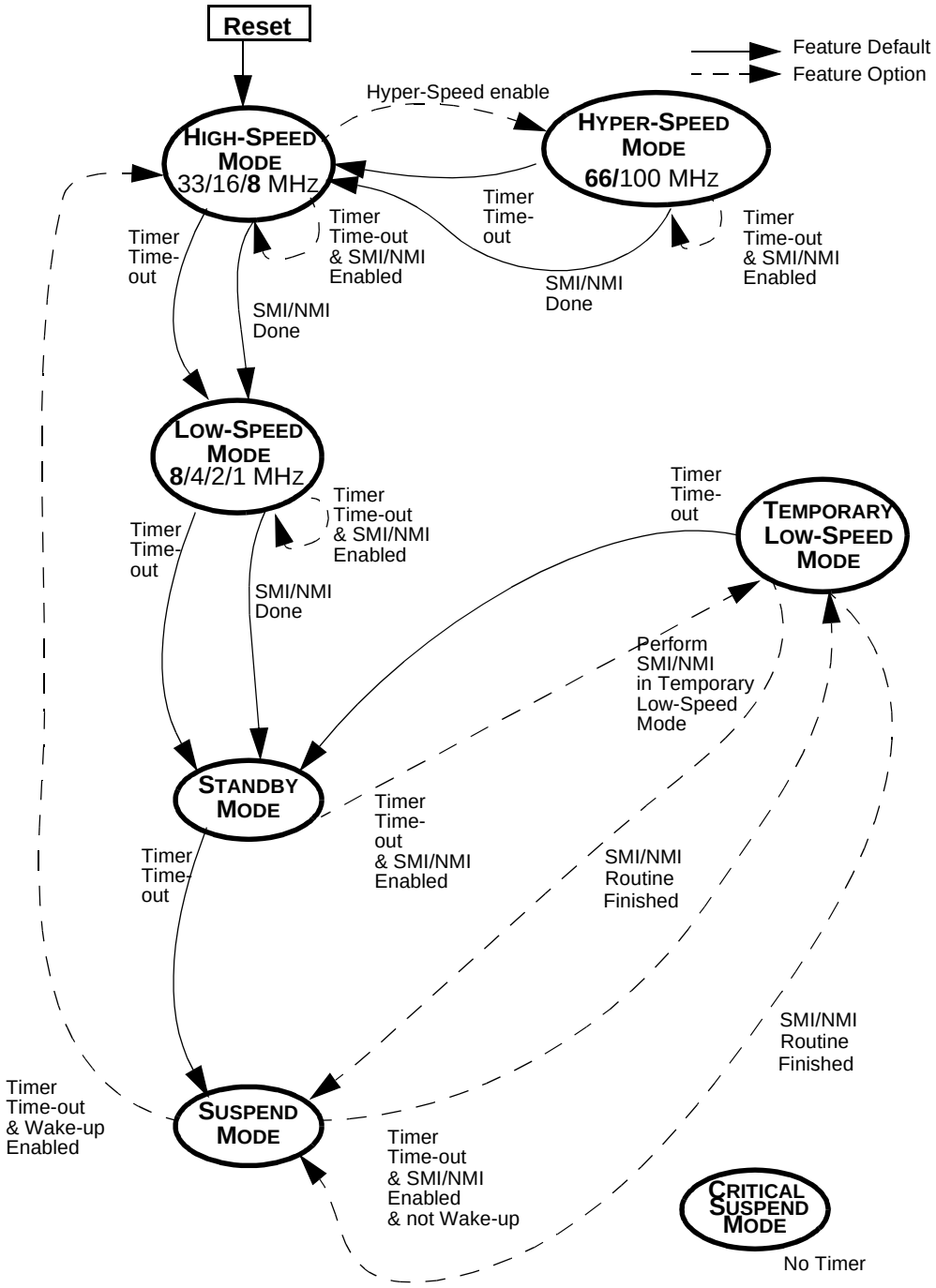


Figure 5-3 PMU Timer Mode Flow



5.4.9 Wake-Up Sources

Several options are available to wake up the system from Suspend mode. Table 5-2 shows the wake-up sources. The Suspend and wake-up/resume mode flow is diagrammed in Figure 5-4. The wake-up trigger is only valid to take the system from Suspend mode to High-Speed or Low-Speed mode. (Some of the $\overline{BL2}$—$\overline{BL0}$ signals can limit the PMU modes to Low-Speed; see Section 5.4.11.2.) The wake-up trigger has no use in any mode except Suspend. If Temporary Low-Speed mode was entered from Suspend, then wake-ups can be detected and the PMU will wake up from Temporary Low-Speed (it will not go back to Suspend mode to wake up). When receiving a wake-up in Suspend mode, any section of the PMU that has its clock disabled must be clocked again. Next, the PMU can start up the PLLs (if they were programmed to be off), gate the clocks, and resume the system.

Table 5-2 PMU Wake-Up Sources

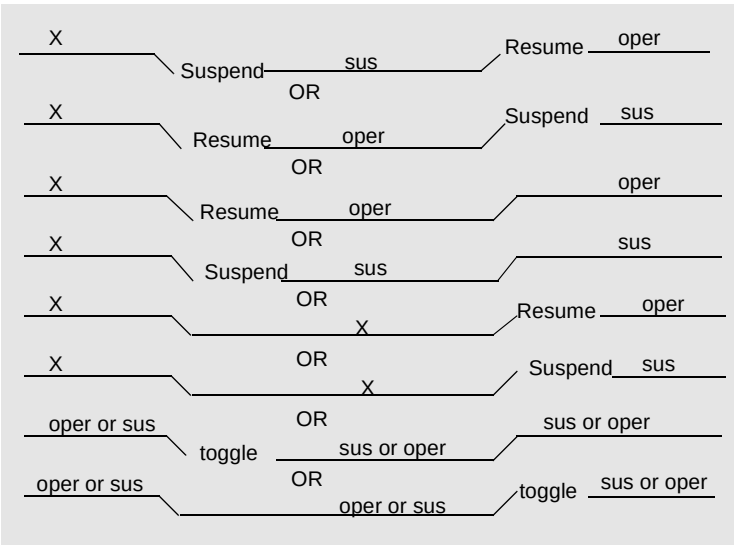
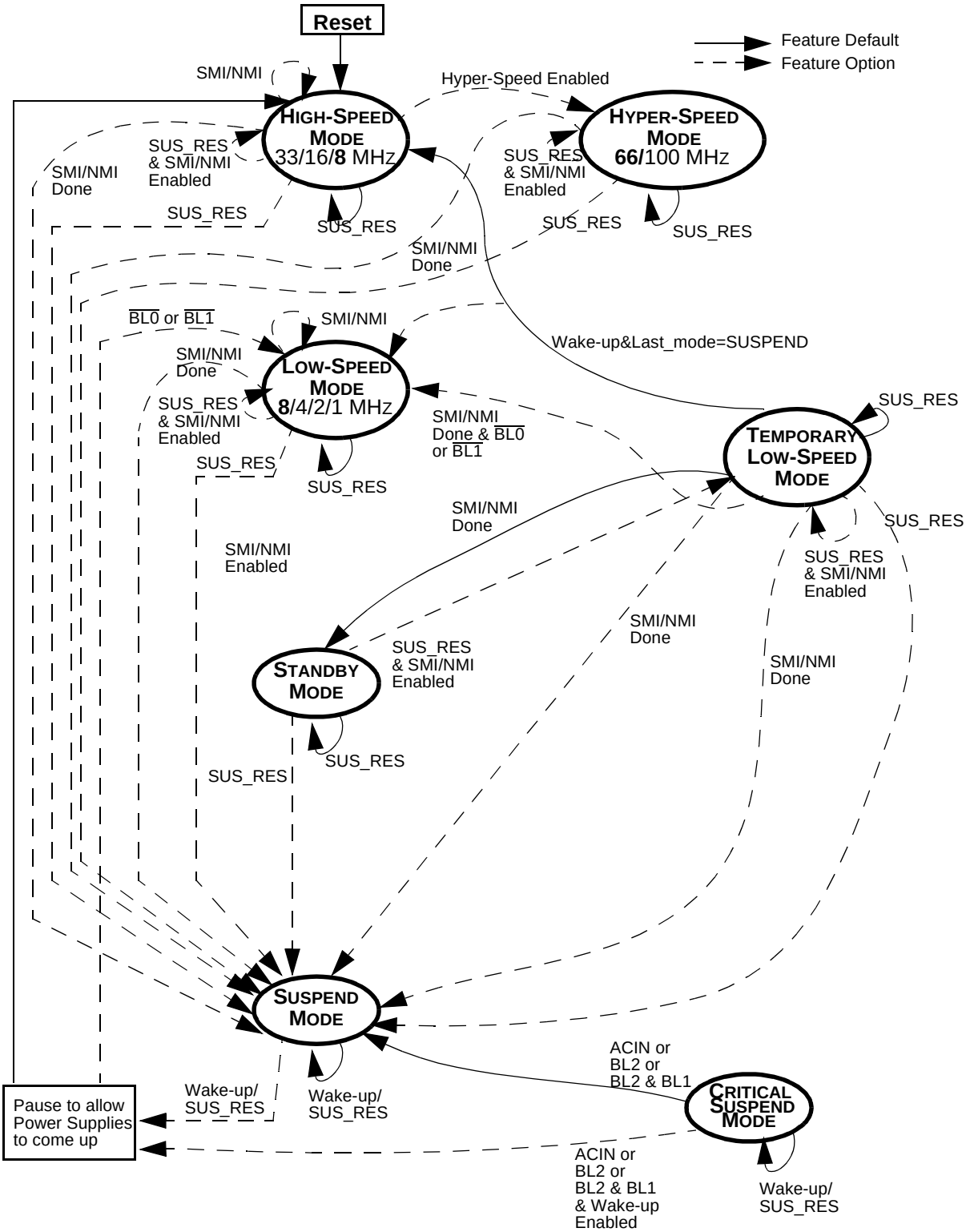
Wake-Up Sources	Description
ACIN signal	The ACIN signal rising or falling edge can cause a wake-up
$\overline{BL2}$–$\overline{BL0}$ signals	Any of the $\overline{BL2}$–$\overline{BL0}$ signals' rising or falling edge can cause a wake-up
SUS_RES signal	The default is disabled. This signal is also used as a keyboard row input. Programmable to cause Suspend, Resume, both, or neither. Programmable to Suspend on rising or falling edge, Resume on rising or falling edge, or toggle mode (Suspend if operating, Resume if Suspended) on rising or falling edge. The SUS_RES pin has a 15 ms debounce time. The waveforms below describe the different possible actions of the SUS_RES signal, depending on how it is programmed.  ***Notes:*** *Oper—The PMU is operating in Hyper/High/Low/Standby/Temporary Low-Speed mode* *Sus—The PMU is in Suspend mode* *X—The PMU is in any mode* *Suspend—The SUS_RES signal forces the PMU to Suspend mode* *Resume—The SUS_RES signal resumes the system from Suspend mode* *Toggle—The SUS_RES signal forces the PMU to Suspend mode if the PMU is operating, or resume the system from Suspend mode.*

Table 5-2 PMU Wake-Up Sources (continued)

Wake-Up Sources	Description
Suspend mode timer time-out	Suspend mode timer time-out can cause a wake-up
External DMA request	DMA request pin (either PDRQ0 or PDRQ1) rising-edge triggered. Only active if the PDRQ is enabled and mapped to a DMA channel in the DMA Controller, and the Pin Mux Register A (CSC index 38h[0]) selects the DMA function of the pin.
External IRQ	Any of the three external IRQ lines PIRQ2–PIRQ0 rising edge causes a wake-up. Only active if the PIRQ is enabled and mapped to an IRQ in the interrupt controller, and the Pin Mux Register A (CSC index 38h[1,2] selects the IRQ function of the pin.
RTC alarm	IRQ8 rising-edge triggered
UART ring indicate signal	The internal UART Ring Indicate ($\overline{\text{RIN}}$) falling-edge triggered
UART receive signal	Falling edge of the internal UART receive (SIN) signal triggered
Matrix keyboard key press	Internal keyboard controller key-pressed interrupt falling edge causes trigger
GPIO_CS14–GPIO_CS0 signals	Triggered by the falling edge on the signal
PC Card detect signals	Either PC Card Detect signal rising or falling edge can cause a wake-up
PC Card ring indicate signals	When the PC Card controller on the ÉlanSC400 microcontroller is programmed (PC Card index 03h or 43h) for a ring indicate signal, a falling edge can cause a wake-up. The PC Card controller uses the BVD1_x pins for ring indicate signals.
PC Card IRQ signals	Either PC Card Interrupt Request signal rising edge can cause a wake-up. Only active if the IRQ is enabled in the interrupt controller.
PC Card status change IRQ signals	Either PC Card Status Change Interrupt Request signal rising edge can cause a wake-up. Only active if the IRQ is enabled in the interrupt controller.

Figure 5-4 Suspend and Wake-Up/Resume Mode Flow



5.4.10 General-Purpose I/O (GPIO) Pins

The ÉlanSC400 and ÉlanSC410 microcontrollers support several general-purpose I/O pins (GPIOs) that can be used for power management. (The GPIO pins are fully described in Chapter 17.)

The GPIO_CSx signals have many programmable options for power management. As outputs, these pins are individually programmable to be High or Low for each PMU mode (Hyper-Speed/High-Speed/Low-Speed/Standby/Suspend). As inputs or outputs, they can be programmed to cause SMI/NMIs, wake-ups, or to be activities for the PMU. They can also be used as I/O or memory chip selects.

As an output, a GPIO_CSx can be:

- A PMU mode change output: set for High or Low for each PMU mode
  - — A maximum of four of the GPIO_CSx signals can be PMU mode change outputs at any one time. (See Section 5.4.10.1 and Chapter 17.)
- Enabled to cause an SMI/NMI
  - — Only one GPIO_CSx can cause an SMI/NMI at any one time.
- Enabled to cause an activity and wake-up
- Memory or I/O decode

As an input, a GPIO_CSx can be:

- Enabled to cause an SMI/NMI (Only one GPIO_CSx can cause an SMI/NMI at any one time)
- Enabled to cause an activity and wake up the system from Suspend mode

5.4.10.1 Mappable GPIO_PMUA–GPIO_PMUD Signals

Up to four GPIO_CS pins can be programmed to inform external hardware of internal PMU states. The internal signal names associated with this information are PMUA, PMUB, PMUC, and PMUD. Each of these signals has a register, GPIO_PMUx Mode Change Register (CSC index AA–ADh), that defines its value during every distinct PMU state. Each of these signals has a 4-bit field in the GPIO_PMU to GPIO_CS Map Registers A and B (CSC index AE–AFh) that defines which, if any, GPIO_CS pin it drives. The pin's output bit in CSC indexed registers A0–A5h must be 1 to set the pin to output mode. The pin's I/O bit in CSC indexed registers A6–A9h must be 0 to allow the PMU signal to propagate.

5.4.11 ACIN Detect and Battery Low

Four signals are brought into the microcontroller from outside so that the state of the system power can be reported to the microcontroller and used in the power management scheme. The Alternating Current INput (ACIN) signal is meant as an indication that the system is connected to a greater source of power (such as an AC wall plug) and that power savings are no longer as important as performance. The Battery Low ($\overline{BL0}$, $\overline{BL1}$, and $\overline{BL2}$) signals are digital inputs that external voltage comparators or an external processor can drive to inform the microcontroller of the state of the charge on the system batteries. Each Battery Low signal can report a different level in the battery discharge. For example, they may be used as follows:

- $\overline{BL0}$—Batteries are getting weak, so slow down the clock in High-Speed Mode
- $\overline{BL1}$—Batteries are weaker, so disable High-Speed mode and limit the PMU to go to Low-Speed mode as the highest mode.

- $\overline{BL2}$ —The batteries are so low they cannot operate the system. Force the system into Critical Suspend mode and do not allow a resume until there is AC power or the batteries are changed.

5.4.11.1 ACIN

The ACIN signal is used to indicate that the system is connected to a permanent source of power (i.e., an AC wall adapter) and that power management is not required (Suspend mode is still accessible). The ACIN mode flow is diagramed in Figure 5-5.

There is a register bit in the Battery/AC Pin Configuration Register (CSC index 70h[5] to perform a software ACIN, which, when set, has the same affect as asserting the ACIN pin. This is useful for software to emulate the effect the hardware ACIN line has on the function of the PMU. There is no functional difference between the ACIN pin being active and the ACIN software bit being set. Software can determine which is active by reading the Battery/AC Pin State Register (CSC index 72h[5].

ACIN is similar to a primary activity. Both can take the PMU back up to Hyper- or High-Speed mode, but the ACIN will keep it there by masking the timer time-outs. If the PMU Force Mode Register is programmed while ACIN is active (and programmed to disable PMU functions) the PMU will change mode, but will immediately switch back to High-Speed or Hyper-Speed mode because of ACIN.

Activities, wake-ups, and SMI/NMIs still work when ACIN is active also. SMI/NMIs are still accessible and the system will still wake up from Suspend when ACIN is active.

ACIN can also be used as part of the Critical Suspend unlock scheme.

When the ACIN signal is enabled and active, it causes the following to happen:

- Forces the system into High-Speed or Hyper-Speed mode (if Hyper-Speed mode is enabled) if it is in Low-Speed, Temporary Low-Speed, or Standby modes. If it is in Suspend mode, ACIN active does not cause a mode change unless programmed to be a wake-up.
- Forces most PMU mode timers' time-outs to be ignored by the PMU so the microcontroller does not time out and change modes. The microcontroller can still go into Suspend mode through a SUS_RES pin toggle or register force. The Suspend mode timer remains operational when ACIN is active.
- Disables $\overline{BL0}$, $\overline{BL1}$, or $\overline{BL2}$ from causing a mode or clock-speed change, unless it is also programmed as an SMI or a wake-up.

The state of the ACIN signal can be read from CSC index 72h[3].

5.4.11.2 Battery Low

The three Battery Low pins ($\overline{BL0}$, $\overline{BL1}$, and $\overline{BL2}$) are active Low signals that allow the system to monitor the state of the system batteries with up to three different levels. The mode flows for these three signals are diagrammed in Figure 5-6 and Figure 5-7. As a result of the battery-low monitoring, the PMU can be programmed to reduce the CPU clock speed in High-Speed mode, disable High-Speed mode and use Low-Speed mode as the fastest mode, or go to Critical Suspend Mode.

All three Battery Low inputs are negative edge-triggered. There is a 60-ms debounce time during which all further edges will be ignored. After the debounce time, another edge can be detected. If a Battery Low input changes polarity during the debounce time, and remains changed after 60 ms, this other edge will be detected (after the first 60 ms debounce time).

These power saving features occurs on the falling edge of the respective Battery Low signal unless ACIN is enabled and active. When ACIN goes inactive, any active and enabled battery-low feature will take affect at that time.

The state of all Battery Low signals can be read from the Battery/AC Pin State Register (CSC index 72h[2–0].

5.4.11.2.1 CPU Clock Speed Reduction

$\overline{BL0}$ and $\overline{BL1}$ can be programmed to force the microcontroller to disable Hyper-Speed mode and use 8.29 MHz as the High-Speed CPU frequency, or to disable High-Speed mode and force the microcontroller to go to Low-Speed mode as the highest mode. The PMU Force Mode Register does not override the Battery Low feature. If the PMU Force Mode Register is used to force Hyper- or High-Speed, the system returns to Low-Speed or High-Speed due to $\overline{BL0}$ and $\overline{BL1}$.

5.4.11.2.2 Critical Suspend Mode Access

Battery Low 2 is programmable to force the microcontroller to Critical Suspend mode (within 55 µs from the falling edge of $\overline{BL2}$) and lock the system into this mode to stop it from resuming until it is unlocked. The unlock requires special handling because the $\overline{BL2}$ signal may go High again after Suspend mode is reached. Because system current consumption is reduced, the voltage from the battery may rise. When the $\overline{BL2}$ signal is used as the Critical Suspend mode change signal, all wake-up sources can be detected and latched, but they will not cause a wake-up until the system is unlocked. Unlocking the system from Critical Suspend is a programmable function. The system is locked into Critical Suspend after a $\overline{BL2}$ signal is seen active until one of the following unlock sources happens:

- ACIN is seen active.
- $\overline{BL2}$ alone is seen inactive.
- Both $\overline{BL2}$ and $\overline{BL1}$ are inactive.

These unlock sources do not automatically cause a wake-up (unless programmed as wake-up sources). They only disable the lock circuit so a wake-up source can resume the system.

If the $\overline{BL2}$ signal is enabled to cause an SMI/NMI, the system will still enter Critical Suspend in 55 µs, and then service the SMI/NMI after the system wakes up.

When the system is active and the LCD is displaying data, the $\overline{BL2}$ force to Critical Suspend mode occurs without regard to normal LCD power sequencing. The $\overline{LVEE}$, $\overline{LVDD}$, and LCD signals do not sequence off as they normally do when going to Suspend. They all go inactive at approximately the same time. This is done so Critical Suspend mode is entered as quickly as possible.

A signal is available on the microcontroller to indicate when the microcontroller is locked into Critical Suspend mode by a $\overline{BL2}$: the $\overline{LBL2}$ signal (Latched $\overline{BL2}$). The $\overline{LBL2}$ signal goes Low during Critical Suspend mode and goes High again when the PMU leaves Critical Suspend.

A bit is available in the Battery/AC Pin Configuration Register (CSC index 70h[7]) to indicate to the system that it has been in Critical Suspend mode. This feature can be used by SMI/firmware/software to indicate the system has resumed from a Critical Suspend so that any problems this has caused can be fixed. For example, if a PC Card was being written and was powered down by the Suspend, the card can then be reconfigured and the write continued.

Figure 5-5 ACIN Mode Flow

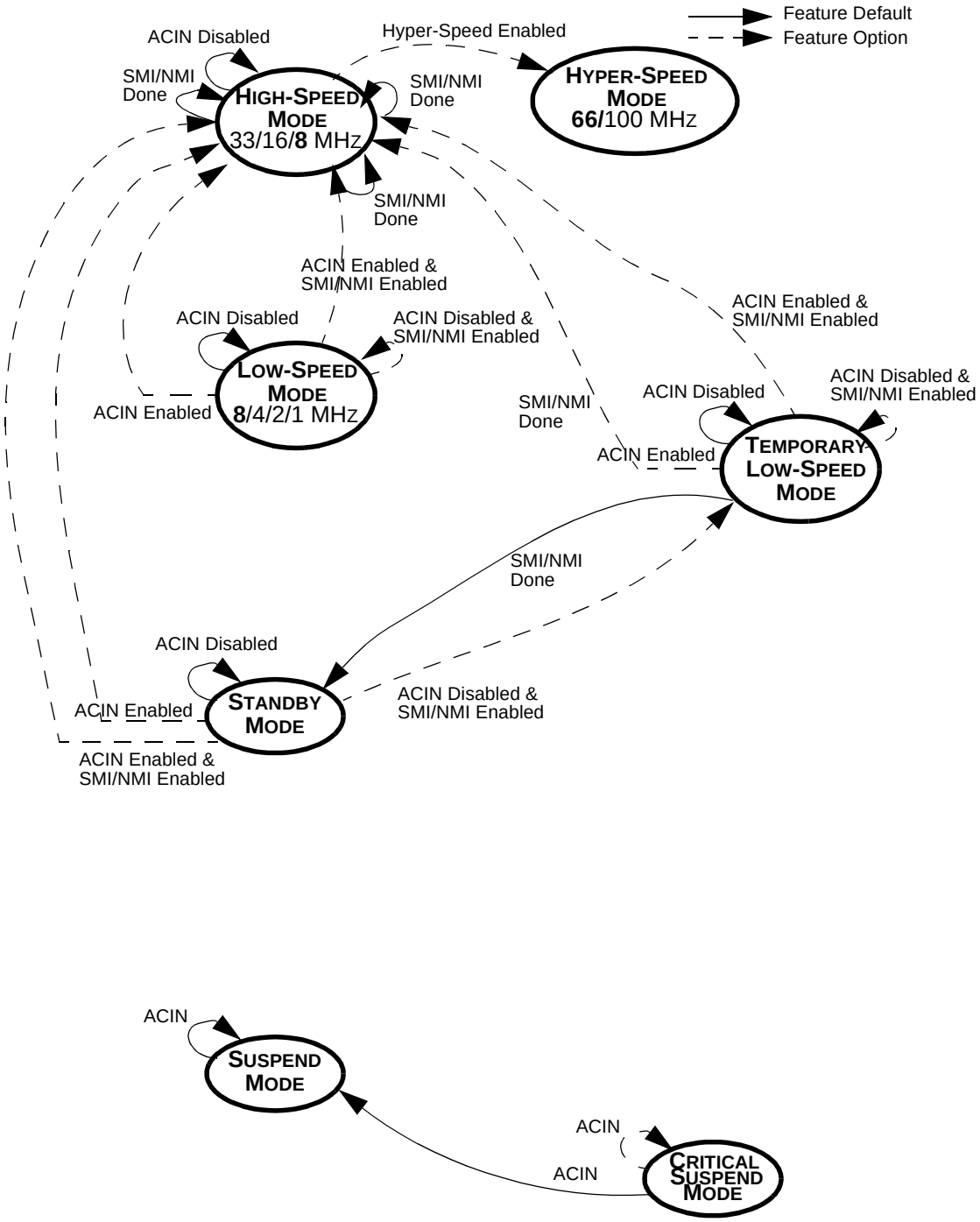


Figure 5-6 $\overline{BL1}$–$\overline{BL0}$ Mode Flow

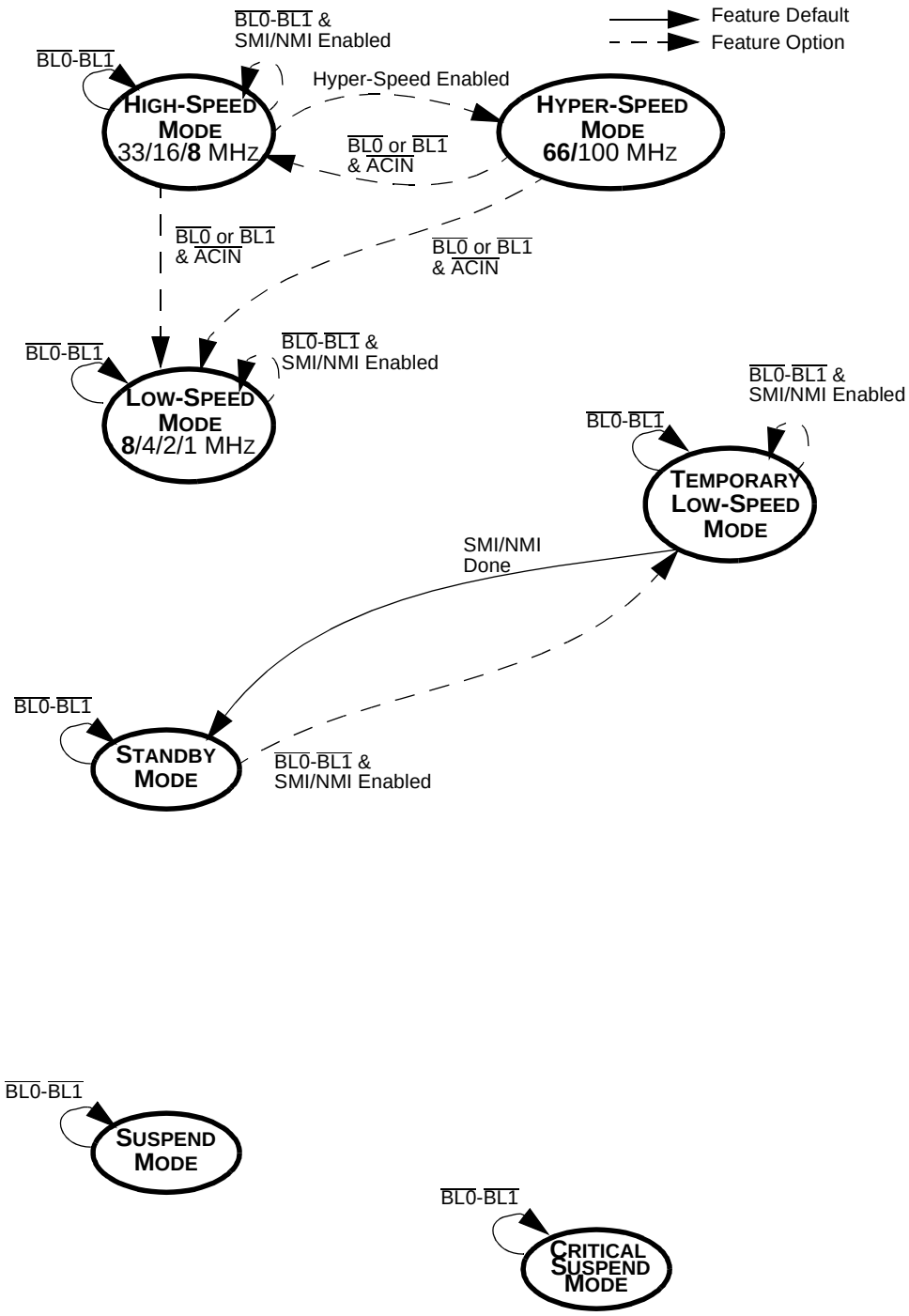
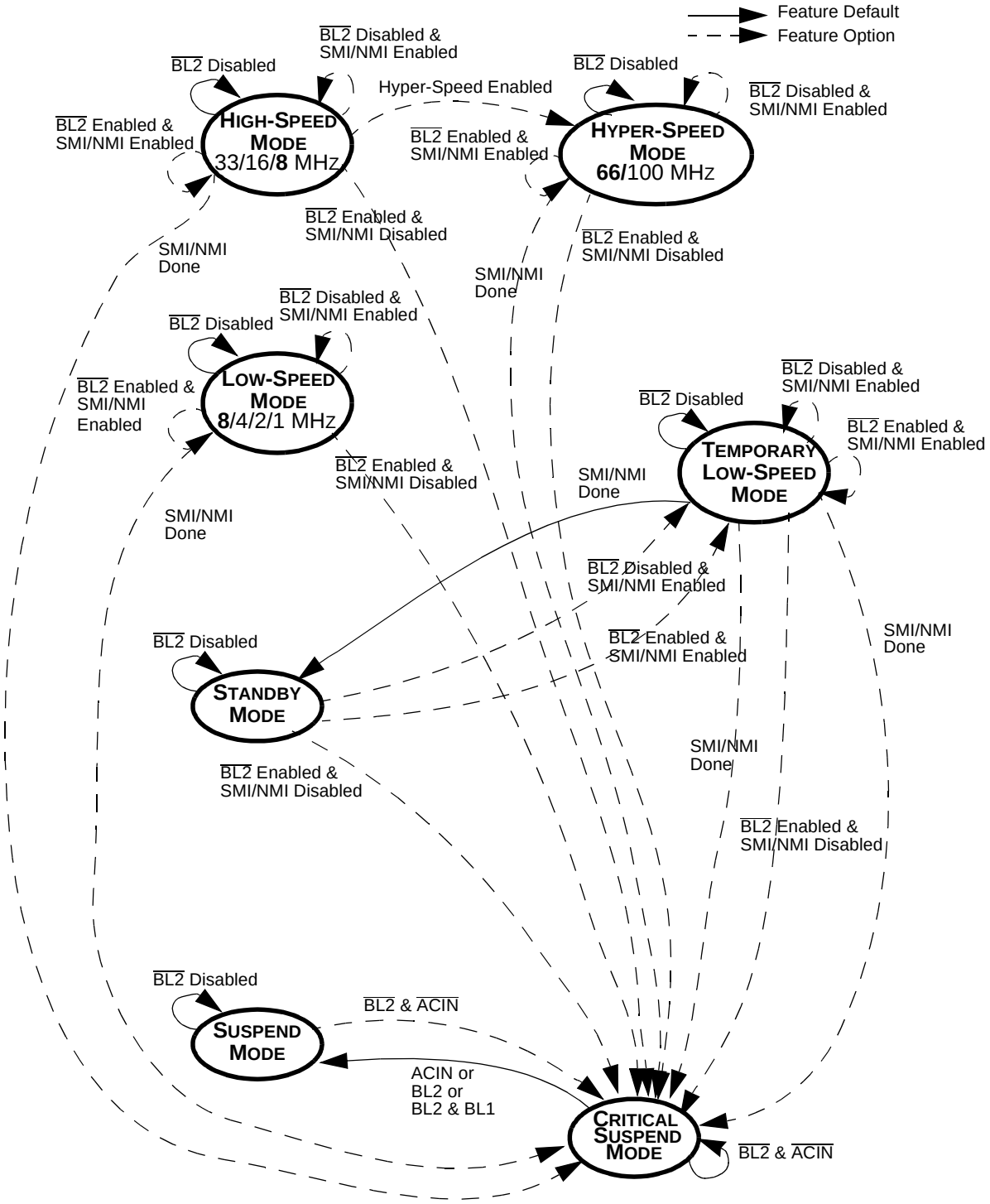


Figure 5-7 BL2 Mode Flow



5.4.12 SMI/NMI Generation

The System Management Mode (SMM) feature of the CPU works closely with power management. Using the System Management Interrupt (SMI) allows the CPU to pause its application code execution and manage the system power usage without affecting the application software. The code execution is effectively hidden from the application. With an SMI, the CPU state is automatically saved and Real mode is entered automatically. This is particularly important for Protected-mode operating systems that use Real-mode BIOS for handling power management functions. This interrupt is truly non-maskable; it is not part of the PC/AT architecture, so other programs will not interfere with the operation. It is also well suited for I/O trapping.

Non-Maskable Interrupts (NMIs) are useful in a closed system—one that runs only known software and does not have to hide the power management code from the application software. NMIs have the advantage of running faster than SMIs, because SMIs need to save the whole state of the CPU to RAM before executing and then restore the state when done. NMIs only save a limited state and there is less setup involved in using it so it is simpler to implement.

The power management unit, keyboard scan timer, 8042 emulation logic, and (on the ÉlanSC400 microcontroller) the PC Card controller are the only possible sources for the generation of an NMI to the internal CPU. There is also a master enable function provided which can inhibit any NMIs from reaching the CPU regardless of the state of the individual source enables. NMI can be enabled by writing a 0 to the most significant bit at I/O address 0070h. Port 0070h is a write-only register, and bits 0–6 function as the RTC index address port.

All the interrupts discussed here can be programmed to cause SMIs or NMIs, except the I/O trapping, which uses SMIs to service.

Interrupt flag registers are provided in the CSC indexed registers to determine the source of the SMI/NMI.

If an SMI/NMI occurs while the system is in Suspend mode, the interrupt will not wake up the system. Only wake-ups can do that. An exception to this is the Suspend Mode timer time-out. When this is enabled as an SMI/NMI, the system will go to Temporary Low-Speed mode to service the SMI/NMI.

Note: *This is the only SMI/NMI source that can be serviced while in Suspend.*

When an SMI/NMI is triggered in a Standby mode, the PMU will go to Temporary Low-Speed mode to service it. When an SMI/NMI is triggered by a timer time-out in High-Speed, Low-Speed, or Temporary Low-Speed modes, it is serviced in that mode before changing modes.

When exiting the SMI routine, any flag register that is still set will cause a new SMI and force the system back into the SMI routine.

When exiting the NMI routine, the NMI_DONE bit (CSC index 9Dh[1]) must be set to clear the NMI to the processor.

When an SMI/NMI source is asserted while enabled to cause an SMI/NMI, it generates an SMI/NMI.

Table 5-3 shows the SMI/NMI sources.

Table 5-3 SMI/NMI Sources

SMI/NMI Source	Description
ACIN signal	Rising or falling edge can cause interrupt
$\overline{BL2}$–$\overline{BL0}$ signals	A falling or rising edge on any of the $\overline{BL2}$–$\overline{BL0}$ signals can cause an interrupt
SUS_RES signal	Rising edge, falling edge, or both can cause an interrupt. Note that if the system is in Suspend mode and SUS_RES is not enabled for resume, the SMI/NMI will not occur.
Hyper-Speed mode, High-Speed mode, Low-Speed mode, Stand-By mode, and Suspend mode timers	These timer time-outs can cause interrupts
RTC alarm (IRQ8)	IRQ8 rising edge can cause an interrupt
UART ring indicate	Internal UART Ring Indicate ($\overline{RIN}$) signal falling edge can cause an interrupt
UART receive	Falling edge of internal UART receive (SIN) signal can cause an interrupt
Matrix keyboard key pressed	Internal keyboard controller key-pressed interrupt falling edge can cause an interrupt
Keyboard timer	Internal keyboard controller timer time-out can cause an interrupt
Keyboard input buffer written	Internal keyboard controller input buffer written can cause an interrupt
Keyboard output buffer read	Internal keyboard controller output buffer read can cause an interrupt
GPIO_CS14–GPIO_CS0 signals	Falling edge can cause SMI/NMI
PC Card Detect signals	Either edge of a Card Detect change can cause an SMI/NMI
PC Card INTR signal	Falling edge can cause an SMI/NMI
PC Card Ring Indicate signal	Falling edge can cause an SMI/NMI
Force SMI/NMI bits	Bits for software to force an SMI/NMI to occur
Peripheral I/O trapping	Causes an interrupt
Wake-up	Any wake-up can cause an SMI/NMI

5.4.12.1 I/O Access SMIs

Causing an SMI from the following I/O instruction cycles allows the SMI code to program the I/O Instruction Restart Slot Register in the CPU. This register causes the CPU to re-execute the I/O cycle that caused the SMI. This can be used to power up external devices for use, start up clocks, etc., before the device is actually accessed by the I/O cycle.

Table 5-4 shows the I/O trap sources.

Table 5-4 I/O Trap Sources

SMI/NMI Source	Description
Parallel port access	LPT1 (0378–037Fh) or LPT2 (0278–027Fh) can cause a trap
UART access	COM1 (03F8–03FFh) or COM2 0(2F8–02FFh) can cause a trap
Keyboard access	Reads and writes to ports 0060h and 0064h can cause a trap
GP_CSA–GP_CSB	Can cause a trap even when not programmed to come off the microcontroller at a pin
PC Card Socket A I/O access	Can cause a trap; the actual address range is programmed in the PC Card controller on the ÉlanSC400 microcontroller
PC Card Socket B I/O access	Can cause a trap; the actual address range is programmed in the PC Card controller on the ÉlanSC400 microcontroller
Graphics I/O access	I/O accesses to the graphics controller on the ÉlanSC400 microcontroller can cause a trap. This includes addresses: 03B4h, 03B5h, 03B8h, 03BAh, or 03D4h, 03D5h, 03D8–03DCh.
External VGA video I/O access	I/O access to addresses 03B4h, 03B5h, 03D4h, 03D5h, 03C0–03CAh, 03CCh, 03CEh, 03CFh, and/or 03DAh can cause a trap
IDE hard drive access	I/O accesses addressed to 01F0–01F7h, 03F6h, and/or 03F7h can cause a trap
Floppy controller access	I/O accesses addressed to 03F0–03F2h, 03F4h, 03F5h, and/or 03F7h can cause a trap

5.4.13 Activity Monitor

An activity monitor keeps track of activities that indicate the CPU or peripherals are needed or in use so the PMU can determine what mode and clock speed is needed. Activities reset timers and/or cause mode changes. The activity mode flow is diagrammed in Figure 5-8.

Two levels of activity are provided, primary and secondary activities.

- **Primary activities**—These activities require extensive CPU involvement and force the PMU back to High-Speed mode from Low-Speed or Standby modes.

  When a primary activity is received while in High-Speed mode, it resets the High-Speed time-out timer. Primary activities have no affect in Suspend mode. Suspend mode is exited using wake-ups instead of activities. When a primary activity is received in Temporary Low-Speed mode, it forces a switch to High-Speed mode unless Temporary Low-Speed was entered from Suspend. When Temporary Low-Speed is entered from Suspend, it is an extension of Suspend mode, so only a wake-up can cause a mode change (activities have no effect).

- **Secondary activities**—These activities require CPU involvement, but they do not need the highest performance in the system. Secondary activities are handled differently, depending on the state the PMU is in when the secondary activity is received.

  — In High-Speed or Hyper-Speed mode, secondary activities have no effect, since the CPU is already in the highest performing mode.

  — In Low-Speed mode, if the timer is enabled, a secondary activity causes the timer to be reset and to begin counting down.

  — In Standby mode, a secondary activity causes the PMU to switch to Temporary Low-Speed mode. Once the activity is complete, the Temporary Low-Speed timer begins counting down. On a timer time-out, the PMU returns to Standby mode. When another secondary activity comes before the timer times out, the PMU remains in Temporary

Low-Speed mode and begins the countdown from the start. When Temporary Low-Speed is entered from Suspend mode, secondary activities do not reset the Temporary Low-Speed timer.

— In Suspend or Critical Suspend modes, secondary activities have no effect.

When events can be programmed to be both activities and SMI/NMIs, the SMI/NMI will be generated and the mode will change during the SMI/NMI routine.

5.4.13.1 Using the Activity Source Flag Registers

The activity source flag registers are read to determine what caused an activity. Write to '1' has no effect, write to '0' to clear. If an activity source is asserted when enabled as an activity, it generates an activity. The activity sources are listed in Table 5-5.

Note: *When an activity occurs in Suspend mode, it sets the flag register.*

Primary activities occurring in Hyper-Speed, High-Speed, or Suspend/Critical Suspend mode do not incur a mode change, but set the status bit for that activity. If the primary activity occurs in Hyper-Speed or High-Speed PMU modes, the respective mode timers are reset. If the primary activity occurs in Suspend/Critical Suspend mode, the Hyper-Speed/High-Speed mode time-out is increased by 60 µs upon wake up.

If a secondary activity occurs in any mode except Standby, the associated status bit is set. However, the activity is not latched until Temporary Low-Speed or Low-Speed mode is entered. The secondary activity event (but not the status bit) is cleared in High-Speed or Hyper-Speed mode.

It is possible to configure the microcontroller to allow a secondary activity that occurs while in Low-Speed mode to reset the Low-Speed mode timer (CSC index 40h[7]).

Also note that if an event is active when it is enabled as an activity, that activity will be detected by the PMU, and the status bit for this activity will be set. For this reason, it is recommended that the associated status bit be cleared immediately following an activity being enabled. PMU activity status bits are undefined when the associated event is not enabled as an activity.

Figure 5-8 PMU Activity Mode Flow

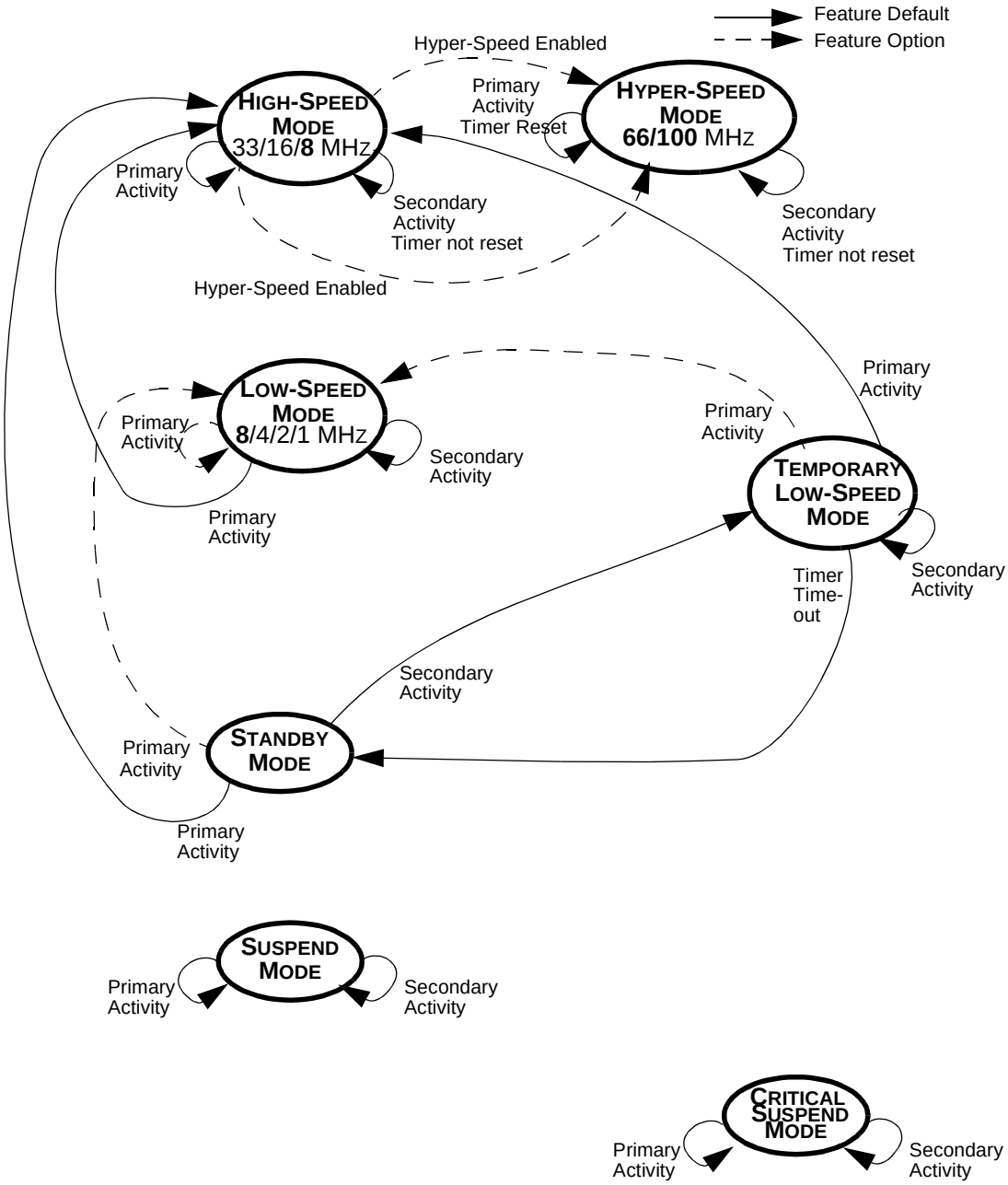


Table 5-5 Activity Sources

Activity	Enable (CSC index)	Primary or Secondary	Trigger State
ACIN signal	64h	Programmable	Rising edge of the ACIN signal
CPU access to internal system registers	65h	Programmable	Falling edge of address decodes qualified with command
Any VL-bus activity (memory or I/O)	62h	Programmable	Rising edge of the internal signal that decodes a VL-bus cycle
CPU access to $\overline{\text{ROMCS2}}$–$\overline{\text{ROMCS0}}$	62h	Programmable	Falling edge of chip select qualified with command
CPU access to DRAM not in graphics controller range	63h	Programmable	When the DRAM_IS_ACT bit (CSC index 63h[1]) is asserted (rising edge)
DMA request	64h	Programmable	Rising edge of qualified PDRQ1–PDRQ0 (the pin must be programmed as a PDRQ and assigned to a DMA channel that must be unmasked in the DMA controller
Interrupt active (all except IRQ0 timer tick)	63h	Programmable	Rising edge of any of the IRQs coming to the PMU
Timer tick (IRQ0)	63h	Programmable	Rising edge of IRQ0
CPU access to parallel port	65h	Programmable	Falling edge of address decode qualified with command
CPU access to UART, internal or external	62h	Programmable	Falling edge of address decode qualified with commands
UART ring indicate	64h	Programmable	Falling edge of $\overline{\text{RIN}}$ pin
UART receive	64h	Programmable	Falling edge of SIN pin
Matrix keyboard key press	63h	Programmable	Falling edge of internal keyboard key-pressed interrupt
Keyboard timer time-out	63h	Programmable	The keyboard timer interrupt
CPU access to internal keyboard (ports 60h and 64h)	63h	Programmable	Falling edge of internal keyboard chip select
GPIO_CS14–GPIO_CS0	A0–A3h	Primary	Falling edge of the signal
GP_CSA–GP_CSD I/O and memory signals		Programmable	Falling edge of the signal qualified with the correct command
CPU access to PC Card Socket A and B memory	65h	Programmable	Falling edge of address decode qualified with command
CPU access to PC Card Socket A and B I/O	65h	Programmable	Falling edge of address decode qualified with command
PC Card Ring Indicate signal	65h	Programmable	Falling edge of the PC Card Ring Indicate signal
PC Card INTR signal	65h	Programmable	Falling edge of the PC Card INTR signal
CPU access to graphics controller I/O	62h	Programmable	Falling edge of I/O chip selects qualified with command
CPU access to DRAM within graphics controller memory range	62h	Programmable	When the VID_DRAM bit in graphics index 4Fh is asserted (rising edge) and the CPU accesses DRAM within graphics memory space
CPU access to external VGA video controller I/O	64h	Programmable	Falling edge of address decode qualified with command
CPU access to external VGA video controller memory	64h	Programmable	Falling edge of address decode qualified with command
CPU access to floppy controller	64h	Programmable	Falling edge of address decode qualified with command
CPU access to IDE hard drive	64h	Programmable	Falling edge of address decode qualified with command

5.4.14 State Options in PMU Modes

5.4.14.1 Suspend State Options

The ÉlanSC400 and ÉlanSC410 microcontrollers allow external board components to be left either powered in Suspend mode or powered off. When an external component is left powered, its inputs should not toggle or else power will be wasted. The interface signals are held in an inactive state. When the external component is to be powered off in Suspend mode, the interface signals are held Low. Any signal that is left High tries to power the device through an I/O pin, resulting in possible damage. Three registers (CSC index E3–E5h) allow each interface group of pins to be individually programmed to a specific state in Suspend mode and allow for the overriding of pull-ups and pull-downs. Power-down groups for each pin are listed in the *Élan™SC400 and ÉlanSC410 Microcontrollers Data Sheet* (order #21028).

5.4.14.2 Programmable Pull-Up and Pull-Down Options

The GPIO and GPIO_CS pins all have default termination. Four registers (CSC index 3B–3Eh) are used to enable or disable the default pull-up or pull-down resistors. Any time the termination configuration is changed, the TERM_LATCH bit (CSC index E5h[0]) must be set to enable the current configuration. See Section 2.4.2 and Appendix B for more information on pin termination.

5.5 INITIALIZATION

The power management unit is enabled at power-on reset. The default mode is High-Speed mode at an 8-MHz CPU clock.

CHAPTER

6 CLOCK CONTROL

6.1 OVERVIEW

To support power management features, the internal cores of the ÉlanSC400 and ÉlanSC410 microcontrollers operate over a range of frequencies. The PMU determines the optimal clock speed, based on current system activities and programmable register values. The ÉlanSC400 and ÉlanSC410 microcontrollers require only one 32.768-KHz crystal to generate all the other clock frequencies required by the system. The output of the on-chip crystal oscillator circuit is used to generate the various frequencies by utilizing four Phase-Locked Loop (PLL) circuits. An additional PLL in the CPU is used for Hyper-Speed mode.

6.2 REGISTERS

A summary listing of the chip setup and control (CSC) and graphics index registers used to control the clocks on the ÉlanSC400 and ÉlanSC410 microcontrollers is shown in Table 6-1. Complete descriptions for all registers can be found in the *Élan™ SC400 Microcontroller Register Set Reference Manual* (order #21032).

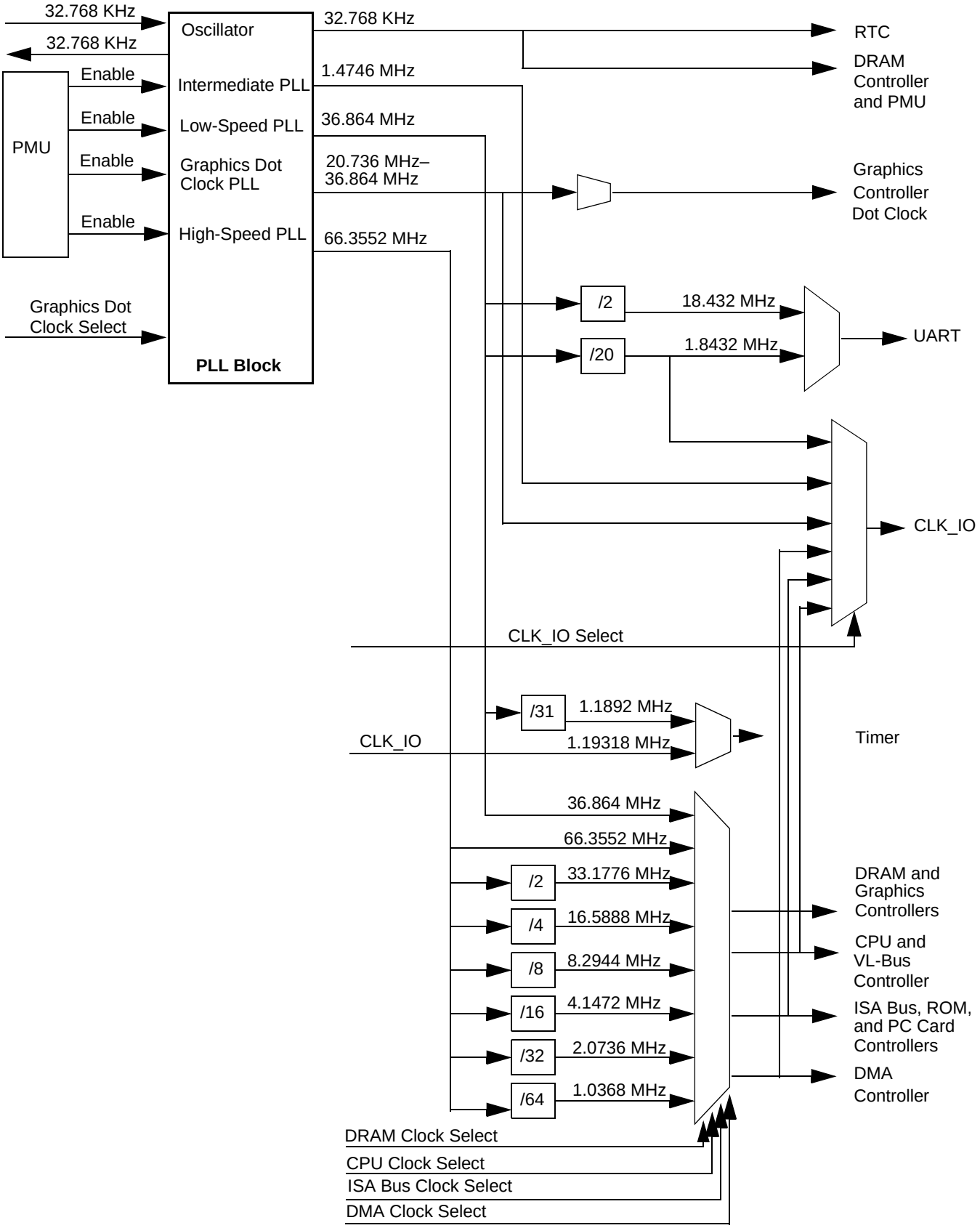
Table 6-1 Clocking Register Summary

Register	I/O Address	Clock Function Keyword	Description in Register Set Manual
Chip Setup and Control (CSC) Index Registers			
CPU Clock Speed Register	22h/23h Index 80h	CPU clock speeds in Hyper-, High-, and Low-Speed modes; present speed of CPU clock	page 3-87
CPU Clock Auto Slowdown Register	22h/23h Index 81h	Fast clock duration in High-Speed mode, slow clock duration in Low-Speed mode, auto slowdown	page 3-88
Clock Control Register	22h/23h Index 82h	PLL enable, restart delay time, 32-KHz clock state, DMA clock frequency	page 3-90
CLK_IO Pin Output Clock Select Register	22h/23h Index 83h	CLK_IO pin clock source	page 3-91
PC Card Mode and DMA Control Register	22h/23h Index F1h	Clock speed for PC Card controller	page 3-198
Graphics Index Registers			
Pixel Clock Control Register	3x4h/3x5h Index 4Ch	Graphics dot clock base frequency and divide select	page 5-36

6.3 BLOCK DIAGRAM

Figure 6-1 shows a high-level block diagram of the clock sources on the ÉlanSC400 and ÉlanSC410 microcontrollers and how the clocks are generated. is the definitive information source for what clock speeds are supported in each peripheral core.

Figure 6-1 Clock Source Block Diagram



Note: *The graphics controller and the PC Card controller are not supported on the ÉlanSC410 microcontroller.*

6.4 OPERATION

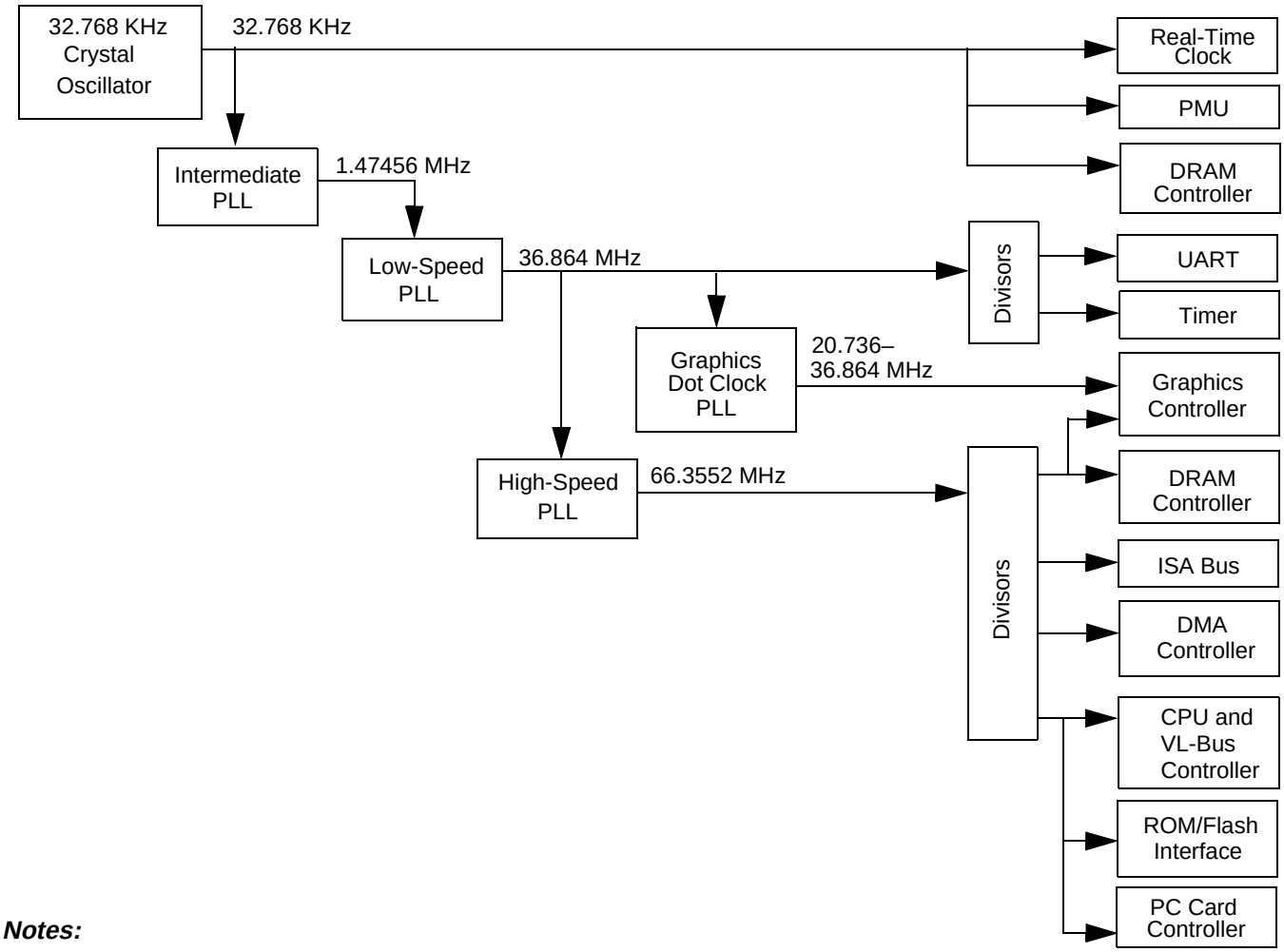
6.4.1 Clock Generation

The output of the crystal oscillator circuit on the ÉlanSC400 microcontroller generates the various clock frequencies by utilizing four Phase-Locked Loop (PLL) circuits. (Only three of these PLL circuits are available on the ÉlanSC410 microcontroller.) The PLL clock distribution scheme is shown in Figure 6-2. Table 6-2 shows all the PLL output frequencies and their usage. (Note that these PLL circuits are in addition to the internal CPU-core PLL and do not replace it.)

The four PLLs are called Intermediate PLL, Low-Speed PLL, High-Speed PLL, and Graphics Dot Clock PLL. (The Graphics Dot Clock PLL is not available on the ÉlanSC410 microcontroller.) Each of the integrated phase-locked loops has a dedicated pin to support the required external loop filter. These pins are: LF_INT (Intermediate PLL), LF_LS (Low-Speed PLL), LF_HS (High-Speed PLL), and LF_VID (Graphics Dot Clock PLL). Two capacitors and one resistor are required to implement each loop filter. The LF_VID pin is not supported on the ÉlanSC410 microcontroller.

The crystal oscillator needs two pins, but it does not require any external components except the crystal; the load capacitors and the feedback resistor are integrated on-chip.

Figure 6-2 Clock Generation



Notes:

On the ÉlanSC400 microcontroller, the graphics controller's DRAM interface is clocked by the 66 MHz DRAM clock.

Both the ROM/Flash interface and the PC Card controller are clocked from the CPU clock. They also have the option of being run from the slow system clock.

Neither the graphics controller nor the PC Card controller are supported on the ÉlanSC410 microcontroller.

Table 6-2 Integrated Peripheral Clock Sources

Source PLL	Divider	Resultant Frequency	Where Used
Intermediate PLL 1.4746 MHz	1	1.4746 MHz	Low-Speed PLL input
Low-Speed PLL 36.864 MHz	1	36.864 MHz	High-Speed PLL input Graphics Dot PLL input
	20	1.8432 MHz	UART
	2	18.4328 MHz	UART
	31	1.1892 MHz	PIT
Graphics Dot Clock PLL 36.864 MHz	Programmable	20.736–36.864 MHz	Graphics controller dot clock
	1	36.864 MHz	DRAM controller Graphics controller
High-Speed PLL 66.3532 MHz	1	66.3532 MHz	DRAM controller Graphics controller
	2	33.1776 MHz	CPU VL-bus controller
	4	16.5888 MHz	CPU VL-bus controller DMA controller
	8	8.2944 MHz	CPU VL-bus controller ISA bus controller ROM/Flash interface DMA controller PC Card controller
	16	4.1472 MHz	CPU VL-bus controller ISA bus controller ROM/Flash interface DMA controller PC Card controller
	32	2.0736 MHz	CPU VL-bus controller ISA bus controller ROM/Flash interface DMA controller PC Card controller
	64	1.0368 MHz	CPU VL-bus controller ISA bus controller ROM/Flash interface DMA controller PC Card controller

6.4.1.1 32-KHz Crystal Oscillator

The 32-KHz oscillator circuit is shown in Figure 6-3 and Figure 6-4; the only external component required for operation is a 32.768-KHz crystal. The inverting amplifier (AMP) is integrated on-chip with the feedback resistor and the load capacitors. The on-chip oscillator circuit can be bypassed by removing the external crystal, grounding the 32KXTAL1 pin, and driving the 32KXTAL2 pin with an external 32-KHz clock. When 32KXTAL1 is grounded, the amplifier no longer affects the circuit.

Figure 6-3 32-KHz Crystal Circuit

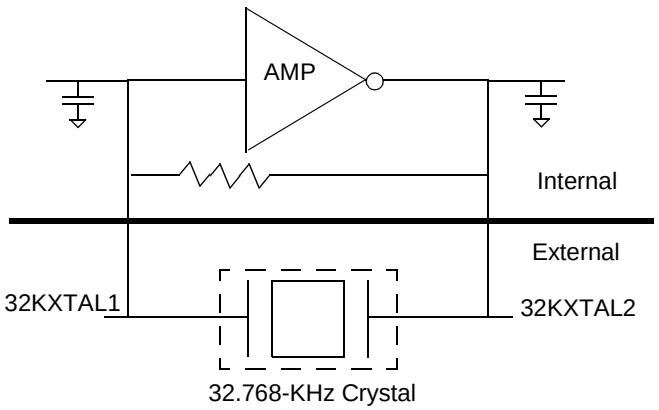
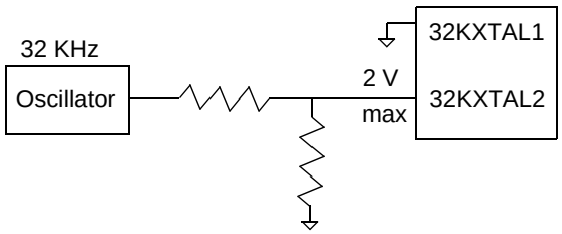


Figure 6-4 32-KHz Oscillator Circuit



6.4.1.2 Intermediate and Low-Speed PLLs

Figure 6-5 shows the block diagram for both the Intermediate and Low-Speed PLLs. Each consists of a phase detector, a charge-pump, a voltage controlled oscillator (VCO), an external loop filter, and a feedback divider. This is a generic implementation of the charge-pump PLL architecture; all four PLLs use the same architecture. The Intermediate and Low-Speed PLLs differ only in component values and frequency of operation.

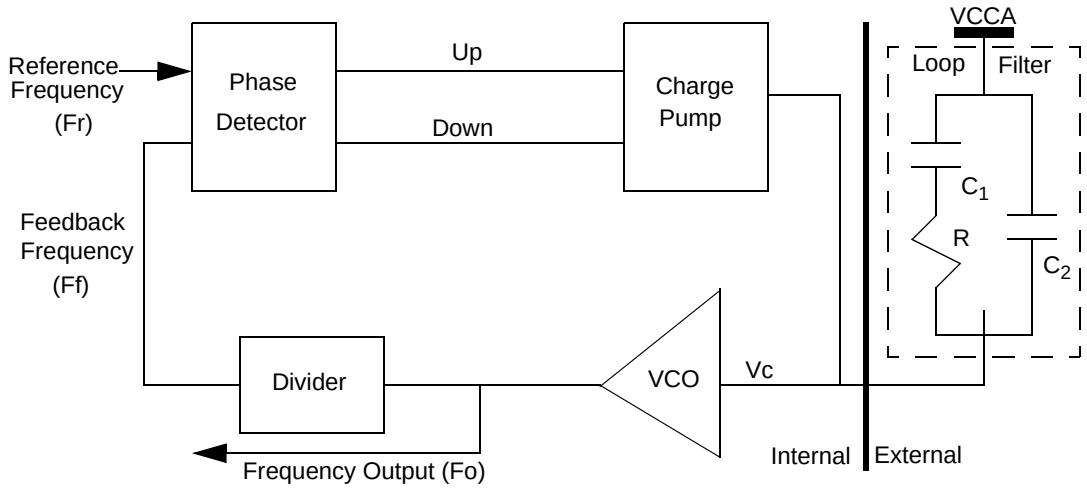
The phase detector compares the phase and frequency of the two clock signals, reference frequency (Fr) and feedback frequency (Ff). The Up signal is a logic one if Fr leads Ff, while the Down signal is a logic one if Ff leads Fr. The Up and Down signals control the charge pump. The charge pump either charges or discharges the loop filter capacitors to change the VCO input voltage level. Since the VCO output frequency tracks the VCO input voltage, the VCO output frequency is adjusted whenever Fr and Ff differ in phase or frequency.

The feedback divide ratio determines the frequency multiplication factor. Frequency multiplication is 1/(Feedback Divider).

For the Intermediate PLL, the feedback divider is 1/45; therefore, the frequency multiplication is 45. With an input frequency of 32.768 KHz, the output frequency is 1.47456 MHz.

The input clock for the Low-Speed PLL, Fr, originates at the Intermediate PLL output. It is multiplied by 25 to generate the 36.864-MHz clock output.

Figure 6-5 Intermediate and Low-Speed PLLs Block Diagram



6.4.1.3 Graphics Dot Clock PLL

The input clock to the Graphics Dot Clock PLL is the output clock (36.864 MHz) of the Low-Speed PLL divided by 16.The output frequency is programmable using three CSC indexed register bits (PLLRATIO[2–0]) in the range of 20.736 MHz to 36.864 MHz (spaced 2.304 MHz apart). These three bits in the Pixel Clock Control Register (graphics index 4Ch) control the output frequency by selecting the divide value in the feedback divider as shown in Table 6-3.

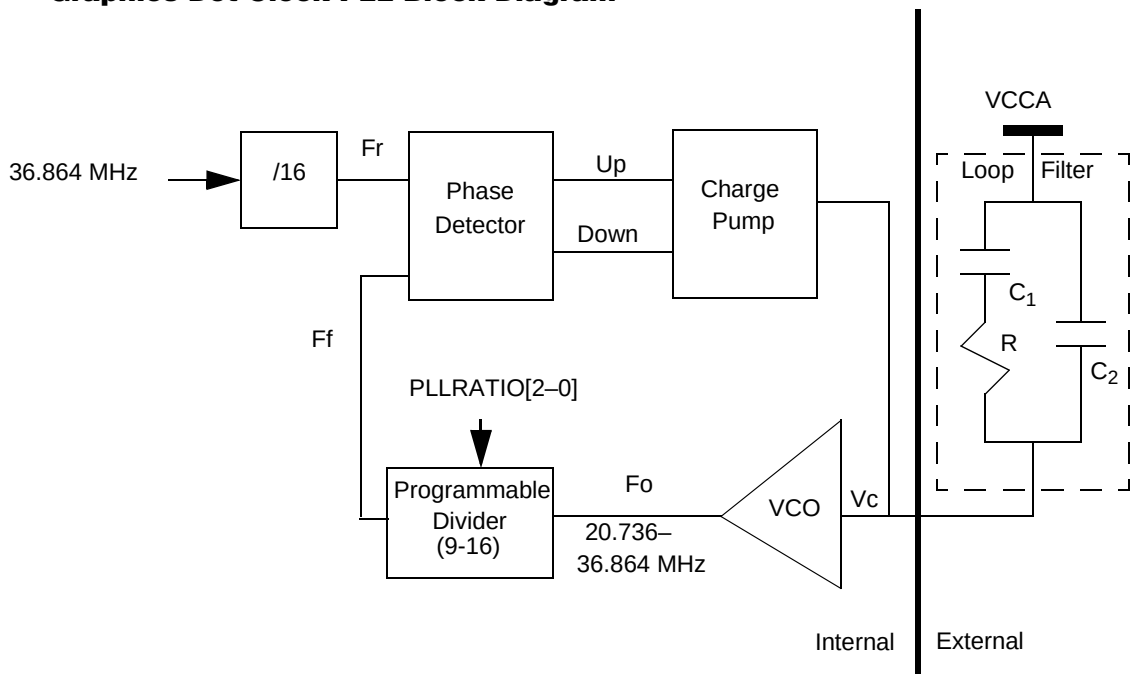
The Graphics Dot Clock PLL requires a stabilization period after changing frequency. Figure 6-6 shows the block diagram for the Graphics Dot Clock PLL.

The Graphics Dot Clock PLL is not available on the ÉlanSC410 microcontroller.

Table 6-3 Frequency Selection Control for Graphics Dot Clock PLL

PLLRATIO[2–0]	Divider	Output Frequency
000	9	20.736 MHz
001	10	23.04 MHz
010	11	25.344 MHz
011	12	27.648 MHz
100	13	29.952 MHz
101	14	32.256 MHz
110	15	34.56 MHz
111	16	36.864 MHz

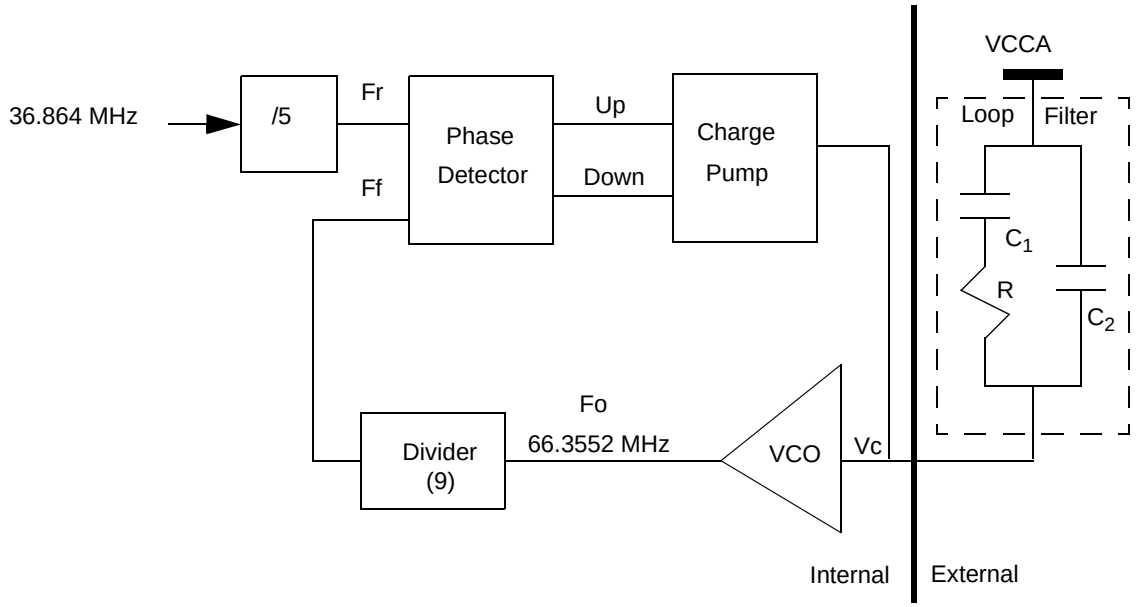
Figure 6-6 Graphics Dot Clock PLL Block Diagram



6.4.1.4 High-Speed PLL

The High-Speed PLL generates a 66.3552-MHz clock for the DRAM controller. Figure 6-7 shows the block diagram for the High-Speed PLL. The input to the High-Speed PLL is the output of the Low-Speed PLL divided by 5. The feedback divider is 9, which results in a output frequency (Fo) of 66.3552 MHz. This frequency is divided by two in the PMU to provide the 33-MHz input for the PLL in the CPU core.

Figure 6-7 High-Speed PLL Block Diagram



6.4.2 Clock Control

Several of the core clocks on the ÉlanSC400 and ÉlanSC410 microcontrollers are programmable. This programmability is either directly controlled by system firmware or is forced due to a power-management mode change. Table 6-4 shows the speeds for each clock, and Table 6-5 shows bus cycle clock speeds for the ÉlanSC400 and ÉlanSC410 microcontrollers.

6.4.2.1 CPU 1x Clock

The speed of the CPU's static clock is programmable based on:

- PMU mode—Programmable values for High- and Low-Speed modes, stopped for Standby and Suspend modes, 33 MHz for Hyper-Speed mode.
- CPU Clock Speed Register settings—Program the clock value used in High- and Low-Speed modes.
- Auto Slowdown enabled—Changes the CPU clock speed based on the programmed duty cycle when the PMU is in High- and Hyper-Speed modes.

The CPU is put in hold before changing this clock.

6.4.2.2 Memory Clock

This clock is used by the DRAM controller to time the cycles to the DRAM. The clock is either 66 MHz (when the LCD graphics controller on the ÉlanSC400 microcontroller is enabled and displaying as indicated by the $\overline{\text{LVDD}}$ signal) or it is 2x the CPU clock when the LCD controller is not displaying data. The speed is selected by $\overline{\text{LVDD}}$, the PMU mode, and the CPU clock speed selected.

6.4.2.3 Timer Clock

This clock is used by the Programmable Interval Timer (PIT). The clock is either the Low-Speed PLL output divided by 31, or it is an external oscillator brought in on the CLK_IO pin. This option defaults to using the internal PLL for the timer clock; if the pin multiplexing registers select CLK_IO to be active as an input, then the PIT gets its clock from this input.

6.4.2.4 UART Clock

This clock is used by the UART. It operates at either 1.8432 MHz for standard UART interfaces, or 18.432 MHz to support the serial infrared 1-Mbit/s transfer frequency. The UART clock is stopped in Suspend mode or when the UART is disabled (CSC index D1h[0]). The clock is changed based on the indication that the infrared interface needs High-Speed Infrared mode and that the UART is in use.

6.4.2.5 System Clock

This clock is used by the ISA bus controller, the PC Card controller, internal ISA cycles, and PC Card cycles at ISA speeds.

The system clock is a maximum of 8.29 MHz and will be 4, 2, or 1 MHz, depending on the CPU clock frequency. This clock is controlled by the PMU mode and the CPU clock frequency.

6.4.2.6 RTC Clock

Used by many cores, this clock is the 32.768 KHz generated by the internal oscillator. it is always available.

6.4.2.7 DMA Clock

This clock is used by the ISA bus controller and the DMA controller. The DMA clock is controlled by CSC index 82h.

Table 6-4 Clock Speeds

Clock	Programmable Speed	Comments
CPU 1x clock	33.18 MHz/16.59 MHz/8.29 MHz Default: 8.29 MHz on reset	Programmable to one speed at a time for High-Speed mode 33.18 MHz for Hyper-Speed mode; clock multiplied by the CPU-core PLL to be 66 MHz or 100 MHz to the CPU only
	8.29 MHz/4.15 MHz/2.07 MHz/1.04 MHz Default: 8.29 MHz on reset	Programmable to one speed at a time for Low-Speed and Temporary Low-Speed modes
	0 MHz	Clock is stopped in Standby and Suspend modes
Memory clock	66 MHz	Clocked at 66 MHz whenever the graphics controller on the ÉlanSC400 microcontroller is enabled and displaying data to the LCD. The graphics controller uses the main DRAM as its memory and must access it at 66 MHz whenever data is being displayed to the LCD.
	2x CPU clock rate	Clocked at the 2x CPU clock rate whenever the graphics controller is not displaying data to the LCD
	36.864 MHz	Clocked from the Low-Speed PLL in Standby mode when this feature is enabled and the LCD is enabled
	0 MHz	Clock is stopped when no DRAM accesses are occurring, such as in Suspend mode or Standby mode when the LCD is shut off. DRAM refreshes will continue under the control of the 32-KHz clock.
Graphics dot clock	20.736 MHz to 36.864 MHz	Speed required is selected by the graphics controller, depending on the LCD to be driven and graphics mode selected
	0 MHz	Clock is stopped in modes in which LCD is not displaying data
Timer clock	1.1892 MHz	PC/AT standard is 1.19318 MHz; speed on the ÉlanSC400 and ÉlanSC410 microcontrollers is 1.1892 MHz
	Clocked from CLK_IO pin	For designs that need exact timer counts, the CLK_IO pin can be driven with the PC/AT standard clock from an external oscillator
	0 MHz	Clock is stopped in Suspend mode, because it does not need the timer active
UART clock	1.8432 MHz or 18.432 MHz	Programmable to use either speed, can be changed at any time. 1.8432 MHz is standard PC/AT, 18.432 MHz is support for 1-Mbit/s serial infrared
	0 MHz	Clock is stopped in Suspend mode or when the UART is disabled via CSC index D1h[0]
System clock	8.29 MHz/4.15 MHz/2.07 MHz/1.04 MHz	8 MHz in High-Speed mode, equals the CPU clock in Low-Speed and Temporary Low-Speed modes
	0 MHz	Clock stopped in Standby and Suspend modes

Table 6-4 Clock Speeds (continued)

Clock	Programmable Speed	Comments
RTC clock	32 KHz	Always runs as long as there is power
PMU clock	32 KHz	Always runs as long as there is power
DMA clock	16.59 MHz/8.29 MHz/4.15 MHz/2.07 MHz/1.04 MHz	Follows CPU clock when it is operating
	0 MHz	Clock stopped when DMA is disabled or not in use
High-Speed PLL	66 MHz	Runs in all modes except Critical Suspend. Programmable to be shut off in Standby and Suspend modes.
Low-Speed and Intermediate PLL	36.864 MHz/1.4746 MHz	Runs in all modes except Critical Suspend. Programmable to be shut off in Suspend mode.
Graphics Dot Clock PLL	20.736 MHz-36.864 MHz	Runs in all modes except Critical Suspend. Programmable to be shut off in Suspend mode. Only runs when internal graphics controller on the ÉlanSC400 microcontroller is enabled.

Table 6-5 Bus Cycle Clock Speeds

Clock	Mode	MHz	MHz	MHz	MHz	MHz	MHz	MHz
CPU		33 (66)	16	8	4	2	1	0
VL-Bus		33	16	8	4	2	1	0
DRAM	LCD	66	66	66	66	66	66	0
	LCD (Standby)	66	66	66	66	66	66	36
	No LCD	66	33	16	8	4	2	0
ISA		8	8	8	4	2	1	0
DMA	Programmable Option	16	16	8	4	2	1	0
		8	8	4	4	2	1	0
		4	4	4	4	2	1	0
ROM and Internal Registers	Programmable Option	33	16	8	4	2	1	0
		8	8	8	4	2	1	0
PC Card	Programmable Option	33	16	8	4	2	1	0
		8	8	8	4	2	1	0

6.5 INITIALIZATION

The CPU Clock Speed Register (CSC index 80h) controls CPU clock speed in Hyper-Speed, High-Speed, and Low-Speed PMU modes. The Clock Control Register (CSC index 82h) controls the DMA clock frequency, the internal CPU PLL restart delay time, and the microcontroller-specific PLLs.

Note: *If the graphics controller on the ÉlanSC400 microcontroller is enabled, the memory (DRAM) clock is always 66 MHz. If the graphics controller is not enabled, the memory clock is always 2x the CPU clock. On the ÉlanSC410 microcontroller, the memory clock is always 2x the CPU clock.*

6.6 POWER MANAGEMENT

The PMU controls the clock generation circuitry to change the clocks the other cores receive. Table 6-6 shows the clock speeds for each PMU mode.

The CPU clock is programmable to run at 33.18 MHz to 1.04 MHz in High-Speed and Low-Speed modes, and at 33.18 MHz for Hyper-Speed mode (the 33 MHz is multiplied up by the CPU-core PLL to 66 MHz or 100 MHz). When the CPU clock is at 33, 16, or 8 MHz, the system clock used for ISA access will occur using the 8.29 MHz clock. When the CPU clock is below 8 MHz (4, 2, or 1 MHz), the clock for ISA access will occur using the same clock speed (4, 2, or 1 MHz).

The automatic slowdown feature is another way to fine tune the system by giving up some performance for lower power. When enabled via CSC index 81h, the automatic slowdown feature will cause the CPU clock to switch between two clock speeds at a programmed duty cycle. Although this will impact system performance, it is a way to fine-tune the power requirements of the system. Caution should be taken when using this feature while DMA transfers are active.

Auto slowdown also provides thermal protection, should this become necessary. Occasionally slowing down the CPU clock reduces the CPU's heat. This feature is effective when the PMU is in Hyper- or High-Speed modes.

- When Hyper-Speed mode is enabled and entered, the PMU will switch to using the High-Speed mode CPU clock speed.
- When Hyper-Speed mode is disabled, the PMU will switch between High- and Low-Speed CPU clock speeds.

If the High-Speed CPU clock is programmed to 8.29 MHz, the system should be programmed to use the Low-Speed CPU clock at less than 8.29 MHz. Otherwise this will not have any power saving affect, but it will have a performance affect, because the CPU will be put in hold occasionally to switch the clock.

Note that the automatic slowdown feature does not actually change the PMU's mode; it simply changes the CPU clock speed.

The CPU clock speeds can be changed from any mode; speed switching is done without violating the clock specifications. For example, when in High-Speed mode the CPU clock can be changed between 33 MHz, 16 MHz, and 8 MHz without exiting to Low-Speed mode to program the new speed.

The High-Speed PLL can be disabled in Standby mode for additional power savings. Note that it will take on the order of 200 µsec to get it started back up. In Standby Mode if the graphics controller on the ÉlanSC400 microcontroller is displaying data, the memory controller will operate off of the Low Speed PLL clock, 36 MHz (regardless of the High-Speed PLL enable.

Table 6-6 Clock Speed Per PMU Mode

Clock	Hyper-Speed	High-Speed	Low-Speed	Standby	Temporary Low-Speed	Suspend
CPU 1x Clock	33 MHz	33 MHz–8 MHz	8 MHz–1 MHz	DC	8 MHz–1 MHz	DC
Memory Clock	On	On	On	On/DC[1]	On	DC
System Clock	8.29 MHz	8.29 MHz	8 MHz–1 MHz	DC	8 MHz–1 MHz	DC
Graphics Dot Clock[4]	On	On	On	On/DC[2]	On/DC[2]	DC
PMU Clock	32 KHz	32 KHz	32 KHz	32 KHz	32 KHz	32 KHz
Timer Clock	On	On	On	On	On	DC
RTC Clock	32 KHz	32 KHz	32 KHz	32 KHz	32 KHz	32 KHz
UART CLock[3]	On/DC	On/DC	On/DC	On/DC	On/DC	DC
High-Speed PLL	On	On	On	On/DC	On	On/DC
Low-Speed and Intermediate PLL	On	On	On	On	On	On/DC
Graphics Dot Clock PLL[4]	On/DC	On/DC	On/DC	On/DC	On/DC	On/DC

Notes:

1. *The Memory clock is stopped in Standby mode if the graphics controller on the ÉlanSC400 microcontroller is disabled or the LCD is not refreshed.*
2. *Graphics on the ÉlanSC400 microcontroller is programmable to shut down in standby mode. If Temporary Low-Speed mode is entered from Standby mode, the graphics dot and memory clocks may or may not be enabled.*
3. *The UART clock is stopped in Suspend mode or when the UART is disabled via CSC index D1h[0].*
4. *The graphics dot clock and the Graphics Dot Clock PLL are not supported on the ÉlanSC410 microcontroller.*

CHAPTER

7 MEMORY MANAGEMENT

7.1 OVERVIEW

The ÉlanSC400 and ÉlanSC410 microcontrollers contain a sophisticated memory management unit (MMU). This MMU makes achieving memory-mapped PC/AT compatibility and 82365 compatibility quite easy for the designer. However, if the designer wants to do something different, there is a lot of information to be learned about the MMU. The purpose of this chapter is to explain what the MMU is capable of and how it can be programmed to achieve the designer's goals.

7.2 REGISTERS

A summary listing of the chip setup and control (CSC) registers used to control the MMU windows on the ÉlanSC400 and ÉlanSC410 microcontrollers is shown in Table 7-1. Registers used to configure the address spaces for DRAM (Chapter 9), ROM (Chapter 8), PC Card (Chapter 19), and ISA (Chapter 4) are summarized in the chapters devoted to each block.

Complete register descriptions can be found in the *Élan™SC400 Microcontroller Register Set Reference Manual* (order #21032).

Table 7-1 Memory Management Unit Register Summary

Register	I/O Address	MMU Function Keyword	Description in Register Set Manual
Non-Cacheable Window 0 Address Register	22h/23h Index 10h	Start address bits SA23–SA16 for Non-Cacheable Window 0	page 3-19
Non-Cacheable Window 0 Address/Attributes/SMM Register	22h/23h Index 11h	Start address bits SA25–SA24 and controls window size and SMM caching	page 3-20
Non-Cacheable Window 1 Address Register	22h/23h Index 12h	Start address bits SA23–SA16 for Non-Cacheable Window 1	page 3-21
Non-Cacheable Window 1 Address/Attributes Register	22h/23h Index 13h	Start address bits SA25–SA24 and controls window size	page 3-22
Cache and VL Miscellaneous Register	22h/23h Index 14h	Write-through caching of the LCD graphics memory regions and MMU DRAM access delay	page 3-23
Linear ROM0/Shadow Register	22h/23h Index 21h	Linear access direction using MMS Windows C–F if applicable	page 3-26
Linear ROMCS0 Attributes Register	22h/23h Index 22h	Caching and write protection for regions 00F0000–00CFFFFh	page 3-28
MMS Window C–F Attributes Register	22h/23h Index 30h	Caching and write protection for MMS Windows C–F	page 3-38
MMS Window C–F Device Select Register	22h/23h Index 31h	Physical device selection for MMS Windows C–F	page 3-39

Table 7-1 Memory Management Unit Register Summary (continued)

Register	I/O Address	MMU Function Keyword	Description in Register Set Manual
MMS Window A Destination Register	22h/23h Index 32h	Destination start address bits SA22–SA15 for MMS Window A	page 3-40
MMS Window A Destination/ Attributes Register	22h/23h Index 33h	Destination start address bits SA25–SA23; enabling, caching, write protection, and physical device selection for MMS Window A	page 3-41
MMS Window B Destination Register	22h/23h Index 34h	Destination start address bits SA22–SA15 for MMS Window B	page 3-42
MMS Window B Destination/ Attributes Register	22h/23h Index 35h	Destination start address bits SA25–SA23; enabling, caching, write protection, and physical device selection for MMS Window B	page 3-43
Internal I/O Device Disable/Echo Z-Bus Configuration Register	22h/23h Index D0h	PC Card controller enable—required to setup MMS Windows C–F for either microcontroller	page 3-164
Write-Protected System Memory (DRAM) Window/Overlapping ISA Window Enable Register	22h/23h Index E0h	Stop address bits SA25–SA20 for the write-protected window	page 3-181
Overlapping ISA Window Start Address Register	22h/23h Index E1h	Start address for the overlapping ISA window	page 3-182
Overlapping ISA Window Size Register	22h/23h Index E2h	Window size for the overlapping ISA window	page 3-183
PC Card Mode and DMA Control Register	22h/23h Index F1h	PC Card controller mode, memory window allocation	page 3-198
Graphics Index Registers			
Frame/Font Buffer Base Address Register Low	3x4h/3x5h Index 4Fh	Graphics Frame Buffer MMS Window enable, MMS page select	page 5-39
PC Card Index Registers			
Address Window Enable Register	3E0h/3E1h Index 46h	Socket B: memory windows 1–4 enable	page 6-15
Memory Window 1 Registers (various)	3E0h/3E1h Index 58–5Dh	MMS Window C configuration	page 6-31–page 6-36
Memory Window 2 Registers (various)	3E0h/3E1h Index 60–65h	MMS Window D configuration	page 6-37–page 6-42
Memory Window 3 Registers (various)	3E0h/3E1h Index 68–6Dh	MMS Window E configuration	page 6-43–page 6-48
Memory Window 4 Registers (various)	3E0h/3E1h Index 70–75h	MMS Window F configuration	page 6-49–page 6-54

7.3 ADDRESS DECODING AND ALIASING

Most designers are familiar with address aliasing, which means that if an address is only partially decoded by a device, that device will appear to exist multiple times throughout the address space. However, there are significant implications associated with aliasing on the ÉlanSC400 and ÉlanSC410 microcontrollers, which must be thoroughly understood by the designer before attempting to use the memory management features.

The rest of this chapter assumes a full understanding of the implications of the architectural features discussed in this section.

7.3.1 Internal Address Bus Size

The internal address bus on the ÉlanSC400 and ÉlanSC410 microcontrollers is 26 bits wide. Even though the Am486 CPU has a 32-bit address bus, the top six address lines are not connected, even internal to the ÉlanSC400 and ÉlanSC410 microcontrollers. This means that, from a programming perspective, the ÉlanSC400 and ÉlanSC410 microcontrollers can “see” 64 Mbytes of memory at a time, memory that is aliased 64 times into the 4-Gbyte physical address space of the Am486 CPU.

7.3.2 Special Handling for A20

The Am486 CPU contains logic to perform special handling for A20. Because the ÉlanSC400 and ÉlanSC410 microcontrollers are designed to be PC/AT-compatible, they contain logic to allow backward compatibility all the way to the 8088. One of these 8088 features is the address wrap that occurs from the top of its 1-Mbyte memory back down to the bottom of memory. The Am486 CPU core is required to have direct support for this, because aliasing must occur even before the internal cache sees the address to support backward compatibility.

The Am486 CPU performs this function with the A20 control gate, which can force A20 to always be 0. Since the Am486 CPU defaults to 8088-compatible mode, the programmer must set the gate to allow A20 propagation for most applications.

Note: *Most operating systems, such as MS-DOS, contain code to do this. In the case of MS-DOS, HIMEM.SYS contains the code and has an API to allow program control of A20. A20 will be automatically set to propagate if HIMEM.SYS is loaded and DOS=HIGH[,UMB] is added to CONFIG.SYS. For information about direct control over the A20 gate, see the descriptions for the microcontroller’s direct-mapped registers at ports 0092h and 00EEh.*

7.3.3 Top of Memory CPU Execution

At reset, the processor is in Real mode, which normally can address only a megabyte, but the first instruction is fetched from address FFFFFFF0h, at the top of memory. The initial value of CS, the code segment, is 000F000h, and the initial value of the instruction pointer, IP, is 000FFF0h; however, the internal CPU base address associated with the code segment is FFFF0000h, rather than 00F0000h. The first far jump will cause the CS base address to be set to 16 times the segment of the jump target, so all PC/AT-compatible BIOS implementations have a far jump to a target in segment 000F000h as the first instruction executed.

This may become an issue if the boot ROM is larger than 1 Mbyte. In many implementations a small boot ROM (128 Kbyte or 256 Kbyte) will be used and will alias to all addresses decoded as boot ROM addresses. In this case, the software can effectively ignore the fact that the physical address of the first instruction fetched is nowhere near the physical address of the rest of the boot ROM, because the high-order address lines are not decoded by the ROM.

If, however, the boot ROM is larger than 1 Mbyte, the designer must be aware that the top 16 bytes of the boot ROM must be reserved for a far jump to a location in segment 000F000h, which will reside immediately below 1 Mbyte in the same boot ROM. (Because of compatibility issues, at boot-up the only locations in the CPU address space that map to the boot ROM are the 64 Kbytes at the very top of memory, and the 64 Kbytes immediately below 1 Mbyte. This is discussed in more detail later.)

7.3.4 ISA Bus Addressing

The ÉlanSC400 and ÉlanSC410 microcontrollers provide 26 bits of address on the SA address bus. However, standard 8-bit ISA devices only decode the lower 20 bits and standard 16-bit (PC/AT-compatible) devices decode the lower 24 bits. When a cycle is not claimed by internal devices (DRAM controller or ROM controller), it is driven to the VL-bus. If the cycle is not claimed on the VL-bus via an active $\overline{\text{VL_LDEV}}$ signal, it is then driven to ISA. Since the ISA bus receives all unclaimed cycles and the microcontroller's SA bus is 26 bits, it is possible to address up to 64 Mbytes on the ISA bus.

The definition of the ISA bus only contains 24 address lines, so a peripheral that decodes the "full" 24 lines of the address bus could be aliased four times in the microcontroller's address space. Any 8-bit ISA peripherals and 16-bit ISA peripherals that rely on ISA signals $\overline{\text{SMEMR}}$ and $\overline{\text{SMEMW}}$ will decode only the 20 address lines of the original 8-bit ISA bus, and thus could be aliased 64 times into the microcontroller's address space.

It is up to each designer to determine the requirements for generating $\overline{\text{SMEMR}}$ and $\overline{\text{SMEMW}}$. The most general design generates $\overline{\text{SMEMx}}$ by qualifying $\overline{\text{MEMx}}$ with A20–A25 all equal to 0, avoiding any aliasing for the lower megabyte. However, if the only non-VL memory-mapped peripherals in the system reside below 1 Mbyte, it is probably acceptable to simply connect the microcontroller's $\overline{\text{MEMx}}$ signals to the peripheral's $\overline{\text{SMEMx}}$ lines. Even if there are non-VL, memory-mapped peripherals above 1 Mbyte, for a closed system it is quite likely that the qualification can be performed with fewer than 6 address lines.

The designer should also be aware of the potential for making use of the ISA aliasing. If a design has 16 Mbyte of RAM, it may not be possible to address an ISA peripheral at, for example, 4 Mbyte, but the peripheral could be programmed to respond at 4 Mbyte, and the CPU could address it at 20 Mbyte (16 Mbyte + 4 Mbyte).

7.4 MULTIPLE MEMORY SPACES

One concept which may be foreign to some designers is that of multiple, parallel memory spaces, as opposed to a single linear space. The ÉlanSC400 and ÉlanSC410 microcontrollers can address up to nine distinct memory spaces:

- System memory address space (DRAM)
- ROM0 memory address space
- ROM1 memory address space
- ROM2 memory address space
- PC Card A memory address space (both data and attribute memory spaces) (ÉlanSC400 microcontroller only)
- PC Card B memory address space (both data and attribute memory spaces) (ÉlanSC400 microcontroller only)
- External ISA/VL-bus memory address space

(For the purposes of this discussion, the VL and ISA buses are treated identically. However, the designer should realize that they are prioritized by VL-bus peripherals—if a VL-bus peripheral claims a bus cycle, the ISA bus never sees it.)

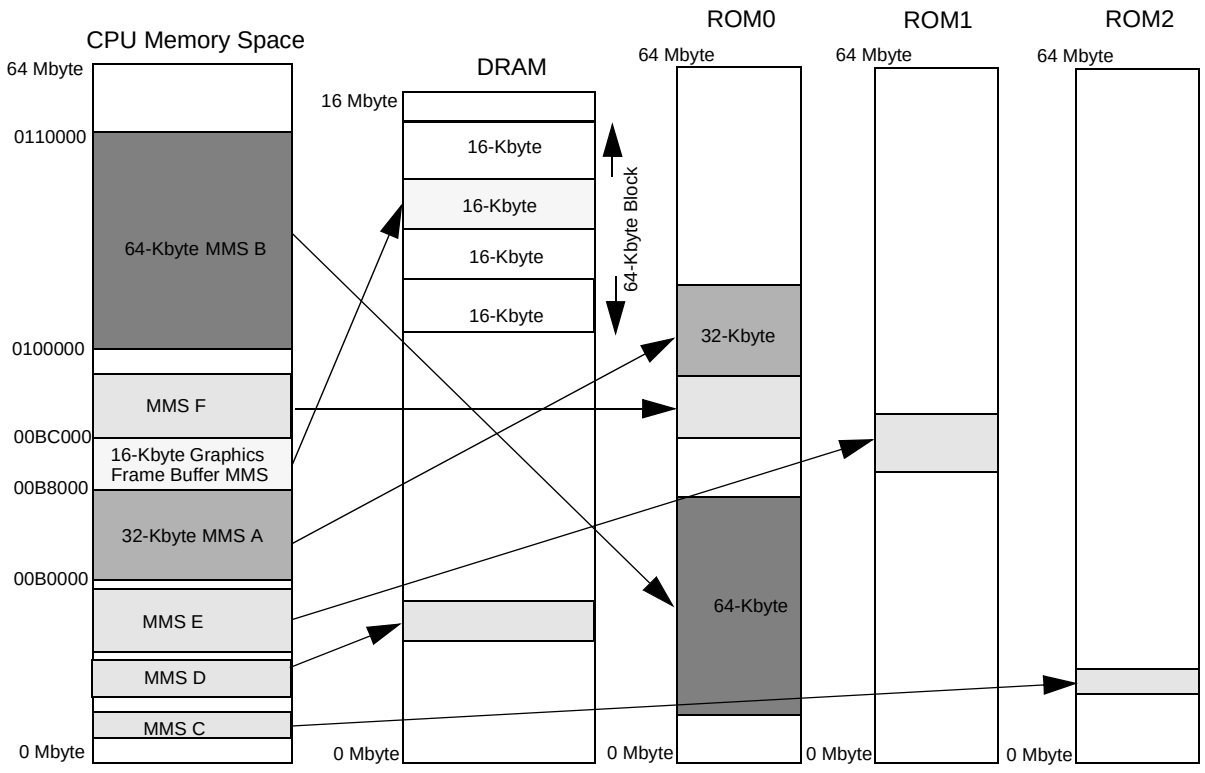
The size of each space is 64 Mbyte; however, as noted in the previous section, the 16-Mbyte ISA bus is aliased four times into its 64 Mbytes.

The ÉlanSC400 and ÉlanSC410 microcontrollers support two classes of memory management schemes: non-translated and translated memory management.

- **Non-translated accesses**—In this case, the MMU hardware simply selects one of the 9 distinct memory spaces for the read or write, and the memory address is passed unchanged to the hardware controlling that space.
- **Translated accesses**—In this case, the MMU translates the address in addition to choosing the space.

The DRAM, ROM0, ISA/VL-bus, and (on the ÉlanSC400 microcontroller) PC Card Socket A spaces are each accessible, to a degree, using non-translated memory management. All spaces except the ISA/VL-bus are fully accessible using translated memory management.

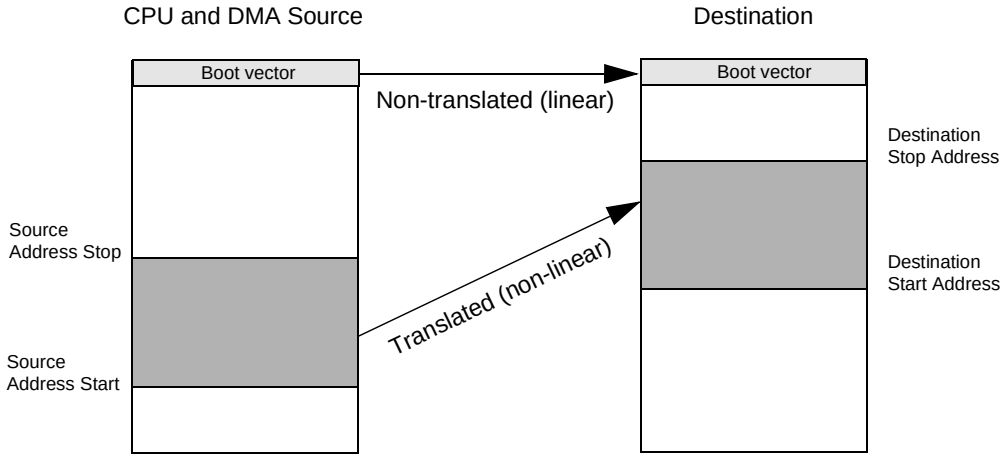
Figure 7-1 Memory Mapping System Example



Note:

MMS Windows C–F are variable in size (minimum 4 Kbytes) and can be located anywhere in the CPU memory address space (except the lowest 64-Kbyte region of the CPU memory space) on 4-Kbyte boundaries. The Graphics Frame Buffer MMS Window is not supported on the ÉlanSC410 microcontroller.

Figure 7-2 Address Translation Example



Note:

MMS Window A–B have a fixed decode region; the user supplies a destination start address only. MMS Windows C–F require the user to program the start and stop address and an offset.

7.5 NON-TRANSLATED MEMORY MANAGEMENT

As noted above, when performing non-translated memory management, the MMU simply decides which device space will receive a given memory cycle by examining the memory address provided by the CPU. However, after examination, the address is passed unchanged to the hardware managing that space.

7.5.1 ROM0 and Non-Translated Memory Management

For most of the CPU address space, the default memory space on power-up is the ISA/VL-bus. The exceptions are CPU address ranges 00F0000–00FFFFFh and 3FF0000–3FFFFFFh, which are mapped to ROM0 (or PC Card Socket A[1]). The CPU boots by jumping to location FFFFFFF0h (which is aliased to 3FFFFFFh), which must execute a far jump to the initialization code. Because the CPU boots in Real mode, the target of the initial far jump must be in the lower megabyte, and for any PC/AT-compatible BIOS, the segment of the jump target will be F000h. This means that the jump target will be in the range 00F0000–00FFFFFh.

In a typical boot ROM scenario, $\overline{\text{ROMCS0}}$ is connected to a single EPROM or Flash device with a capacity of 128 or 256 Kbytes. The upper address lines are not connected to this device, so the device is aliased throughout the entire 64-Mbyte address space. In this scenario, a single contiguous BIOS segment can be programmed into the ROM, and the ROM can be treated as if the upper 64 Kbytes are mapped at F0000, and as if the CPU starts execution at F000:FFF0h.

1. On the ÉlanSC400 microcontroller, all ROM0 accesses may be redirected to PC Card Socket A via a hardware strapping option which is sampled at reset. A design could use PC Card Socket A as the sole boot device, but this option is most useful for cost-sensitive applications using a Flash boot device soldered to the board. If the code in the boot device becomes damaged, it may be reprogrammed by setting the strapping option to boot from Socket A. After it boots, the code in the PC Card card may copy itself to memory (or open an MMS window to point to itself), and redirect ROM0 back to the on-board Flash device by resetting bit 2 in the Pin Strap Status Register (CSC index 20h).

However, if the boot device is larger than 1 Mbyte, or if additional external address decoding is done in the $\overline{\text{ROMCS0}}$ space, note that booting may require a far jump to be stored in the top 16 bytes of the address space and for BIOS code to be stored between 00F0000h and 00FFFFFh in the address space. Again, this is because the default memory management involves no address translation by the ÉlanSC400 and ÉlanSC410 microcontrollers. The MMU simply examines the CPU address and chooses one of several parallel memory spaces to access.

After the code has booted into the 00F0000–00FFFFFh range, it has some programmatic control over which CPU addresses cause an access to ROM0. Using the Linear ROM0/ Shadow Register and the Linear ROM0 Attributes Register (CSC index 21 and 22h), the CPU can discretely control address space selection in five different 64-Kbyte regions: 00C0000–00CFFFFh, 00D0000–00DFFFFh, 00E0000–00EFFFFh, 00F0000–00FFFFFh, and 3FF0000–3FFFFFFh. These are the only regions that may be mapped to ROM0 space without using translated memory management.

7.5.2 DRAM and Non-Translated Memory Management

Before any DRAM can be used, the boot code must program the DRAM controller using CSC index registers 00–07h. The DRAM controller logically concatenates all the system DRAM into a single unified address space which starts at address 0. By default, CPU addresses from 0 to the top of DRAM are mapped to the DRAM space, in preference to ISA/VL-bus space. The two exceptions to this are the window from 640 Kbytes to 1 Mbyte (00A0000–0100000h) which defaults to ISA/VL-bus space or ROM0, as described in the previous section, and the 64-Kbyte window at the top of CPU address space (3FF0000–3FFFFFFh), which defaults to ROM0.

The ÉlanSC400 and ÉlanSC410 microcontrollers offer a limited amount of programmatic control over DRAM using non-translated memory management:

- In the region 00C0000–00FFFFFh, any accesses that would have gone to ROM0 can be redirected to DRAM by setting bit 5 in the Linear ROM0/Shadow Register at CSC index 21h. Any of these 64-Kbyte regions that are mapped to the ISA bus instead of ROM0 are not redirected by setting this bit. This bit was designed to support shadowing slow ROM into faster DRAM; the Linear ROM0 Attributes Register (CSC index 22h) allows this shadowed memory to be write protected and/or made cacheable.
- On the ÉlanSC400 microcontroller, in any region in the lower 16 Mbyte (but typically in the range 00B0000–00BFFFFh for compatibility), the internal LCD controller can be programmed to direct accesses to the frame buffer (32–128 Kbytes, depending on graphics mode) and the 16-Kbyte font buffer (text modes only) to DRAM in preference to ROM or ISA.
- The Overlapping ISA Window Start Address and Overlapping ISA Window Size registers (CSC index E1 and E2h) can be programmed to force accesses that would normally default to DRAM to go to the ISA bus instead. The primary use for this is to allow systems that have 16 Mbytes or more of DRAM to support ISA peripherals that require a large memory window, without relying on ISA bus aliasing.
- The 64 Kbytes at the top of CPU address space (3FF0000–3FFFFFFh), which defaults to ROM0, can be redirected to DRAM by setting bit 3 in CSC index register 21h. Boot code should normally do this, because in most systems, there is no reason to access ROM0 at that address range after the first instruction fetch.
- When System Management Mode (SMM) is entered via an SMI, the 32-Kbyte area where the system state is stored and where SMM execution starts is automatically mapped to DRAM. This allows SMM RAM to be mapped in a location such as 00A8000–

00AFFFFh, which normally is directed to ISA space.[1] This allows SMM RAM to be invisible to normal system operation.

7.6 TRANSLATED MEMORY MANAGEMENT

When the microcontroller performs translated memory management, it translates addresses in addition to selecting the correct address space for each access. A window in the CPU address space is mapped to a particular target location in the target address space.

Note that it is the programmer's responsibility to understand all of the mapping mechanisms, and to avoid using translated memory management in a manner which attempts to map more than one target location to the same CPU address space. This will result in undefined behavior which could possibly damage hardware, e.g., by enabling multiple drivers onto the same bus.

The ÉlanSC400 and ÉlanSC410 microcontrollers have several distinct types of translated memory management:

- MMS Windows A and B
- MMS Windows C–F
- Graphics Frame Buffer MMS Window (ÉlanSC400 microcontroller only)
- 82365-compatible PC Card access (ÉlanSC400 microcontroller only)

A discussion of each of these translated memory management methods follows.

7.6.1 MMS Windows A and B

The simplest translated memory management is provided by MMS windows A and B.

MMS Window A, when enabled, occupies the 32 Kbytes of CPU address space from 00B0000–00B7FFFh, taking precedence over ISA accesses in that region. It can target any address in DRAM, ROM0, ROM1, or ROM2 spaces, allowing access to any 32 Kbytes on 32-Kbyte boundaries. Complete control over MMS Window A is provided via CSC index registers 32 and 33h.

MMS Window B, when enabled, occupies the 64 Kbytes of CPU address space from 0100000h (1 Mbyte) to 010FFFFh. A20 control must be enabled (e.g., via a read from Port 0EEh) before MMS Window B will function properly, because the PC/AT-compatible A20 remapping occurs before the MMU receives the address from the CPU. From Real mode, the last 16 bytes in this window are inaccessible (the rest can be accessed using segment 000FFFFh with an offset from 10h to 000FFFFh); however, the window still allows access to any address in DRAM, ROM0, ROM1, or ROM2 spaces, because the address granularity is 32 Kbytes. This is the same as MMS Window A, even though the size of MMS Window B is 64 Kbytes. Complete control over MMS Window B is provided via CSC index registers 34h and 35h.

MMS Windows A and B differ from MMS Windows C–F in that they have a fixed decode region, and the user supplies a destination start address only.

1. To move SMRAM, which defaults to 3000:8000, the program must first store an initial SMM handler at 38000h, force an SMI to occur (e.g., using CSC index 90h[0]), and change SMBASE from within the SMI handler before issuing an RSM instruction. Advanced memory mapping can be used to store the runtime SMI handler at the desired address.

7.6.2 MMS Windows C, D, E, and F

These four MMS windows are more powerful than MMS windows A and B, but they are more complex to program.

To enable the setup of MMS Windows C–F on *either* the ÉlanSC400 or ÉlanSC410 microcontroller, the PC Card controller indexed register space must be enabled (CSC index D0h[1] = 1) and the PC Card controller must be set up to operate in Standard mode (CSC index F1h[0] = 0). On either microcontroller, once any of MMS Windows C–F is opened via PC Card index space, disabling the internal PC Card controller does not disable the MMS windows, but disallows their reconfiguration until the internal PC Card controller is re-enabled. When the internal PC Card controller is disabled on either microcontroller, I/O accesses to the PC Card indexed register space go off the microcontroller to the ISA bus.

Note: *The register settings described above are required even though the internal PC Card controller is not available on the ÉlanSC410 microcontroller.*

MMS Windows C–F are very flexible. In addition to allowing mapping to any address in the target DRAM or ROM address spaces, they allow selection of window location within the CPU address space, as well as selection of window size. The granularity of all addresses and sizes is 4 Kbytes, which may have some advantages over the 32-Kbyte granularity of MMS windows A and B. MMS Windows C–F differ from MMS Windows A–B in that the user supplies the destination start and stop addresses, as well as an offset address.

After the use of these windows is enabled via resetting CSC index F1h[0], the windows are controlled using two registers in the CSC index space and the PC Card index registers normally used for Socket B Memory Windows 1–4.

- The MMS Window C–F Attributes and MMS Window C–F Device Select registers (CSC index 30h and 31h) contain bits that control the device selection (ROM0, ROM1, ROM2, or DRAM), and write-protect and cacheability options for each of the windows.
- The Address Window Enable Register for PC Card Socket B (PC Card index 46h) contains individual enables for these windows at bits 1–4.
- PC Card index registers 58–75h contain location information. This is programmed as a *start address*, which defines the start of the window in CPU address space; a *stop address*, which defines the end of the window in CPU address space (thus implicitly defining the length); and an *offset address*, which should be programmed to the desired target address, *minus* the Start Address.

Because MMS windows C–F on the ÉlanSC400 microcontroller share the memory mapping logic in the PC Card controller, use of these windows places restrictions on PC Card socket use. This may be unworkable in many designs, especially those expecting to use standard card and socket services for two PC Card cards and those requiring translated PC Card timing or DMA. See the description of the PC Card Mode and DMA Control Register (CSC index F1h) for a list of PC Card restrictions.

7.6.3 Graphics Frame Buffer MMS Window (ÉlanSC400 Microcontroller Only)

On the ÉlanSC400 microcontroller, when the internal LCD controller is enabled and configured for graphics (not text) mode, graphics index 4Fh can be used to set up a specialized memory mapping window. This window occupies the 16 Kbytes of CPU address space from 00B8000–00BBFFFh and can be mapped to the lowest 16 Mbytes of DRAM only; that is, to any of the four 16-Kbyte pages within the 64-Kbyte frame buffer defined by graphics index 4Dh. Typically, the frame buffer will be programmed to 00B0000h, and this mode simply allows backward compatibility for CGA display programming.

When the Graphics Frame Buffer MMS window is set, the frame buffer is not visible to the CPU at the location it actually occupies in DRAM (unless that region of system CPU address space defaults to DRAM anyway). It is visible only one 16-Kbyte page at a time through the MMS window. This window should not be used for anything except the internal LCD controller; enabling the LCD controller causes several side effects, such as disabling caching on the mapped region.

7.6.4 PC Card Memory Management (ÉlanSC400 Microcontroller Only)

7.6.4.1 Standard 82365 PC Card Control

The PC Card controller on the ÉlanSC400 microcontroller is modeled on the 82365 device; a complete discussion of it is beyond the scope of this document. However, as the previous section discusses, the controller's memory mapping is quite sophisticated. This section focuses on differences between the ÉlanSC400 microcontroller and the 82365, with particular emphasis on memory management.

The standard 82365 registers are mapped at I/O locations 03E0 and 03E1h. Additionally, CSC index registers F0–F2h are used for PC Card control.

The ÉlanSC400 microcontroller has two distinct PC Card modes: Standard and Enhanced. When bit 0 in the PC Card Mode and DMA Control Register (CSC index F1h) is clear (Standard mode), the PC Card Socket B memory windows 1–4 are reassigned to be MMS windows. Window 0 in each socket is still available for PC Card, and Socket A's windows 1–4 can be individually remapped to point either to Socket A or Socket B, using bits 4–7 of the PC Card Extended Features Register (CSC index F0h).

When CSC index F1h[0] is set (Enhanced mode), each PC Card socket has its full complement of five memory windows, and MMS Windows C–F are disabled.

7.6.4.2 Simplified PC Card Control

In addition to the standard access of the PC Card space, PC Card A data space may be accessed by remapping $\overline{\text{ROMCS0}}$ and/or $\overline{\text{ROMCS1}}$ to the PC Card.

$\overline{\text{ROMCS0}}$ remapping is provided to support reprogramming of soldered down Flash boot parts from a PC Card when a jumper is set. The $\overline{\text{ROMCS0}}$ redirection feature also allows testing of code by placing it on a PC Card memory card (linear Flash or SRAM, but not ATA) and booting the BIOS or XIP (eXecute In Place) O/S image. Thus multiple builds can be kept on different PC Cards and swapped out quickly as required.

There are several caveats to keep in mind when redirecting $\overline{\text{ROMCS0}}$ to PC Card Socket A via the CFG2 pin strap.

First of all, the PC Card that is used must not decode more of the PC Card space than it actually has physical memory for. Many linear Flash/SRAM cards perform only a partial decode of the address space. The amount of decode is equal to the physical memory on the card. Such a PC Card will be aliased throughout the PC Card memory space.

For example, a 4-Mbyte card with this type of address decoding will appear at 0–03FFFFFh, 0400000–07FFFFFh, and so on, all the way through the 64-Mbytes PC Card memory space. This is important because the boot vector address driven to the PC Card will always be 3FFFFF0h, so a card that does not alias and that is less than 64-Mbyte will have no way to hook the boot vector. Because the CPU will begin fetching from 3FFFFF0h, PC Cards must supply a boot vector hook in the top 16 bytes of the card space.

Note that the first access beyond the current segment will cause A25–A20 to be asserted. As long as no inter-segment code control transfer (call, jmp, etc.) occurs, code can be fetched from any location in the top 64 Kbytes of the PC Card indefinitely. In order to

continue operation from the PC Card above 1 Mbyte, but outside of the top 64 Kbytes, Protect mode must be entered, and an MMS window must be set up and pointed to the ROM0 device.

Finally, it is important to note that default termination on the PC Card Socket A V_{CC} control pin at reset is such that PC Card socket power is enabled. This was done to support redirection of $\overline{\text{ROMCS0}}$ to Socket A. However, software running in the configuration must be careful to manually turn the socket power on via the PC Card V_{CC} control registers prior to configuring the PC Card socket power controls as such via CSC index 39h[1–0]. Failure to do this will shut off card power while instructions are being fetched from it.

After boot, the $\overline{\text{ROMCS0}}$ redirection can be cancelled by resetting bit 2 in the Pin Strap Status Register (CSC index 20h).

$\overline{\text{ROMCS1}}$ remapping is provided as a simple method (e.g. using MMS windows A or B) of accessing a memory card in PC Card Socket A without having to learn all the intricacies of programming the 82365. This is controlled with bit 6 in the Linear ROM0/Shadow Register (CSC index 21h).

7.7 SYSTEM CONSIDERATIONS

7.7.1 2.7-Volt Operation

If the microcontroller is operated at 2.7 volts, the boot code should set bit 5 in the Cache and VL Miscellaneous Register (CSC index 14h), or MMU DRAM accesses will not work properly.

7.7.2 $\overline{\text{ROMCS2}}$ Operation

Unlike $\overline{\text{ROMCS0}}$ and $\overline{\text{ROMCS1}}$, $\overline{\text{ROMCS2}}$ is not mapped to an external pin by default. It can be mapped to any of the GPIO_CS14–GPIO_CS0 pins. It is the programmer's responsibility to ensure that other options which may use the selected pin are disabled.

The following C code fragment shows using GPIO0 as $\overline{\text{ROMCS2}}$:

```
SetIO(GP0STAT_CTL,1);      // Force GPIO_CS_0 output value to 1
SetIO(CS0_DIR,1);          // Make sure GPIO_CS_0 is an output
SetIO(CS0_PUEN,0);         // Disable internal GPIO_CS_0 pull-up
SetIO(TERM_LATCH,1);       // Set termination latch
do {} while (GetIO(TERM_LATCH));  // Wait for disable to take place
SetIO(GPROM_CS2_MUX,0);    // Map ROMCS2 to GPIO_CS_0
SetIO(GP0STAT_CTL,0);      // Stop forcing GPIO_CS_0 output
```

7.7.3 Memory Mapping and Caching

The ÉlanSC400 and ÉlanSC410 microcontrollers provide a great deal of control over the cacheability of various memory regions.

- ISA/VL-bus and PC Card spaces are never cached.
- Memory mapped to the internal graphics controller is never cached.
- DRAM, in general, is cacheable by default, but two non-cache windows are provided to allow programmer control over areas that should not be cached. These two windows are controlled via CSC index registers 10–13h. Use of a “virtual desktop” with the LCD screen (e.g., making the logical screen larger than the physical LCD size and scrolling the physical LCD around on the logical screen) requires a larger non-cacheable window than is provided automatically by the LCD controller. One of the non-cacheable windows can be used to mark the entire virtual screen area as non-cacheable so that the physical memory always reflects the actual desired display.

The programmer has control over cacheability of BIOS code segments by using the Linear ROM0 Attributes Register (CSC index 22h). For compatibility, the BIOS should usually be left non-cacheable, but in an embedded design it may be desirable to allow it to be cached.

The programmer also controls the caching of each MMS window. MMS and/or PC Card caching should only be enabled under very special circumstances (such as completely static window mapping), as the CPU is not aware of MMU mapping (the CPU caching operates using linear memory addresses).

The programmer should also be careful not to access the same 16-byte cache line through two different linear CPU addresses, especially if one of the accesses is non-translated, and thus cached by default.

7.7.3.1 Caching in System Management Mode

Caching during SMM operation is controllable using bits 5 and 6 in the Non-Cacheable Window 0 Address/Attributes/SMM Register (CSC index 11h). By default, the cache will be flushed upon entry to SMM, and caching will not be enabled during SMM execution. The programmer could speed up SMM entry and execution by changing these bits, but careful consideration must be given to system issues. The following list gives information about each of the possible bit combinations:

- **Auto-flush enabled, SMM caching disabled**—This is the default state. The cache is flushed immediately upon entry to SMM, and no caching is performed during SMM. This dramatically reduces the performance of systems that depend on SMI interrupts, but is safe to use with overlaid SMM RAM.
- **Auto-flush enabled, SMM caching enabled**—This could be even lower performance than the previous case for overlaid SMM RAM, because a manual flush should be performed upon exiting SMM. The only possible reason to use this configuration is if SMM routines are very lengthy.
- **Auto-flush disabled, SMM caching disabled**—This should work for systems where the SMM RAM is not overlaying anything which is cacheable, but is not itself always present. For example, if SMM RAM has been relocated to 00A0000, it (potentially) overlays an ISA bus VGA card memory. Because the ISA bus is not cacheable, VGA memory will not be in the cache when SMM is entered, and the cache will not need to be flushed. Because caching during SMM is disabled, no flush needs to be performed upon exit from SMM.
- **Auto-flush disabled, SMM caching enabled**—This could be useful in a closed environment where SMM RAM is always visible, to make SMIs faster.

CHAPTER

8 ROM/FLASH INTERFACE

8.1 OVERVIEW

The integrated ROM/Flash interface includes the following features:

- 8-, 16-, and 32-bit ROM/Flash interfaces
- Three ROM/Flash chip selects
- Dedicated ROM Read and Flash Write signals for better performance
- Generates $\overline{\text{ROMWR}}$ for writes to Flash devices
- Assembles/disassembles double word to and from the CPU for fast ROM cycles
- Supports programmable wait states based on the CPU bus clock for faster ROMs.
- Slower ROMs are also supported by starting the ISA controller and using the ISA bus speed $\overline{\text{MEMR}}$ and $\overline{\text{MEMW}}$ signals
- High-performance support for burst mode ROMs
- Drives appropriate data steering signals during 8- and 16-bit cycles

The ROM/Flash interface operates at the CPU bus speed (maximum 33 MHz) and provides three separate ROM chip selects.

Note that DMA to ROM devices is not supported on the ÉlanSC400 and ÉlanSC410 microcontrollers. Note also that, if the 32-bit ROM interface is enabled, the matrix keyboard interface is not available, and, on the ÉlanSC400 microcontroller, the internal graphics controller is unavailable.

8.2 REGISTERS

A summary listing of the chip setup and control (CSC) index registers used to control the ROM/Flash interface is shown in Table 8-1. Complete register descriptions can be found in the *Élan™ SC400 Microcontroller Register Set Reference Manual* (order #21032).

Table 8-1 ROM/Flash Interface Register Summary

Register	I/O Address	ROM/Flash Interface Function Keyword	Description in Register Set Manual
Pin Strap Status Register	22h/23h Index 20h	Data bus width, default boot interface (ROM0 or PC Card), availability of the external buffer control signals	page 3-25
Linear $\overline{\text{ROMCS0}}$/Shadow Register	22/22h Index 21h	Linear ROM0 decode, boot ROM caching, and shadowing; ROM1 space access redirection to PC Card Socket A	page 3-26
Linear $\overline{\text{ROMCS0}}$ Attributes Register	22h/23h Index 22h	Write protection and caching for regions 00FFFFF–00C0000h	page 3-28

Table 8-1 ROM/Flash Interface Register Summary (continued)

Register	I/O Address	ROM/Flash Interface Function Keyword	Description in Register Set Manual
$\overline{\text{ROMCS0}}$ Configuration Register A	22h/23h Index 23h	Access speed, burst mode support, and early chip-select for ROM0	page 3-29
$\overline{\text{ROMCS0}}$ Configuration Register B	22h/23h Index 24h	Fast-Speed ROM mode, wait states for burst and non-burst cycles for ROM0	page 3-31
$\overline{\text{ROMCS1}}$ Configuration Register A	22h/23h Index 25h	Access speed, burst mode support, and early chip-select for ROM1	page 3-32
$\overline{\text{ROMCS1}}$ Configuration Register B	22h/23h Index 26h	Fast-Speed ROM mode, wait states for burst and non-burst cycles for ROM1	page 3-34
$\overline{\text{ROMCS2}}$ Configuration Register A	22h/23h Index 27h	Access speed, burst mode support, and early chip-select for ROM2	page 3-35
$\overline{\text{ROMCS2}}$ Configuration Register B	22h/23h Index 28h	Fast-Speed ROM mode, wait states for burst and non-burst cycles for ROM2	page 3-37
Activity Source Enable Register A	22h/23h Index 62h	Activity source enable: CPU access to $\overline{\text{ROMCS0}}$ and $\overline{\text{ROMCS2}}$–$\overline{\text{ROMCS1}}$	page 3-71
Activity Source Status Register A	22h/23h Index 66h	Activity source enable: CPU access to $\overline{\text{ROMCS0}}$ and $\overline{\text{ROMCS2}}$–$\overline{\text{ROMCS1}}$	page 3-75
Activity Classification Register A	22h/23h Index 6Ah	Primary or secondary activity classification: CPU access to $\overline{\text{ROMCS0}}$ and $\overline{\text{ROMCS2}}$–$\overline{\text{ROMCS1}}$	page 3-79
Standard Decode to GPIO_CS Map Register	22h/23h Index B1h	ROM Chip Select 2 ($\overline{\text{ROMCS2}}$) mapping to one of the GPIO_CS pins	page 3-131
Suspend Pin State Register A	22h/23h Index E3h	Status of ROM interface in Suspend mode (powered, not powered)	page 3-184
Suspend Pin State Register B	22h/23h Index E4h	Status of $\overline{\text{R32FOE}}$ in Suspend mode	page 3-185
Suspend Mode Pin State Override Register	22h/23h Index E5h	Power Down Group B output signals three-state when ROM interface remains powered in Suspend mode	page 3-186

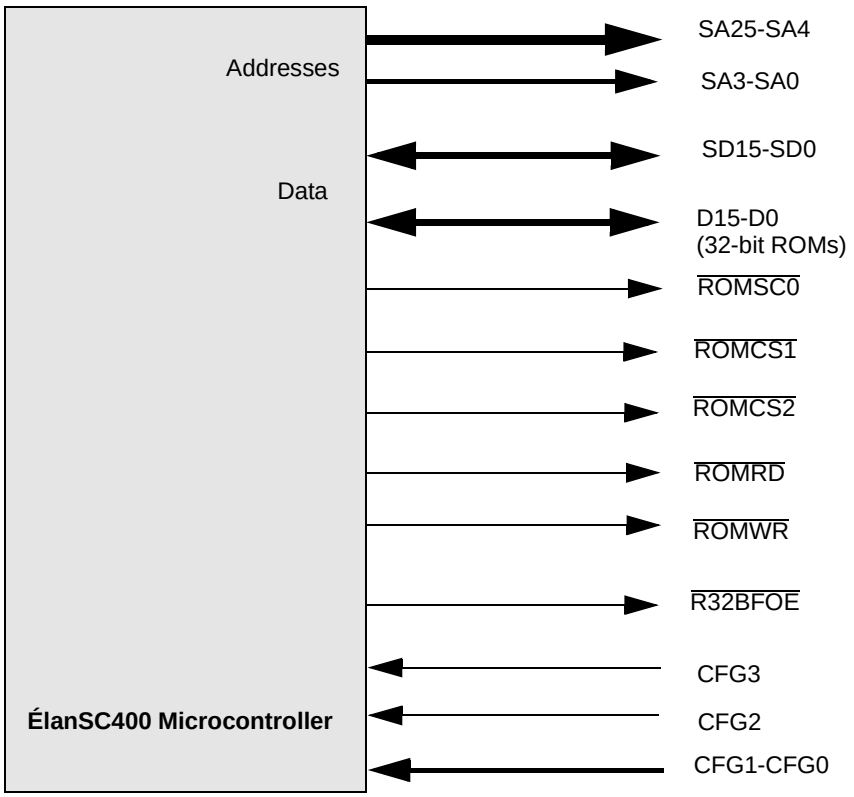
8.3 BLOCK DIAGRAM

Figure 8-1 is a simplified block diagram showing all the external signals used by the ROM/Flash interface. More complex examples showing how these signals are used in different configurations can be found in Figure 4-3, Figure 4-4, and Figure 4-5.

If the 32-bit ROM interface is enabled, the matrix keyboard interface is not available, and, on the ÉlanSC400 microcontroller, the internal graphics controller is unavailable. The $\overline{\text{R32BFOE}}$ signal is shared with the KBD_ROW13 signal.

Note that, unlike $\overline{\text{ROMCS0}}$ and $\overline{\text{ROMCS1}}$, $\overline{\text{ROMCS2}}$ is not mapped to an external pin by default. It can be mapped to any of the GPIO_CS14–GPIO_CS0 pins. This process is described in Section 7.7.2.

Figure 8-1 ROM/Flash Interface Block Diagram



8.4 OPERATION

8.4.1 Architectural Overview

The ROM controller provides for control over three ROM interfaces, and each of the interfaces may be individually configured for interface width (8/16/32 bit) with 26-bit (64 Mbyte) addressability. Although there is a chip select ($\overline{\text{ROMCS0}}$, $\overline{\text{ROMCS1}}$, and $\overline{\text{ROMCS2}}$) that is dedicated to each of these ROM interfaces, the remainder of the standard bus signals are shared.

The ROM interfaces also share two signals that are specific to the ROM interface, $\overline{\text{ROMRD}}$ and $\overline{\text{ROMWR}}$. These signals are similar in function to the ISA $\overline{\text{MEMR}}$ and $\overline{\text{MEMW}}$ commands, but provide further isolation of the ROM interface from the ISA bus, and also support the non-ISA-standard timings that are present when Fast-Speed ROM mode is enabled.

Each of the three interfaces has separate configuration and timing controls. Of the three interfaces, only $\overline{\text{ROMCS0}}$ may be accessed via direct-mapped (non-MMS translated) memory cycles, and only the regions between 00C0000–00FFFFFh and 3FF0000h–3FFFFFFh are included in this direct-mapped access capability. To access the remainder of $\overline{\text{ROMCS0}}$, and any portion of $\overline{\text{ROMCS1}}$ or $\overline{\text{ROMCS2}}$ spaces, an MMS window is required. (See Chapter 7 for more detail on using MMS windows.) $\overline{\text{ROMCS0}}$ must be connected to the boot ROM device which is why the direct-mapped accesses to the 3FF0000–3FFFFFFh region are included.

The 00C0000–00FFFFFh region is broken down into four *segments*, each having independent controls. Each segment is 64 Kbytes wide:

- 00C0000–00CFFFFh
- 00D0000–00DFFFFh
- 00E0000–00EFFFFh
- 00F0000–00FFFFFh

Each of these four segments has individual controls for enable, and also for cacheability and write protection of linear accesses. The direct-mapped accessibility is provided for these segments in order to support the standard PC/AT ROM memory map compatibility with minimum effort on the part of the system designer/software engineer.

Accesses to any segment that is not enabled for $\overline{\text{ROMCS0}}$ linear decode will go to the external ISA or VL-bus.

Accesses to any segments that have been enabled for linear $\overline{\text{ROMCS0}}$ decode may be redirected to DRAM for use in shadowing ROM BIOS. This is commonly referred to as *shadowing support* or simply *shadowing*. On the ÉlanSC400 and ÉlanSC410 microcontrollers, the shadowing control operates on an “all or nothing” basis. If shadowing is enabled, then accesses to all of the above segments that have been enabled for linear $\overline{\text{ROMCS0}}$ decode will be redirected to DRAM.

Note that neither PC Card windows nor MMS windows C–F may be located in any segment that has been enabled for $\overline{\text{ROMCS0}}$ linear decode, regardless of whether or not shadowing has been enabled. Doing so will result in unexpected system operation, and must be avoided. Any segment that is not enabled for $\overline{\text{ROMCS0}}$ linear decode may be overlaid with a PC Card or MMS C–F window. The $\overline{\text{ROMCS0}}$ linear decode may be redirected to PC Card Socket A to support field upgrades of firmware or special development environments. This redirection can be done using either pin strapping, as explained below, or software manipulation of CSC registers. In addition, $\overline{\text{ROMCS1}}$ can also be redirected to PC Card Socket A under software control only. The ROM controller supports enhanced access times for “burst-mode” ROM devices. These devices support faster access speeds for certain transfers to improve ROM interface performance as described below.

8.4.2 Data Bus Usage

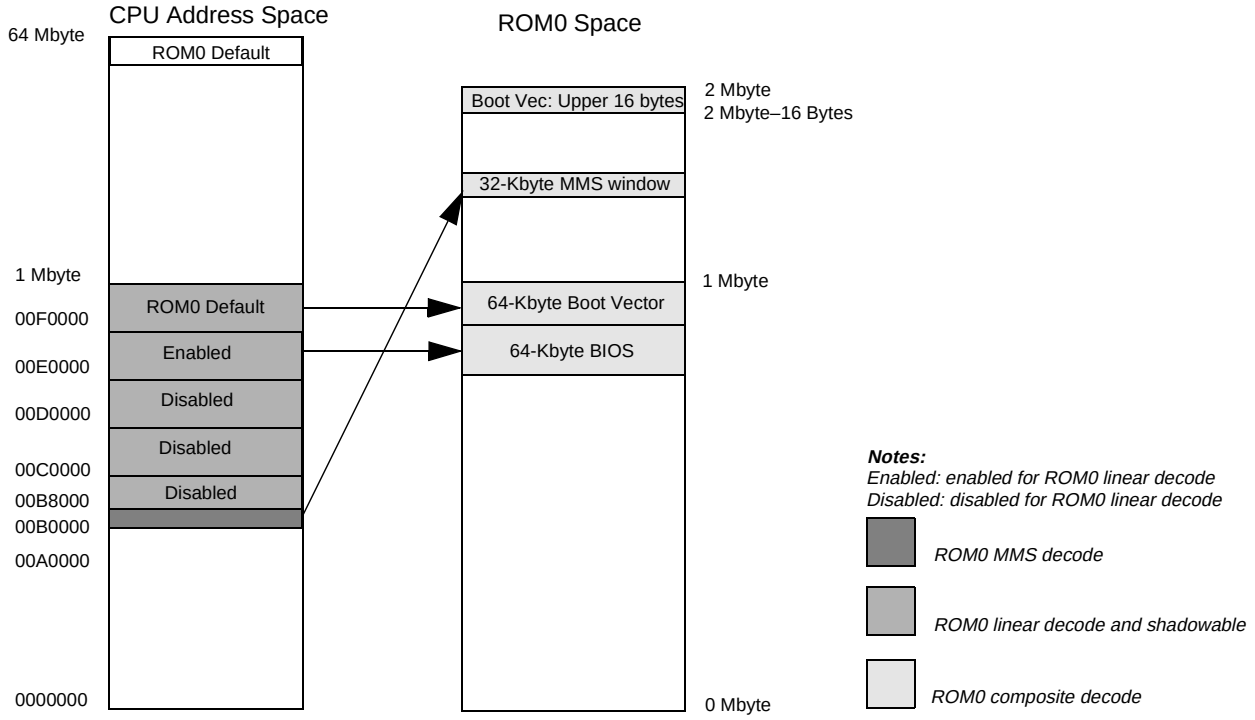
This section provides a brief overview of the data bus usage by the ROM controller, because it is not intuitively obvious. This section is included for the benefit of those who are trying to connect a logic analyzer to the microcontroller’s ROM interface. The ÉlanSC400 and ÉlanSC410 microcontrollers are highly configurable, but system-level resources must be shared for several configurations.

The 32-bit data bus on the ÉlanSC400 and ÉlanSC410 microcontrollers is broken down into four byte lanes: V3–V0. These byte lanes carry data to and from the CPU from different devices depending on the current microcontroller configuration (see Table 4-11). It may help to think of the use of the microcontroller’s data bus as being “DRAM-centric”, because the byte-lane assignments always seem to make the most sense from the standpoint of the DRAM controller.

When the DRAM controller is configured to be 16 bits wide, it uses byte lanes V1 and V0 to carry DRAM data D15–D8 and D7–D0 respectively.

When a ROM interface is configured to be 16 bits wide, it uses the other 2 byte lanes, V3 and V2, to carry ROM data RD15–RD8 and RD7–RD0 respectively.

Figure 8-2 ROM Decode Example



In this way, a system using a 16-bit DRAM interface and a 16-bit ROM interface is simplified, because the data buses for these two functions are completely isolated. It is important to note that V3 and V2 are collectively known as the system data bus (16 bits). This is because they are used to support not only ROM data, but also PC Card and ISA data, as well as DRAM and VL-bus data, if so configured. Further references in this section to the “system bus” should be taken to mean that portion of the V3 and V2 byte lanes which service the PC Card, ROM, and ISA interfaces.

When the DRAM controller is configured to be 32 bits wide, it uses V3–V0 to carry DRAM data D31–D0. Assuming a 16-bit ROM interface, the DRAM and ROM controller must share byte lanes V3 and V2 in this configuration. Because V3 and V2 are used for the system bus as well as the DRAM interface in this configuration, the loading on byte lanes V3 and V2 from these other system interfaces must be avoided while they are being used for DRAM data transfers. This is where the $\overline{\text{DBUFOE}}$ signal comes into play. It is used to electrically connect the devices on the system bus to byte lanes V3 and V2 when PC Card, ROM, or ISA accesses are being performed. When VL-bus or DRAM accesses are being performed, the system bus is electrically disconnected from V3 and V2.

Regardless of the DRAM controller data bus width, if the ROM controller is configured to be 32 bits wide, the byte lane usage for ROM accesses changes. This time, however, the change is in a fashion that is more intuitive from the perspective of the ROM controller. With a 32-bit ROM configuration, V3–V0 carry ROM data RD31–RD0 in a byte lane usage that becomes similar to the DRAM controller. Relative to the 16-bit ROM interface byte lane usage, this is a byte lane switch for RD15–RD0 which use V1–V0 in a 32-bit ROM configuration, but use V3–V2 in a 16-bit ROM configuration. Note that any data transfer between either PC Card or ISA controllers always uses byte lanes V3 and V2.

In a 32-bit configuration, the ROM controller is using byte lanes that were previously used only by the VL and DRAM interfaces, so further external buffering may be required. Whereas the $\overline{\text{DBUFOE}}$ signal is used to control the electrical connection of the ROM devices with

byte lanes V3 and V2 when a 16-bit ROM interface is used with a 32-bit DRAM interface, the R32BFOE signal is used to control the electrical connection of the ROM devices with byte lanes V1 and V0 when a 32-bit ROM interface is used with any DRAM interface width. The DBUFRDH and DBUFRDL signals are the data direction controls for the buffers which are connected to bytes lanes V3 and V2 respectively. The ROMRD signal is used as the direction control for the V1 and V0 byte lane buffers, should they be required in the system.

The use of R32BFOE and associated buffer is at the discretion of the system designer. It should be used if the ROM device that is connected to the low word of a 32-bit ROMCS0 interface will load the bus too heavily for proper DRAM/VL-bus operation. The use of DBUFOE is also at the discretion of the system designer, but will probably be required if the system allows use of PC Card or ISA expansion buses.

8.5 INITIALIZATION

A portion of the ROM/Flash interface is enabled at power-on reset to support boot-up of system firmware.

By default, only two regions are enabled by the ROM controller. They are enabled for ROMCS0 and for linear accesses only. These regions are the 64-Kbyte block from 3FF0000–3FFFFFFh that encompasses the normal CPU boot vector segment, and the 64-Kbyte block from 00F0000–00FFFFFh that encompasses the aliased boot-vector segment. On an x86 CPU, the normal boot vector (the place where the CPU fetches the first instruction after reset) will be at the top of the address space minus 15 bytes. Because the ÉlanSC400 and ÉlanSC410 microcontrollers do not in any way utilize the CPU address bits A32–A26, these address bits are ignored, and only the 26 address bits from A25–A0 are used to specify the boot vector. This means that on the ÉlanSC400 and ÉlanSC410 microcontrollers, the normal boot vector will be 3FFFFF0h (instead of FFFFFFF0h for a standard Am486 microprocessor), and the first instruction following reset will be fetched from this location.

After reset on an Am486 CPU, the code segment register is set to F000h, and A31–A20 (effectively A25–A20 on the ÉlanSC400 and ÉlanSC410 microcontrollers) are held in the asserted state. Because segment registers must be multiplied by 16 to obtain the base physical address, at reset, the base physical address for the ÉlanSC400 and ÉlanSC410 microcontrollers is 3FF0000h. The default instruction pointer value of FFF0h is added to this base address, and the result is that the absolute physical address for the first instruction fetch for the ÉlanSC400 and ÉlanSC410 microcontrollers is 3FFFFF0h as stated above. Even though the CPU is in real mode, A25–A20 will remain asserted until an inter-segment (far) jump or call is made. When this is done, address bits A25–A20 are deasserted by the CPU, and the code fetches come from addresses that are below 1 Mbyte. Because of this Am486 CPU behavior, the ÉlanSC400 and ÉlanSC410 microcontrollers by default support an enabled linear address decode of 64 Kbytes in this high segment of the ROMCS0 space to support extended boot code that may want to reside at the top of the ROMCS0 space.

On a typical PC/AT-compatible system, the boot vector behavior is as described above, but in the top 15 bytes, the code performs a far jump to some entry point in the PC/AT-compatible BIOS ROM with a code segment of F000h. As described above, the far jump causes subsequent accesses to be performed with A25–A20 deasserted. This means that immediately following the far jump, code fetches will be from the PC/AT-compatible BIOS that resides in the 64-Kbyte segment from 00F0000–00FFFFFh. To support this PC/AT quirk, the ÉlanSC400 and ÉlanSC410 microcontrollers enable this region also by default for linear ROMCS0 accesses.

Note that, if the device connected to the boot ROM chip select (ROMCS0) is less than or equal to 1 Mbyte in size, it will alias throughout the 64-Mbyte ROMCS0 address space,

and the ROM device will not be able to distinguish between two addresses such as 3FFFFF0h and 00FFFF0h. This is the typical case in a PC/AT-compatible system. If, however, the device is greater than1 Mbyte, the ROM will decode more address lines, and the device will be able to distinguish between the sample addresses of 3FFFFF0h and 00FFFF0h. Because of this, boot ROM devices used in PC/AT-compatible environments that are larger than 1 Mbyte must have far jump instructions located in the top 16 bytes of the physical ROM device. Failure to do this will cause invalid instructions to be fetched by the CPU during boot-up.

8.5.1 Configuring the ROMCS0 Interface Using Pin Straps

Several aspects of the ROMCS0 interface must be established for devices that contain the boot code prior to the first instruction fetch. These include selection of the data bus width (8/16/32 bits), selection of the boot device (ROMCS0 or PC Card Socket A), and the selection of GPIO pins or buffer control signals (GPIO_CS4–GPIO_CS2 or DBUFOE, DBUFRDH, DBUFRDL, and R32BFOE).

Four configuration pin straps, which are sampled at power-on reset, are used to configure those functions that must be selected at reset, prior to firmware execution.

- CFG1-CFG0 are used to select between 8-, 16-, or 32-bit data bus widths for the physical device that is connected to the ROMCS0 pin. (Data-width selection for the devices that connect to ROMCS1 and ROMCS2 is done through a programmable register.)
- The CFG2 pin strap on the ÉlanSC400 microcontroller selects whether or not the system will boot from the device attached to ROMCS0 or from the PC Card Socket A memory card. See Section 7.6.4.2 for more information on the redirection of ROMCS0 to PC Card Socket A.
- The CFG3 pin strap is used for selecting between the GPIO_CSx I/O pins and the SD bus buffer control signals: DBUFOE, DBUFRDL, and DBUFRDH. When the buffer control signal configuration is selected using the CFG3 pin, the DBUFOE, DBUFRDL, and DBUFRDH signals will be driven from boot time on for all accesses to the peripheral data bus. These signals are used for the external transceiver control.

Each configuration pin has an internal pull-down that will take effect to configure the ROM interface if no other external termination is supplied. The internal pull-downs on the CFG pins are very weak and may be pulled up to the CPU core voltage via a 10-kilohm resistor to select the configuration options described above.

Table 8-2 provides an overview of the configuration pin functions.These pins are described in more detail in Chapter 4.

Table 8-2 Pin Strap Bus Buffer Options

CFG3	CFG1	CFG0	$\overline{\text{ROMCS0}}$ DATA WIDTH	$\overline{\text{DBUFOE}}$ $\overline{\text{DBUFRDL}}$ $\overline{\text{DBUFRDH}}$	$\overline{\text{R32BFOE}}$
0	0	0	8-bit	Disabled	Disabled
0	0	1	8-bit	Disabled	Disabled
0	1	0	16-bit	Disabled	Disabled
0	1	1	32-bit	Disabled	Enabled
1	0	0	8-bit	Enabled	Disabled
1	0	1	8-bit	Enabled	Disabled
1	1	0	16-bit	Enabled	Disabled
1	1	1	32-bit	Enabled	Enabled

Notes:

1. *In the table above, CFG3 is defined as the enable/disable for the $\overline{\text{DBUFOE}}$, $\overline{\text{DBUFRDL}}$, and $\overline{\text{DBUFRDH}}$ signals. They can be enabled independently of whether or not a 32-bit D bus is selected via the firmware to support the VL local bus or 32-bit DRAM interface.*
2. *The 32-bit ROM option must be selected on $\overline{\text{ROMCS0}}$ for the $\overline{\text{R32BFOE}}$ signal to be enabled. The selection of the $\overline{\text{DBUFOE}}$, $\overline{\text{DBUFRDL}}$, and $\overline{\text{DBUFRDH}}$ signal are still dependent only on the CFG3 signal.*

8.5.2 Other $\overline{\text{ROMCSx}}$ Interface Configuration Options

As seen above, some features of the $\overline{\text{ROMCS0}}$ interface must be configured using hardware pin straps. Other $\overline{\text{ROMCS0}}$ features, and all features of $\overline{\text{ROMCS1}}$ and $\overline{\text{ROMCS2}}$, may be configured by software at any time after the boot code gets control. Note that even the $\overline{\text{ROMCS0}}$ interface width may be changed by software after the pin straps have initially configured it. This was provided mainly for test purposes. All of the ROM chip select interfaces support the following additional features which may be configured by software/ firmware:

8.5.2.1 Data Width Control

The $\overline{\text{ROMCSx}}$ data bus widths may each be independently configured for 8-, 16-, or 32-bit wide operation using the CSC registers for $\overline{\text{ROMCS0}}$, $\overline{\text{ROMCS1}}$, and $\overline{\text{ROMCS2}}$. As mentioned above, software control for the $\overline{\text{ROMCS0}}$ interface width was provided mainly for testing. It is not recommended that the $\overline{\text{ROMCS0}}$ data width be set outside of the pin-strap method.

Note that setting the $\overline{\text{ROMCS0}}$ interface width to 32-bit automatically enables the $\overline{\text{R32BFOE}}$ signal. Once $\overline{\text{ROMCS0}}$ is configured as 32-bit, all accesses to 32-bit ROM devices on $\overline{\text{ROMCS2}}$–$\overline{\text{ROMCS0}}$ will result in the assertion of the $\overline{\text{R32BFOE}}$ signal. Setting $\overline{\text{ROMCS1}}$ or $\overline{\text{ROMCS2}}$ to a 32-bit interface does not automatically enable $\overline{\text{R32BFOE}}$; if buffering is required in this case, it must be supplied by the board designer.

On the ÉlanSC410 microcontroller, having a 32-bit ROM interface is mutually exclusive with the matrix keyboard. On the ÉlanSC400 microcontroller, having a 32-bit ROM interface is mutually exclusive with the internal LCD graphics controller and with the matrix keyboard.

Finally, if the $\overline{\text{ROMCS0}}$ cycles have been redirected to the PC Card Socket A on the ÉlanSC400 microcontroller, the width of the access is still controlled by the CFG0 and CFG1 pin straps. The 32-bit ROM option should not be selected concurrently with the option to boot from a PC Card.

8.5.2.2 Access Speed

The ROM devices connected to $\overline{\text{ROMCS2}}$–$\overline{\text{ROMCS0}}$ can be accessed at either normal speed or at fast speed.

8.5.2.2.1 Normal-Speed Mode

When Normal-Speed mode is selected, accesses to the ROM interface occur using standard ISA-bus-compatible timings. The wait state control registers in CSC indexes 24h, 26h, and 28h have no effect in this mode. The standard ISA bus IOCHRDY signal may be driven Low during Normal-Speed ROM data transfers to add wait states to a ROM cycle.

8.5.2.2.2 Fast-Speed Mode

Fast-Speed mode can be enabled directly by a configuration bit on a per-chip select basis. Additionally, if a $\overline{\text{ROMCSx}}$ interface width is configured for 32-bit operation, that interface will automatically be forced to use fast-speed timings. If Fast-Speed mode is selected for a $\overline{\text{ROMCSx}}$ access, that access will operate at the same rate as the CPU 1x clock up to a limit of 33 MHz. In Fast-Speed mode, the access time can be slowed down to accommodate slower ROM devices by inserting wait states.

Wait states for $\overline{\text{ROMCSx}}$ cycles are controlled using the $\overline{\text{ROMCSx}}$ Configuration Register B (CSC index 24h, 26h, and 28h for $\overline{\text{ROMCS0}}$, $\overline{\text{ROMCS1}}$, and $\overline{\text{ROMCS2}}$ respectively).

The ÉlanSC400 and ÉlanSC410 microcontrollers provide wait state control for both burst and non-burst accesses. Note that burst-type accesses are not limited to burst-mode ROMs. The term *burst* as used here refers to a technology designed into some ROM devices that allows operation with fewer wait states on the second and subsequent accesses that make up a 16-byte transfer than is required on the first access of the transfer. The *burst-mode ROM* terminology comes from supporting ROM devices whose internal architecture uses a burst-mode paradigm. On the ÉlanSC400 and ÉlanSC410 microcontrollers, this support includes providing two timing sets for the device: one slower set for the first access of the burst (or non-burst) device and another faster set of timings for the remainder of the burst.

The first type of wait state (specified in the WAIT_NBRSTx bit field) is always used in the first access for either burst or non-burst supported device. It starts at the assertion of the chip select or at the transition of SA3–SA0, whichever occurs later.

The second type of wait state (specified in the WAIT_BRSTx bit field) is used only for any subsequent burst read accesses to a burst mode ROM device. It starts at the transition of SA3–SA0. The burst address valid duration depends on which wait state is used. If the wait state is set to 0, then the minimum address duration is 30 ns (one bus clock cycle). If wait states are added via the deassertion of IOCHRDY, the data setup time to IOCHRDY assertion is 0 ns (minimum).

System firmware must set up the wait state usage via the ROMCSx_WS_SLCT bits. These bits are located in the $\overline{\text{ROMCSx}}$ Configuration Register A (CSC index 23h, 25h, and 27h for $\overline{\text{ROMCS0}}$, $\overline{\text{ROMCS1}}$, and $\overline{\text{ROMCS2}}$ respectively).

If ROMCSx_WS_SLCT = 0, then it will be assumed that a burst mode capable ROM is *not* installed in the system, and the WAIT_NBRSTx timings will always be used for all ROM accesses.

If ROMCSx_WS_SLCT = 1, then it will be assumed that a burst-mode-capable ROM is installed in the system. The first access to the ROM under these conditions will use the wait states defined by the WAIT_NBRSTx bit field, and then the remainder of the accesses that make up a 16-byte transfer will use the faster timing that is specified by the WAIT_BRSTx bit field.

Note that burst-mode timings on the ROM interface will only be used when the ROM controller is fulfilling an internal CPU burst request to support a cache line fill. At all other times, non-burst-mode wait states will be used. Thus, burst-mode ROM timings will only be used for paragraph-aligned accesses, because the CPU will not request an internal burst cycle otherwise.

Note that, under certain conditions, the ROM controller assembles data as a double word before transfer to the CPU. The conditions are that the ROM access is a double-word-aligned read which is configured to be cacheable with the CPU cache enabled, and the ROM interface width is configured to be 8 or 16 bits. While the ROM controller is building the double word, both the ROM chip select and the $\overline{\text{ROMRD}}$ signal are held in the active state while A0 and A1 change to address ROM data as required. This is done regardless of whether a burst-mode-capable ROM is in the system or not. While this feature improves performance for very fast ROM devices, it can cause some confusion if the $\overline{\text{ROMCSx}}$ or $\overline{\text{ROMRD}}$ signals are being used as clocks for a logic analyzer that is capturing state-mode data. Simply making the ROM accesses noncacheable will cause the chip select and $\overline{\text{ROMRD}}$ signal to toggle for each ROM access.

8.5.2.3 Early Chip Select

Controls exist for each of the ROM chip selects to specify chip select qualification. Reducing the qualifiers brings the chip select out earlier, which may be required under certain circumstances.

For Normal-Speed mode read operations, disabling the early chip select feature causes the chip select to come out when the address decode is true and the $\overline{\text{ROMRD}}$ or $\overline{\text{ROMWR}}$ command is asserted, and an edge is seen on the internal ROM controller clock. Normal-Speed mode write operations (to a Flash device, for example) require that the early chip select feature be enabled. When the early chip select feature is enabled, the chip select comes out as a result of address decode being true with no other qualification, regardless of whether Normal or Fast-Speed mode is configured.

For Fast-Speed mode operations with the early chip select feature disabled, the chip select comes out when the address decode is true, and an edge is seen on the internal ROM controller clock. In this case, no qualification with the $\overline{\text{ROMRD}}$ or $\overline{\text{ROMWR}}$ command is performed.

Table 8-3 shows how various fields in the CSC indexed registers control configuration of the ROM/Flash interface.

Table 8-3 $\overline{\text{ROMCSx}}$ Configuration Dependencies

$\overline{\text{ROMCSx}}$ Configuration Summary	DSIZEx[1–0]	$\overline{\text{ROMCSx}}$ Data Bus Width	$\overline{\text{ROMCS0}}$_ WS_SLCT	FAST_ $\overline{\text{ROMCSx}}$
8-bit, Normal-Speed, Non-Burst	0 x	8-bit	don't care	0
8-bit, Fast-Speed, Non-Burst	0 x	8-bit	don't care	1
16-bit, Normal-Speed, Non-Burst	1 0	16-bit	don't care	0
16-bit, Fast-Speed, Non-Burst	1 0	16-bit	0	1
16-bit, Fast-Speed, Burst-Capable	1 0	16-bit	1	1
32-bit, Fast-Speed, Non-Burst	1 1	32-bit	0	don't care
32-bit, Fast-Speed, Burst-Capable	1 1	32-bit	1	don't care

Notes:

Non-burst = Not capable of burst-mode ROM interface timings

Burst-capable = Capable of burst-mode ROM interface timings under conditions specified in bit 3 of CSC index registers 23h, 25h, and 27h.

8.6 POWER MANAGEMENT

To improve power dissipation, the ROM/Flash interface's internal clock is turned off if there is no access to the interface or if the access is to the ISA bus.

Operation of the ROM/Flash interface is affected by the power-management functions shown in Table 8-4.

Table 8-4 Power Management in the ROM/Flash Interface

ROM/Flash Interface Event	Description	Power Management Effect			
		Wake-Up	Activity	SMI	NMI
ROM access	Triggered by the falling edge of the $\overline{\text{ROMCS2}}$–$\overline{\text{ROMCS0}}$ chip selects qualified with the command (ROM Read/Write)		Programmable		

CHAPTER

9 DRAM CONTROLLER

9.1 SYSTEM DESIGN

The ÉlanSC400 and ÉlanSC410 microcontrollers can directly control up to 64 Mbytes of DRAM. The integrated DRAM controller interfaces gluelessly to most commodity FPM (Fast Page Mode) and EDO (Extended Data Out, sometimes referred to as hyper-page mode) 3.3-V, 70 ns DRAM devices. The following features and constraints should be considered carefully, as they may affect overall system design.

A. Up to four DRAM banks are supported, unless the matrix keyboard is to be used (see item F below).

B. Each bank has an independently selectable width of 16 or 32 bits. However, if any DRAM bank is configured to be 32 bits, the system must meet these constraints:

   — On the ÉlanSC400 microcontroller, the internal graphics controller must not be used.

   — The internal matrix keyboard interface must not be used (see item F below).

   — An external buffer might be required for the 16-bit SD bus, which is multiplexed with D31–D16, and a pull-up might be required on CFG3 to reconfigure GPIO_CS4–GPIO_CS2 as buffer control signals $\overline{\text{DBUFOE}}$, $\overline{\text{DBUFRDL}}$, and $\overline{\text{DBUFRDH}}$.

C. Each bank has an independently selectable depth and symmetry. (Symmetry is the term used to describe the DRAM's internal row/column configuration, e.g., how close the number of rows is to the number of columns.) All devices in a given bank must have the same depth and symmetry, but the physical width of the devices making up the bank is irrelevant to the ÉlanSC400 and ÉlanSC410 microcontrollers as long as electrical signal loading constraints are not violated. Supported device depths and symmetries are listed in Table 9-3. The data sheet for the DRAM device should be checked against the table to make sure the device is supported.

D. Each bank's device type (FPM or EDO) can be set independently. The device type must be set correctly, and FPM and EDO devices may not be mixed in the same bank.

E. If DRAMs requiring the MA12 signal (e.g., asymmetric 8-Mbit or 16-Mbit depths) are to be used, the matrix keyboard interface may not be used (see item F below). Also, in this case, if all DRAM banks are 16 bits wide, at least one of the enabled banks must be Bank 2 or Bank 3, to force proper output of the MA12 signal. (Any given set of banks can be enabled, e.g., Bank 2 can be enabled without enabling Bank 0 or Bank 1.)

F. Setting the width of Bank 0 or Bank 1 to 32 bits, or enabling Bank 2 or Bank 3, causes the DRAM controller to pre-empt KBD_ROW6–KBD_ROW0. If the internal matrix keyboard interface is to be used, the following limitations apply:

   — All banks must be 16 bits wide because $\overline{\text{CASL2}}$, $\overline{\text{CASL3}}$, $\overline{\text{CASH2}}$, and $\overline{\text{CASH3}}$ are multiplexed with KBD_ROW0, KBD_ROW1, KBD_ROW2, and KBD_ROW3.

   — Only two banks (0 and 1) may be used because $\overline{\text{RAS2}}$ and $\overline{\text{RAS3}}$ are multiplexed with KBD_ROW4 and KBD_ROW5.

   — Asymmetric 8-Mbit and 16-Mbit depth DRAMs are not supported because MA12 is multiplexed with KBD_ROW6.

G. Bank 0 may be interleaved with Bank 1, and/or Bank 2 may be interleaved with Bank 3, as long as the banks to be interleaved with each other contain identical FPM devices. The ÉlanSC400 and ÉlanSC410 microcontrollers do not alter memory access timing on interleaved banks (because data bus contention would increase power consumption), but the page size is effectively doubled, which can increase page hit frequency, and thus performance, in some applications.

H. The DRAM controller is disabled at power-on reset. The DRAM drive strength, timing, and interleaving parameters, and each bank's type (EDO or FPM) and bank configuration (depth, width, symmetry) must be programmed before the DRAM is used. This requires system software (even in embedded systems, unless the DRAM type is guaranteed never to change) to detect the DRAM type and configuration, and program the controller, very early in the boot process. Section 9.5 describes the algorithm required to determine the type and configuration.

I. If a DRAM device requiring refresh at greater than a 64-KHz rate (note that no such devices are available at press time) is used, the device cannot be refreshed during Suspend mode unless self-refresh is chosen. Self-refresh mode is global—if chosen, all DRAM devices in the system must support self-refresh.

J. If the microcontroller is to operate at 2.7 volts, one wait state must be added to DRAM hits generated by the MMU. This is done by setting bit 5 in the Cache and VL Miscellaneous Register (CSC index 14h).

9.2 REGISTERS

A summary listing of the chip setup and control (CSC) registers used to control the DRAM controller is shown in Table 9-1. Complete register descriptions can be found in the *Élan™SC400 Microcontroller Register Set Reference Manual* (order #21032).

Table 9-1 DRAM Controller Register Summary

Register	I/O Address	DRAM Controller Function Keyword	Description in Register Set Manual
DRAM Bank 0 Configuration Register	22h/23h Index 00h	DRAM Bank 0 configuration[1]: enable, data width and depth, address symmetry, and FPM/EDO selection	page 3-10
DRAM Bank 1 Configuration Register	22h/23h Index 01h	DRAM Bank 1 configuration[1]: enable, data width and depth, address symmetry, and FPM/EDO selection	page 3-11
DRAM Bank 2 Configuration Register	22h/23h Index 02h	DRAM Bank 2 configuration[1]: enable, data width and depth, address symmetry, and FPM/EDO selection	page 3-12
DRAM Bank 3 Configuration Register	22h/23h Index 03h	DRAM Bank 3 configuration[1]: enable, data width and depth, address symmetry, and FPM/EDO selection	page 3-13
DRAM Control Register	22h/23h Index 04h	All banks: EDO detect, interleave options, $\overline{RAS}$-to-$\overline{CAS}$ delay, $\overline{CAS}$ precharge delay, $\overline{CAS}$ pulse width, and $\overline{MWE}$ setup time	page 3-14
DRAM Refresh Control Register	22h/23h Index 05h	All banks: Refresh enable, request period, self-refresh, input source of the refresh timer, $\overline{RAS}$ time-out value	page 3-16
Drive Strength Control Register A	22h/23h Index 06h	All banks: I/O pad drive strength for D15–D0, MA12–MA0, $\overline{MWE}$, $\overline{RAS3}$–$\overline{RAS0}$	page 3-17
Drive Strength Control Register B	22h/23h Index 07h	All banks: I/O pad drive strength for SA23–SA0, SD15–SD0	page 3-18
Cache and VL Miscellaneous Register	22h/23h Index 14h	MMU DRAM access delay, 2.7-V operation	page 3-23
Activity Source Enable Register B	22h/23h Index 63h	Activity source enable: CPU access to DRAM (non-graphics access)	page 3-72
Activity Source Status Register B	22h/23h Index 67h	Activity source status: CPU access to DRAM (non-graphics access)	page 3-76
Activity Classification Register B	22h/23h Index 6Bh	Primary or secondary activity classification: CPU access to DRAM (non-graphics access)	page 3-80
Suspend Pin State Register A	22h/23h Index E3h	DRAM interface state in Suspend mode	page 3-184

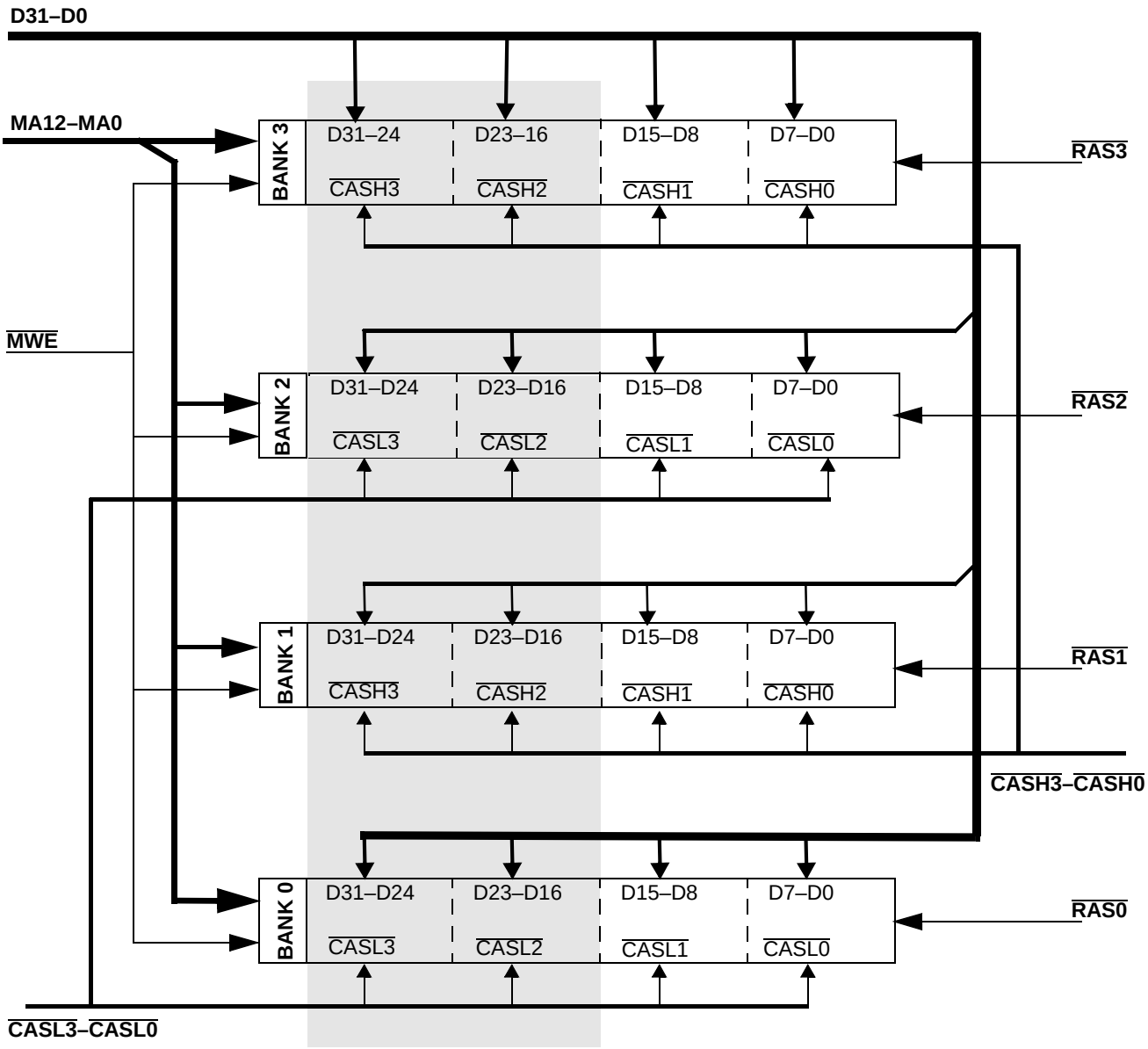
Note:

1. $\overline{CASL3}$–$\overline{CASL2}$, $\overline{CASH3}$–$\overline{CASH2}$, $\overline{RAS3}$–$\overline{RAS2}$, and MA12 *can be enabled by setting the correct bits in any of the four configuration registers (32-bit data width and either Bank 0 or Bank 1 enabled, or just Bank 2 or Bank 3 enabled).*

9.3 BLOCK DIAGRAM

Figure 9-1 shows an example DRAM subsystem with all four banks populated. The memory address (MA), data (D), and memory write enable ($\overline{MWE}$) signals are shared by all banks. The DRAM output enables ($\overline{OE}$) are not driven by the ÉlanSC400 and ÉlanSC410 microcontrollers and should be grounded. Each bank, 0–3, has a corresponding $\overline{RAS}$ signal. Each microcontroller byte lane, 0–3, has a corresponding $\overline{CAS}$ signal. The $\overline{CAS}$ signals are further subdivided into Low and High ($\overline{CASLx}$ and $\overline{CASHx}$) signals to support interleaving. Banks 0 and 2 share $\overline{CASL3}$–$\overline{CASL0}$ and banks 1 and 3 share $\overline{CASH3}$–$\overline{CASH0}$. Banks configured for 16-bit operation do not use $\overline{CASL3}$–$\overline{CASL2}$, $\overline{CASH3}$–$\overline{CASH2}$, or D31–D16, and, if the matrix keyboard controller is to be used, $\overline{CASL3}$–$\overline{CASL2}$, $\overline{CASH3}$–$\overline{CASH2}$, $\overline{RAS3}$–$\overline{RAS2}$, and MA12 may not be used by the DRAM array.

Figure 9-1 DRAM Bank Configuration



Note:

The shaded area of each bank and its associated signals are used for 32-bit DRAM only.

The OE signals for all banks should be grounded, since the ÉlanSC400 and ÉlanSC410 microcontrollers implement "early" write.

9.4 OPERATION

9.4.1 System Address Decoding

The DRAM controller receives physical addresses from the CPU, the DMA controller, and the graphics controller, and decomposes them as follows:

- The DRAM controller uses information about each bank's address and size to select the correct bank (which $\overline{RAS}$ strobe will be asserted). If two banks are interleaved (using the DRAM Control Register, CSC index 04h), both banks' $\overline{RAS}$ strobes are asserted simultaneously.
- The DRAM controller generates an address offset by subtracting the start of the selected bank from the physical address.
- The highest-order bits of the address offset will be asserted on MA12–MA0 as the row address (with the $\overline{RAS}$ strobe), the middle bits of the offset will be asserted on MA12–MA0 as the column address (with the $\overline{CAS}$ strobe(s)), and the lowest order bits will be used in conjunction with the size of the read or write request to determine which byte lanes will be read or written (which $\overline{CAS}$ strobes will be asserted). The number of row, column, and byte lane address bits depends on the particular DRAM bank's device configuration. Table 9-2 shows the byte lane mapping. Table 9-4 shows the row and column mapping for non-interleaved banks, and Table 9-5 shows the row and column mapping for interleaved banks.

9.4.1.1 $\overline{RAS}$ Strobe Assertion (Bank Selection)

Bank 0 is considered to be the first bank, and Bank 3 is the last bank. Any combination of banks can be enabled (e.g., it is not necessary to enable Bank 0 in order to enable Bank 2). The first enabled DRAM bank is located in the CPU address space at physical address 0000000h. The size of each enabled bank is automatically calculated by the ÉlanSC400 and ÉlanSC410 microcontrollers using the WIDTH and DEPTH fields programmed into each DRAM configuration register, and all enabled banks are automatically placed contiguously in the memory space. There is no direct programmer control over bank location or ordering, and there are no bank alignment restrictions for the programmer to worry about. For the purposes of length and start address calculation, interleaving two banks effectively combines them into a single larger bank.

9.4.1.2 $\overline{CAS}$ Strobe Assertion (Byte Lane Selection)

Table 9-2 shows a mapping of physical addresses to $\overline{CAS}$ strobes. The microcontroller simultaneously issues up to two $\overline{CAS}$ strobes during a memory cycle addressed to a 16-bit bank, or up to four strobes during a cycle addressed to a 32-bit bank. The number of $\overline{CAS}$ cycles required depends on the bank width and the originator of the memory request:

- DMA controller requests are always satisfied in one $\overline{CAS}$ cycle. 8-bit DMA requests assert only one $\overline{CAS}$ strobe, and 16-bit DMA requests assert two $\overline{CAS}$ strobes and access an aligned word.
- On the ÉlanSC400 microcontroller, graphics controller requests fill up the graphics controller FIFO, by burst-reading as much data as required via optimized back-to-back $\overline{CAS}$ cycles, starting with the lowest order address. Because the graphics controller only supports 16-bit DRAM reads, two $\overline{CAS}$ strobes are asserted on each cycle.
- CPU requests are always treated by the DRAM controller as 32 bits wide, so if the request is addressed to a 16-bit bank, two $\overline{CAS}$ cycles will always be generated, even if $\overline{CAS}$ no strobes are asserted during one of them. The highest order word is always read or written first.

The DRAM controller will "burst" CPU cache line fills and flushes using four 32-bit or eight 16-bit back-to-back $\overline{CAS}$ cycles, if the CPU clock speed is 16 MHz or above. The CPU core dictates the order in which the four double words are accessed. See the *Am486DX/DX2 Microprocessor Hardware Reference Manual* (order #17965) for details. For 16-bit banks, each of the four 32-bit memory cycles is stretched into two $\overline{CAS}$ cycles, with the highest order word accessed first.

Table 9-2 System Address to $\overline{CAS}$ Strobe Mapping

Byte Lanes	$\overline{CASL0}$	$\overline{CASL1}$	$\overline{CASL2}$	$\overline{CASL3}$	$\overline{CASH0}$	$\overline{CASH1}$	$\overline{CASH2}$	$\overline{CASH3}$
16-Bit Non-interleaved	$\overline{A0}$	A0	inactive	inactive	$\overline{A0}$	A0	inactive	inactive
32-bit Non-interleaved	$\overline{A1}$ * $\overline{A0}$	$\overline{A1}$ * A0	A1 * $\overline{A0}$	A1 * A0	$\overline{A1}$ * $\overline{A0}$	$\overline{A1}$ * A0	A1 * $\overline{A0}$	A1 * A0
16-bit Interleaved	$\overline{A1}$ * $\overline{A0}$	$\overline{A1}$ * A0	inactive	inactive	A1 * $\overline{A0}$	A1 * A0	inactive	inactive
32-bit Interleaved	$\overline{A2}$ * $\overline{A1}$ * $\overline{A0}$	$\overline{A2}$ * $\overline{A1}$ * A0	$\overline{A2}$ * A1 * $\overline{A0}$	$\overline{A2}$ * A1 * A0	A2 * $\overline{A1}$ * $\overline{A0}$	A2 * $\overline{A1}$ * A0	A2 * A1 * $\overline{A0}$	A2 * A1 * A0

Table 9-3 Supported DRAM Bank Configurations

	Physical Bank Configuration				CSC Index 00–03h Bit Values		
Bank Size	**Depth (Bits)**	**Width (Bits)**	**Rows**	**Columns**	**ASYM**	**WIDTH**	**DEPTH**
512 Kbytes	256 K	16	9	9	0	0	000
1 Mbyte	256 K 512 K	32 16	9 10	9 9	0 1	1 0	000 001
2 Mbytes	512 K 1 M	32 16	10 10 12	9 10 8	1 0 1	1 0 0	001 010 010
4 Mbytes	1 M 2 M	32 16	10 12 11 12	10 8 10 9	0 0 1	1 1 0 0	010 010 011 011
8 Mbytes	2 M 4 M	32 16	11 12 11 12	10 9 11 10	0 1 0 1	1 1 0 0	011 011 100 100
16 Mbytes	4 M 8 M	32 16	11 12 12 13[1]	11 10 11 10	0 1 0 1	1 1 0 0	100 100 101 101
32 Mbytes	8 M 16 M	32 16	12 13[1] 12 13[1]	11 10 12 11	0 1 0 1	1 1 0 0	101 101 110 110
64 Mbytes	16 M	32	12 13[1]	12 11	0 1	1 1	110 110

Note:

1. In this case, if all DRAM banks are 16 bits wide, at least one of the enabled banks must be Bank 2 or Bank 3, to force proper output of the MA12 signal.

Table 9-4 Non-Interleaved System Address (A) to Memory Address (MA) Mapping

CSC Index 00–03h Bit Values			DRAM Configuration	Non-Interleaved MA Mapping System Address to MA Mapping for Rows/Columns												
Asym	Width	Depth	Bytes: Banks x Rows x Cols x Bits, Page Size, Refresh Cycles	MA 12	MA 11	MA 10	MA 9	MA 8	MA 7	MA 6	MA 5	MA 4	MA 3	MA 2	MA 1	MA 0
0	0	000	0.5 MB: 1x9x9x16 1 Kbyte, 512					A12 A9	A11 A8	A10 A7	A13 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A1
0	0	001	N/A													
0	0	010	2 MB: 1x10x10x16 2 Kbyte, 1024				A13 A10	A12 A9	A11 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A1
0	0	011	4 MB: 1x11x10x16 2 Kbyte, 2048			A11	A13 A10	A12 A9	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A1
0	0	100	8 MB: 1x11x11x16 4 Kbyte, 2048			A22 A11	A13 A10	A12 A9	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A1
0	0	101	16 MB: 1x12x11x16 4 Kbyte, 4096		A23	A22 A11	A13 A10	A12 A9	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A1
0	0	110	32 MB: 1x12x12x16 8 Kbyte, 4096		A23 A12	A24 A11	A13 A10	A22 A9	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A1
0	0	111	N/A													
0	1	000	1 MB: 1x9x9x32 2 Kbyte, 512					A13 A9	A12 A8	A11 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
0	1	001	N/A													
0	1	010	4 MB: 1x10x10x32 4 Kbyte, 1024				A21 A11	A13 A9	A12 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
0	1	011	8 MB: 1x11x10x32 4 Kbyte, 2048			A22	A21 A11	A13 A9	A12 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
0	1	100	16 MB: 1x11x11x32 8 Kbyte, 2048			A22 A12	A21 A11	A13 A9	A23 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
0	1	101	32 MB: 1x12x11x32 8 Kbyte, 4096		A24	A22 A12	A21 A11	A13 A9	A23 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
0	1	110	64 MB: 1x12x12x32 16 Kbyte, 4096		A25 A13	A22 A12	A21 A11	A24 A9	A23 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
0	1	111	N/A													

Table 9-4 Non-Interleaved System Address (A) to Memory Address (MA) Mapping (cont.)

CSC Index 00–03h Bit Values			DRAM Configuration	Non-Interleaved MA Mapping System Address to MA Mapping for Rows/Columns												
Asym	Width	Depth	Bytes: Banks x Rows x Cols x Bits, Page Size, Refresh Cycles	MA 12	MA 11	MA 10	MA 9	MA 8	MA 7	MA 6	MA 5	MA 4	MA 3	MA 2	MA 1	MA 0
1	0	000	N/A													
1	0	001	1 MB: 1x10x9x16 1 Kbyte, 1024				A13	A12 A9	A11 A8	A10 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A1
1	0	010	2 MB: 1x12x8x16 0.5 Kbyte, 4096		A9	A10	A13	A12	A11 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A1
1	0	011	4 MB: 1x12x9x16 1 Kbyte, 4096		A11	A10	A13	A12 A9	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A1
1	0	100	8 MB: 1x12x10x16 2 Kbyte, 4096		A11	A22	A13 A10	A12 A9	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A1
1	0	101	16 MB: 1x13x10x16 2 Kbyte, 8192	A11	A23	A22	A13 A10	A12 A9	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A1
1	0	110	32 MB: 1x13x11x16 4 Kbyte, 8192	A12	A23	A24 A11	A13 A10	A22 A9	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A1
1	0	111	N/A													
1	1	000	N/A													
1	1	001	2 MB: 1x10x9x32 2 Kbyte, 1024				A11	A13 A9	A12 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
1	1	010	4 MB: 1x12x8x32 1 Kbyte, 4096		A10	A11	A21	A13	A12 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A9
1	1	011	8 MB: 1x12x9x32 2 Kbyte, 4096		A11	A22	A21	A13 A9	A12 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
1	1	100	16 MB: 1x12x10x32 4 Kbyte, 4096		A23	A22	A21 A11	A13 A9	A12 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
1	1	101	32 MB: 1x13x10x32 4 Kbyte, 8192	A12	A24	A22	A21 A11	A13 A9	A23 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
1	1	110	64 MB: 1x13x11x32 8 Kbyte, 8192	A13	A25	A22 A12	A21 A11	A24 A9	A23 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
1	1	111	N/A													

Note:

To use Table 9-4, first find the ASYM, WIDTH, and DEPTH values for the desired DRAM bank configuration in Table 9-3, "Supported DRAM Bank Configurations," on page 9-7.

Table 9-5 Interleaved System Address (A) to Memory Address (MA) Mapping

CSC Index 00–03h Bit Values			DRAM Configuration	Interleaved MA Mapping System Address to MA Mapping for Rows/Columns												
Asym	Width	Depth	Bytes: Banks x Rows x Cols x Bits, Page Size, Refresh Cycles	MA 12	MA 11	MA 10	MA 9	MA 8	MA 7	MA 6	MA 5	MA 4	MA 3	MA 2	MA 1	MA 0
0	0	000	1 MB: 2x9x9x16 2 Kbyte, 512					A12 A9	A11 A8	A13 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
0	0	001	N/A													
0	0	010	4 MB: 2x10x10x16 4 Kbyte, 1024				A13 A11	A12 A9	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
0	0	011	8 MB: 2x11x10x16 4 Kbyte, 2048			A12	A13 A11	A22 A9	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
0	0	100	16 MB: 2x11x11x16 8 Kbyte, 2048			A23 A12	A13 A11	A22 A9	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
0	0	101	32 MB: 2x12x11x16 8 Kbyte, 4096		A23	A24 A12	A13 A11	A22 A9	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
0	0	110	64 MB: 2x12x12x16 16 Kbyte, 4096		A25 A13	A24 A12	A23 A11	A22 A9	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
0	0	111	N/A													
0	1	000	2 MB: 2x9x9x32 4 Kbyte, 512					A13 A9	A12 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A11	A14 A10
0	1	001	N/A													
0	1	010	8 MB: 2x10x10x32 8 Kbyte, 1024				A21 A12	A13 A9	A22 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A11	A14 A10
0	1	011	16 MB: 2x11x10x32 8 Kbyte, 2048			A22	A21 A12	A13 A9	A23 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A11	A14 A10
0	1	100	32 MB: 2x11x11x32 16 Kbyte, 2048			A22 A13	A21 A12	A24 A9	A23 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A11	A14 A10
0	1	101	64 MB: 2x12x11x32 16 Kbyte, 4096		A25	A22 A13	A21 A12	A24 A9	A23 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A11	A14 A10
0	1	110	N/A													
0	1	111	N/A													

Table 9-5 Interleaved System Address (A) to Memory Address (MA) Mapping (cont.)

CSC Index 00–03h Bit Values			DRAM Configuration	Interleaved MA Mapping System Address to MA Mapping for Rows/Columns												
Asym	Width	Depth	Bytes: Banks x Rows x Cols x Bits, Page Size, Refresh Cycles	MA 12	MA 11	MA 10	MA 9	MA 8	MA 7	MA 6	MA 5	MA 4	MA 3	MA 2	MA 1	MA 0
1	0	000	N/A													
1	0	001	2 MB: 2x10x9x16 2 Kbyte, 1024				A13	A12 A9	A11 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
1	0	010	4 MB: 2x12x8x16 1 Kbyte, 4096		A11	A10	A13	A12	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A9
1	0	011	8 MB: 2x12x9x16 2 Kbyte, 4096		A11	A12	A13	A22 A9	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
1	0	100	16 MB: 2x12x10x16 4 Kbyte, 4096		A23	A12	A13 A11	A22 A9	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
1	0	101	32 MB: 2x13x10x16 4 Kbyte, 8192	A12	A23	A24	A13 A11	A22 A9	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
1	0	110	64 MB: 2x13x11x16 8 Kbyte, 8192	A13	A25	A24 A12	A23 A11	A22 A9	A21 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A2	A14 A10
1	0	111	N/A													
1	1	000	N/A													
1	1	001	4 MB: 2x10x9x32 4 Kbyte, 1024				A21	A13 A9	A12 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A11	A14 A10
1	1	010	8 MB: 2x12x8x32 2 Kbyte, 4096		A11	A22	A21	A13	A12 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A9	A14 A10
1	1	011	16 MB: 2x12x9x32 4 Kbyte, 4096		A23	A22	A21	A13 A9	A12 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A11	A14 A10
1	1	100	32 MB: 2x12x10x32 8 Kbyte, 4096		A13	A22	A21 A12	A24 A9	A23 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A11	A14 A10
1	1	101	64 MB: 2x13x10x32 8 Kbyte, 8192	A13	A25	A22	A21 A12	A24 A9	A23 A8	A20 A7	A19 A6	A18 A5	A17 A4	A16 A3	A15 A11	A14 A10
1	1	110	N/A													
1	1	111	N/A													

Note:

To use Table 9-5, first find the ASYM, WIDTH, and DEPTH values for the desired DRAM bank configuration in Table 9-3, "Supported DRAM Bank Configurations," on page 9-7.

9.4.2 Timing and Control Signal Generation

All memory controller timing is derived from a single clock, which operates at 66 MHz if the CPU speed is 33 MHz, or if the graphics controller on the ÉlanSC400 microcontroller is enabled. When the graphics controller is disabled, the memory clock operates at two times the CPU bus clock.

The *Élan™ SC400 and ÉlanSC410 Microcontrollers Data Sheet* (order #21028) shows all the relevant timing diagrams.

9.4.2.1 Page Mode and RAS Time-Outs

The DRAM controller uses the page-mode capabilities of the DRAM whenever the CPU speed is greater than 8 MHz. This can greatly speed up some DRAM accesses, particularly graphics controller FIFO fills and CPU burst cycles. After a row address is driven out on MA12–MA0 with a $\overline{RAS}$ strobe, the DRAM controller may keep issuing new column addresses on MA12–MA0 with $\overline{CAS}$ strobes until either a new page is required, a refresh cycle is required, or the DRAM's t_{RAS} parameter ($\overline{RAS}$ time-out value) would be violated. The t_{RAS} value may be set to either 10 or 100 µs via bit 5 of the DRAM Refresh Control Register (CSC index 05h).

9.4.2.2 $\overline{MWE}$ Generation

The controller asserts $\overline{MWE}$ one cycle before asserting any $\overline{CAS}$ strobes so that the DRAMs can distinguish write from read cycles (this assertion of $\overline{MWE}$ before $\overline{CAS}$ is referred to as an *early write* cycle). The DRAMs will latch the written data on the falling edge of $\overline{CAS}$, assuming that their t_{WCS} parameter is not violated. For systems with heavily loaded $\overline{MWE}$ lines, the DRAM Control Register (CSC index 04h[6]) can be set to delay $\overline{CAS}$ after $\overline{MWE}$ by an extra clock period, to ensure that the t_{WCS} parameter is met. This delay is also applied to reads (to guarantee that $\overline{MWE}$ is inactive before $\overline{CAS}$ strobes active) to meet the DRAMs' t_{RCS} parameter.

For EDO DRAMs, after the completion of a read (or multiple reads, in the case of a graphics controller FIFO fill or a CPU burst), $\overline{MWE}$ will be pulsed low (with all $\overline{CAS}$ strobes deasserted) for one memory clock to disable the DRAM outputs.

9.4.2.3 $\overline{CAS}$ Pulse Width

CSC index 04h[4] determines the minimum value of the t_{CAS} DRAM parameter (minimum active pulse width). Setting this bit adds 1 cycle to the minimum number of memory clock cycles, which is 2 for graphics controller cycles and cycles addressed to EDO DRAM and 3 for CPU or DMA cycles addressed to FPM DRAM.

9.4.2.4 $\overline{CAS}$ Precharge Delay

CSC index 04h[3] determines the minimum value of the t_{CP} DRAM parameter (minimum amount of time $\overline{CAS}$ is inactive before it goes active). If this bit is 0, the minimum t_{CP} value is 1 memory clock for normal reads and writes and 2 memory clocks for write-backs and copy-backs (a four double-word burst). (Note that the additional precharge delay will occur only between consecutive double words, not between two 16-bit writes which were broken up into two cycles to accommodate 16-bit DRAM banks.) If this bit is 1, the minimum t_{CP} value is 2 memory clocks.

9.4.2.5 Refresh

The DRAM controller performs $\overline{CAS}$-before-$\overline{RAS}$ refreshes. Refresh parameters including enable, clock source, divisor, and self refresh are selectable via CSC index 05h. The refresh clock may be sourced from the programmable interval timer (PIT) for backward PC/AT compatibility or from the 32-KHz clock.

When the 32-KHz clock is used, the refresh rate may be programmed to be 8, 16, 32, or 64 KHz. The slowest rate which is within tolerance for the chosen DRAM should be used. DRAM refresh requirements are often specified in terms of a refresh interval (e.g., how long a row can go without being refreshed). The required refresh rate can be calculated by dividing the number of rows that must be refreshed by the required refresh interval. For example, if a DRAM part is organized as 2 Mbit x 8, with 11 row addresses (meaning there are 2048 rows) and 10 column addresses, and must be refreshed in 32 ms, the formula is 2048 rows/32 ms = 64 Kbyte Rows/s.

Some DRAM devices will internally refresh multiple rows per refresh request, so the DRAM data sheet must be read carefully to understand the requirements of the particular device.

If the chosen DRAM devices require a refresh rate faster than 64 KHz (note that no such devices are available at press time), they must be refreshed using the programmable interval timer (PIT), and if the system is to support Suspend mode, the DRAM must support self-refresh, because the PIT is disabled during Suspend mode.

When the self-refresh bit in CSC index 05h is set, whenever the CPU enters Suspend mode, all system DRAMs are placed into self-refresh mode by asserting $\overline{\text{CAS}}$ before $\overline{\text{RAS}}$ and then holding both signals active.

If the memory clock is 33 MHz or greater, the $\overline{\text{RAS}}$ signal assertions and deassertions will be staggered (turned on and off one strobe at a time) to minimize switching currents and noise.

9.5 INITIALIZATION

Complete source code of a sample application that initializes the DRAM controller and determines the type and size of the attached DRAM devices can be found at ftp://ftp.amd.com/pub/epd/e86.

9.5.1 Boot Process Overview

In a closed embedded system, the designer may be able to simply choose the correct values to output to CSC indexed registers 00–07h and be finished. Systems where the DRAM parameters are not known at boot time (e.g., because there is a DRAM DIMM socket available) present more issues. Many DRAM characteristics, such as signal loading, cannot be accurately determined by software. One way to deal with this issue is to have a staged boot process, as follows:

- First, all timing and drive strength registers are programmed to assume a worst-case system. The values for this are: CSC index 04h = 5Ch, index 05h = 40h, index 06h = 00h, and index 07h = 00h. Also, if the microcontroller might be operating at 2.7 V, CSC index 14h[5] should be set.
- Next, the DRAM banks are individually tested for DRAM existence, type (EDO/FPM), and size. Banks which contain DRAM are enabled with the correct parameters. See sections 9.5.2 for a full description of this process.
- A system memory test is then performed to ensure there are no obvious problems. The user may be notified, and bad banks may be disabled, if any problems are encountered.
- If the user has control over DRAM setup parameters, such as timing and drive strength, the user's parameters must not be applied to the DRAM array until late in the boot process so that the setup program can always be used to recover the system if it becomes unbootable. After finishing or bypassing the setup menu, the system can apply user selections to CSC indexed registers 04–07h and finish booting.

9.5.2 Dynamic DRAM Detection Algorithm

Many systems require the capability to dynamically configure the DRAM controller for the installed DRAM. This involves determining the amount and type of DRAM installed, and setting the registers appropriately.

The algorithm that does this must be careful to avoid bus contention between DRAM banks, and between DRAM and ROM during the process. Avoiding this contention is very difficult, because contention can occur in several ways:

- Using DRAM during detection (e.g., using Bank 0 while detecting Bank 1) will result in contention.
- Executing the detection algorithm from 32-bit ROMs will result in contention. (If booting from 32-bit ROMs, the detection algorithm must be run from the cache.)
- Testing for EDO DRAMs must be done carefully, or contention will occur.
- The detection algorithm must disable and enable banks, but if the algorithm disables a bank while a DRAM refresh is active, contention may result. A delay must be inserted between disabling refresh and disabling any bank.
- If disabling or changing device width on a bank causes $\overline{\text{CAS}}$ signals to be transferred to the keyboard controller, a glitch on the upper $\overline{\text{CAS}}$ lines may result, causing contention. $\overline{\text{RAS2}}$, $\overline{\text{RAS3}}$, the upper $\overline{\text{CAS}}$ lines, and MA12 automatically become DRAM control signals if Bank 0 is enabled and set to 32 bits, Bank 1 is enabled and set to 32 bits, or either Bank 2 or 3 is enabled. Otherwise, they become matrix keyboard signals.

While avoiding any contention, the algorithm must determine the following for each bank:

- If the bank is populated with DRAM
- If the DRAM is EDO or FPM
- If the DRAM is asymmetrical or symmetrical
- The depth of the DRAM
- The width of the DRAM

A code sample that contains the algorithm to determine these values and program the CSC registers appropriately can be found at ftp://ftp.amd.com/pub/epd/e86.

To determine total memory size after running the algorithm, simply add up the size represented by each enabled bank (except do not add in Bank 3 if CSC index 03h is equal to 0B0h). The amount of DRAM in each bank is determined by using the depth and width fields in the bank's configuration register in the following formula:

```
DramBytes = 1 << ((depth field) + (width field) + 9);
```

In other words, the DRAM size is always 2^n, where 'n' is 9 plus the 3-bit quantity in the depth field, plus 1 if the bank is 32 bits wide.

9.6 POWER MANAGEMENT

Operation of the DRAM controller is affected by the power-management functions shown in Table 9-6.

Minimizing power consumption was a major goal in the design of the ÉlanSC400 and ÉlanSC410 microcontrollers. Some of the features of the DRAM controller that support this are not applicable to all designs and must be explicitly enabled by the designer.

- The drive strength of the DRAM controller pins can be controlled using CSC indexed registers 06h and 07h. Reducing the drive strength to the minimum required for the application will reduce power consumption and EMI emissions.
- DRAM self refresh during Suspend mode can be selected with CSC index 05h.
- Extended-refresh DRAM devices are supported. The refresh timer may be programmed to run as slowly as 8 KHz.

Other DRAM controller features that minimize power consumption are generally transparent to system design, but might be noticed during system bring-up and debug. These include:

- $\overline{\text{RAS}}$ signals are staggered during refresh for CPU bus clock frequencies of 16 and 33 MHz. $\overline{\text{RAS}}$ signals are not staggered for CPU bus clock frequencies less than 16 MHz.
- $\overline{\text{RAS}}$ and $\overline{\text{CAS}}$ signals are not generated for disabled banks during refresh.
- $\overline{\text{MWE}}$ is pulsed after reads from EDO devices to force them to three-state the data bus.
- Dynamic clock changes initiated by the PMU change the DRAM controller without extra complication.
- Suspend mode operation is accomplished with a single 32-KHz clock.

Table 9-6 Power Management in the DRAM Controller

DRAM Controller Event	Description	Power Management Effect			
		Wake-Up	Activity	SMI	NMI
DRAM access	CPU access to DRAM within graphics controller memory range		Programmable		
DRAM access	CPU access to DRAM not in graphics memory space		Programmable		

CHAPTER

10 DMA CONTROLLER

10.1 OVERVIEW

Direct memory access (DMA) permits data transfer between memory and peripherals without CPU involvement.

On the ÉlanSC400 and ÉlanSC410 microcontrollers, dual cascaded, 8237A-compatible DMA controllers provide seven user DMA channels. Of the seven internal channels, four are 8-bit channels and three are 16-bit channels.

Since the ÉlanSC400 and ÉlanSC410 microcontrollers support the standard PC/AT system architecture, the method for DMA transfer complies with the Industry Standard Architecture (ISA) specifications and will not be described in detail in this chapter.)

Any two of the seven channels can be simultaneously mapped to the external DMA request/acknowledge lines, PRDQ1–PDRQ0 and $\overline{\text{PDACK1}}$–$\overline{\text{PDACK0}}$.

DMA transfers can be initiated by external ISA peripherals or by the serial infrared port and (on the ÉlanSC400 microcontroller) the PC Card interface (Sockets A and B). Each of these internal peripherals has a field in its control register for specifying which DMA channel is to be used for the transfer. Specific information about DMA transfers in the infrared port and the PC Card controller can be found in Section 18.4.2.9 and Section 19.5.7, respectively.

The DMA controller on the ÉlanSC400 and ÉlanSC410 microcontrollers is software-compatible with the PC/AT cascaded 8237 controller pair. Its features include:

- Single, block, and demand transfer modes
- Enable/disable channel controller
- Address increment or decrement
- Software priority
- 64-Mbyte system address space for increased performance
- Dynamic clock-enable design for reducing clocked elements during DMA inactivity
- Programmable clock frequency for performance

10.2 REGISTERS

10.2.1 Direct-Mapped Registers

The DMA controller block on the ÉlanSC400 and ÉlanSC410 microcontrollers supports the following direct-mapped registers.

These registers are one per channel:

- **Memory Address Register (Read/Write)**—This register provides the lower bits of the channel memory address. It is read/written via two successive I/O accesses. It is used in conjunction with the Page Register to form a 24-bit memory address. The microcontroller can perform 26-bit DMA accesses using the Extended Page registers available in CSC indexed register space.

- **Transfer Count Register (Read/Write)**—This register is written and read in two successive bytes. The actual number of transfers will be one more than specified by this register.
- **Page Register (Read/Write)**—Provides the middle address bits during DMA transfers. The processor writes the Page Register before enabling DMA transfers.

The following registers are one per controller (slave/master):

- **Status Register (Read)**—This register is read to determine the status of DMA requests and terminal counts detected per channel.
- **Control Register (Write)**—This register controls various functions of the master or slave controller, such as priority type (fixed or rotating) and timing. It is also used to disable the master/slave controller while writing to the DMA registers.
- **Software Request Register (Write)**—Software can initiate a DMA request, as long as the controller is programmed for block mode. This register is used to select which DMA channel will assert or deassert a DMA request initiated by software.
- **Mask Register (Write)**—This register is used to mask or unmask DMA channels. Setting a mask bit to 1 disables the channel.
- **Mode Register (Write)**—This register is used to specify the transfer mode (demand, single, block, or cascade), address decrement, and type of DMA operation (verify, write, or read) per channel.
- **Clear Byte Pointer Register (Write)**—This register is used across the slave or master controller to determine which byte will be accessed in the 16-bit registers of the DMA controller.
- **Controller Reset Register (Write)**—A write of any data to this register resets the DMA controller to the same state as a hardware reset.
- **Reset Mask Register (Write)**—Writing data to this register resets the Mask Register, thereby activating the associated DMA channels.
- **General Mask Register (Write)**–This register provides another alternative for enabling the DMA channels. It is used to disable or enable incoming requests.

10.2.2 Chip Configuration and Control (CSC) Registers

A summary listing of the chip setup and control (CSC) index registers used to control the DMA controller is shown in Table 10-1. Complete register descriptions can be found in the *Élan™ SC400 Microcontroller Register Set Reference Manual* (order #21032).

CSC indexed registers provide any functionality beyond normal strict PC/AT compatibility, such as Extended Page registers and the ability to map PDRQx and $\overline{\text{PDACKx}}$ signals to specific channels of the DMA controller.

10.2.2.1 Extended Page Registers

The Extended Page registers provide the upper address bits during DMA transfers. The Extended Page registers permit DMA addresses to extend throughout the 64-Mbyte memory address space. The processor writes the Extended Page registers before enabling DMA transfers.

Table 10-1 DMA Controller Register Summary

Register	I/O Address	DMA Controller Function Keyword	Description in Register Set Manual
Pin Mux Register A	22h/23h Index 38h	ISA DMA signals enable: PDRQ0, $\overline{\text{PDACK0}}$, AEN, and TC	page 3-44
Pin Mux Register B	22h/23h Index 39h	ISA DMA signals enable: PDRQ1, $\overline{\text{PDACK1}}$, AEN, and TC	page 3-45
Wake-Up Source Enable Register C	22h/23h Index 54h	Wake-up source enable: PDRQ0 and PDRQ1	page 3-61
Wake-Up Source Status Register C	22h/23h Index 58h	Wake-up source status: PDRQ0 and PDRQ1	page 3-65
Activity Source Enable Register C	22h/23h Index 64h	Activity source enable: DMA request	page 3-73
Activity Source Status Register C	22h/23h Index 68h	Activity source status: DMA request	page 3-77
Activity Classification Register C	22h/23h Index 6Ch	Primary or secondary activity classification: DMA request	page 3-81
Clock Control Register	22h/23h Index 82h	DMA controller clock frequency select, high-speed infrared operation	page 3-90
CLK_IO Pin Output Clock Select Register	22h/23h Index 83h	Internal DMA and 2x DMA clock select for CLK_IO	page 3-91
Internal I/O Device Disable/Echo Z-Bus Configuration Register	22h/23h Index D0h	DMA0 and DMA1 slave controller disable	page 3-164
DMA Channel 0–3 Extended Page Register	22h/23h Index D9h	Highest two bits of memory address for channels 3–0	page 3-175
DMA Channel 5–7 Extended Page Register	22h/23h Index DAh	Highest two bits of memory address for channels 7–5	page 3-176
DMA Resource Channel Map Register A	22h/23h Index DBh	PDRQx/$\overline{\text{PDACKx}}$ and infrared controller mapping to internal DMA controller channels	page 3-177
DMA Resource Channel Map Register B	22h/23h Index DCh	PC Card Sockets A and B mapping to internal DMA controller channels	page 3-178
IrDA Control Register	22h/23h Index EAh	Infrared DMA start-up control, data rate select	page 3-188
IrDA Status Register	22h/23h Index EBh	Infrared DMA IRQ state and generation	page 3-190
PC Card Mode and DMA Control Register	22h/23h Index F1h	DMA enable for PC Card Sockets A and B	page 3-198

10.3 BLOCK DIAGRAM

A block diagram of the DMA controller block on the ÉlanSC400 and ÉlanSC410 microcontrollers is shown in Figure 10-1.

The DMA system supports seven DMA channels. Two DMA controllers are used: the slave controller supports four 8-bit channels and the master controller supports three 16-bit channels. Channels 0–3 must be programmed as 8-bit channels, and Channels 5–7 must

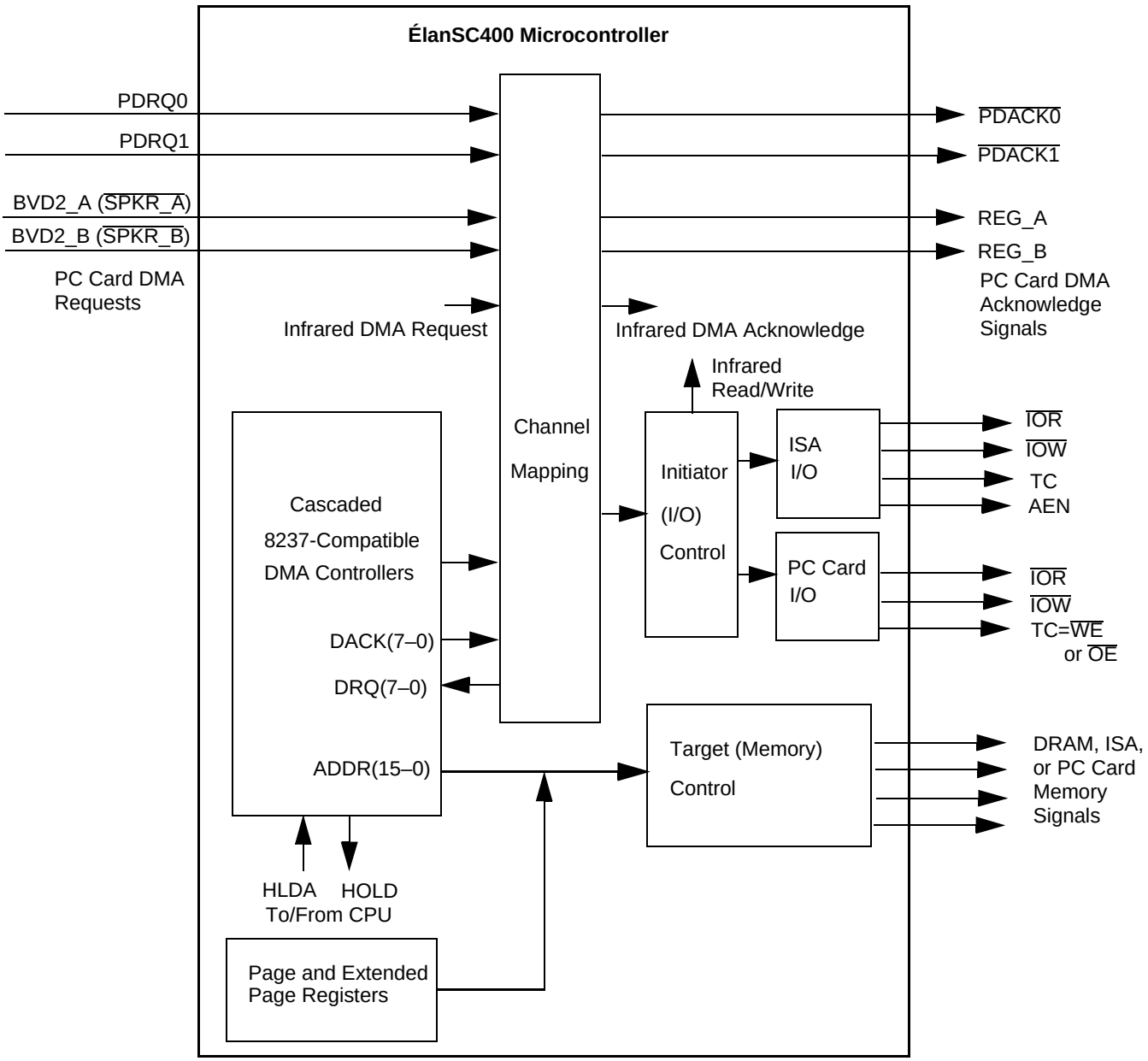
be programmed as 16-bit channels. Channel 4 must be programmed to Cascade mode and must be unmasked if any of the 8-bit channels 0–3 are to be used.

The external DMA ISA signals are shared with other functions.

- PDRQ0 and $\overline{\text{PDACK0}}$ are shared with GPIO_CS12 and GPIO_CS11, respectively.
- AEN and TC and shared with GPIO_CS10 and GPIO_CS9, respectively.
- PDRQ1 and $\overline{\text{PDACK1}}$ are shared with KBD_ROW8 and KBD_ROW7, respectively.

On the ÉlanSC400 microcontroller, PC Card DMA requests can be programmed to appear on either the WP_x pins or the BVD2_x pins.

Figure 10-1 DMA Controller Block Diagram



Note:

Instead of BVD2_A and BVD2_B, the PC Card signals WP_A and WP_B can be programmed as DMA requests. This selection is made in the PC Card Mode and DMA Control Register (CSC index F1h[7–4]). The PC Card controller is not supported on the ÉlanSC410 microcontroller.

10.4 OPERATION

The ÉlanSC400 and ÉlanSC410 microcontrollers support standard PC/AT DMA transfers as follows:

- Only fly-by DMA transfers are supported. A *fly-by transfer* is a transfer in which the data is moved from the I/O device to memory (DMA write), or from memory to the I/O device (DMA read) in a single transaction.
- Single, block, and demand transfers are supported.
- Memory-to-memory transfers are not supported.

The DMA controller operates in standard PC/AT mode at 4 MHz, or optionally at 8 or 16 MHz. The faster speed reduces DMA overhead significantly, but is non-standard. It should only be used when all DMA initiators are capable of the faster timing. The internal infrared controller is capable of using the fast DMA timing. Note that there is no method to automatically change the DMA controller clock based on initiator. If the DMA clock is programmed for 16 MHz, the ISA and PC Card DMA cycle timing will be non-standard and may result in failures. The DMA clock is controlled by CSC index 82h.

10.4.1 Addressing DMA Channels

Channels 0–3 support 8-bit data transfers between 8-bit I/O devices and system memory. 8-bit DMA may access any location within the 64-Mbyte system address space; however, the address counter is only 16 bits wide, so 8-bit DMA requests cannot cross 64-Kbyte physical page boundaries. As shown in Table 10-2, during 8-bit DMA transfers, the DMA slave controller provides the lower 16 bits, DMA Page registers provide the next 8 bits, and Extended Page registers provide the top 2 bits of the system memory address.

DMA Channel 4 is used to cascade channels 0–3 from the slave controller through the master controller to the CPU and is not available for data transfer.

Channels 5–7 support 16-bit data transfers between 16-bit I/O devices and system memory. 16-bit DMA may access any even (word-aligned) location within the 64-Mbyte system address space; however, the address counter is only 16 bits wide, so 16-bit DMA requests cannot cross 128-Kbyte physical page boundaries. As shown in Table 10-3, during 16-bit DMA transfers, A0 is 0, the DMA master controller provides the next 16 bits, DMA Page registers provide the next 7 bits, and Extended Page registers provide the top 2 bits of the system memory address.

Table 10-2 8-Bit DMA Channel Address Generation

Source	Extended Page Registers	DMA Page Registers	Slave Controller Channel x Memory Address Register
Address	A25–A24	A23–A16	A15–A0

Table 10-3 16-Bit DMA Channel Address Generation

Source	Extended Page Registers	DMA Page Registers	Master Controller Channel x Memory Address Register
Address	A25–A24	A23–A17	A16–A1

10.4.2 DMA Transfers

Because the ÉlanSC400 and ÉlanSC410 microcontrollers support the standard PC/AT system architecture, the method for DMA transfer complies with the Industry Standard Architecture (ISA) specifications. The following general rules apply to DMA transfers on the ÉlanSC400 and ÉlanSC410 microcontrollers:

- The DMA *initiator* is the I/O device that asserts DRQ. This is *always* an I/O device residing on either the ISA bus or PC Card bus, or the infrared port, and may be either 8 bits (Channels 0–3) or 16 bits (Channels 5–7). (Note that the infrared port *must* be programmed as an 8-bit channel).
- The DMA *target* is the memory device being accessed by the I/O device (the DMA Initiator). It is *always* a memory resource, and may be either DRAM (16/32 bits), ISA bus (8/16 bits), or PC Card bus (8/16 bits), as listed in Table 10-4. Note that $\overline{\text{ROMCSx}}$ and VL-bus targets are not supported; neither is a PC Card initiator to a PC Card target.
- The target memory must be currently mapped into the CPU address space, either linearly or using an MMS window. This address mapping must not change during the DMA transfer.
- An 8-bit DMA initiator may *not* transfer to a target that is less than its bus width. For example, a 16-bit initiator cannot transfer to an 8-bit target. An 8-bit target can transfer to a 16-bit target.

Table 10-4 Supported DMA Initiator/Target Combinations

DMA Initiator	DMA Target		
	DRAM	ISA Bus	PC Card
Infrared Port (8 bits)	Yes	Yes	Yes
PC Card (8/16 bits)	Yes	Yes	No
ISA bus (8/16 bits)	Yes	Yes	Yes

Note:

The PC Card controller is not supported on the ÉlanSC410 microcontroller.

- All DMA transfers are fly-by type (the data is moved from the I/O device to memory (DMA write), or from memory to the I/O device (DMA read) in a single transaction). A non-fly-by transfer implies two cycles, one for the initiator and one for the target. PC/AT DMA transactions are *always* fly-by type.
- Memory-to-memory transfers are not supported.
- There are three modes of DMA transfers supported: single transfer, demand transfer, and block transfer (described more completely below).

Fly-by DMA transfers require the ability to simultaneously assert an I/O command and a memory command (i.e. $\overline{\text{IOR}}$, $\overline{\text{MEMW}}$ for DMA writes, $\overline{\text{IOW}}$, $\overline{\text{MEMR}}$ for DMA reads). The ISA bus provides an additional signal, AEN, to prevent I/O devices residing on the same bus as the DMA initiator from decoding the memory target address driven by the DMA controller.

10.4.2.1 Transfer Modes

The DMA controller performs read and write operations in single cycle, demand, or block transfer modes.

- A read operation consists of a memory read cycle from the address in the current address register followed by an I/O write cycle.
- A write operation consists of an I/O read cycle followed by a memory write cycle to the address in the current address register. Depending on the DMA channel selected, the data may be 8 bits or 16 bits in width.

ISA bus DMA timing requires that one DMA wait state be inserted during all DMA read cycles, and two wait states must be inserted for DMA write cycles. Also, additional wait states may be added by the actual DMA target.

10.4.2.1.1 Single Transfer Mode

In single transfer mode, the DMA initiator asserts DRQ and holds it active until acknowledged by the assertion of $\overline{\text{DACK}}$. The DMA controller performs the programmed DMA transfer.

10.4.2.1.2 Demand Transfer Mode

In demand transfer mode, the DMA initiator asserts DRQ and holds it active as long as it has data to be transferred. The DMA controller will continue to perform DMA transfers until Terminal Count (TC) is reached or the DRQ is deasserted by the DMA initiator.

10.4.2.1.3 Block Transfer Mode

In block transfer mode, the DMA initiator asserts DRQ and holds it active until acknowledged by the assertion of $\overline{\text{DACK}}$. The DMA controller performs DMA transfers until TC is reached, indicating the programmed number of transfers has been completed. Any channel mapped for use with the infrared port must not be programmed for block mode.

10.4.2.2 Autoinitialize

During autoinitialize, the original values of the Current Address and Current Word Count registers are automatically restored to the values in the Base Address and Base Word Count registers of the given channel following the TC.

10.4.2.3 Priority

After recognition of any one channel for service, the other channels are prevented from interfering with that service until it is complete. After completion of a service, HOLD goes inactive until HLDA is inactive before HOLD is activated for a second cycle.

The fixed priority scheme is based upon the descending value of channel numbers (Channel 0 is the highest priority). DRQ must be held active until $\overline{\text{DACK}}$ becomes active in order to be recognized.

In the rotating priority scheme, the last channel serviced becomes the lowest priority, with the other channels rotating accordingly.

10.4.2.4 DMA Cycles

Table 10-5 shows the eight ISA DMA cycle types and the command strobes generated by each. The ISA command strobes $\overline{\text{MEMR}}$ and $\overline{\text{MEMW}}$ are asserted only for ISA cycles. The $\overline{\text{IOR}}$ and $\overline{\text{IOW}}$ command strobes are asserted for both ISA and PC Card cycles. Separate memory strobes are provided for accesses to ROM and PC Card memory. The ROM interface uses dedicated $\overline{\text{ROMRD}}$ and $\overline{\text{ROMWR}}$ signals, while the PC Card sockets use $\overline{\text{MCEL_A}}$, $\overline{\text{MCEH_A}}$, $\overline{\text{MCEL_B}}$, and $\overline{\text{MCEH_B}}$.

Table 10-5 ISA DMA Cycle Types

I/O Device Sits on this Bus (DMA Initiator)	Memory Device Sits on this Bus (DMA Target)	Data Transfer Direction (DMA Cycle Type)	ISA Command Strobes Generated
ISA	ISA	I/O to Memory (DMA Write)	$\overline{\text{MEMW}}$, $\overline{\text{IOR}}$
ISA	PC Card	I/O to Memory (DMA Write)	$\overline{\text{IOR}}$
ISA	DRAM	I/O to Memory (DMA Write)	$\overline{\text{IOR}}$
PC Card	ISA	I/O to Memory (DMA Write)	$\overline{\text{MEMW}}$, $\overline{\text{IOR}}$
ISA	ISA	Memory to I/O (DMA Read)	$\overline{\text{MEMR}}$, $\overline{\text{IOW}}$
PC Card	ISA	Memory to I/O (DMA Read)	$\overline{\text{MEMR}}$, $\overline{\text{IOW}}$
ISA	PC Card	Memory to I/O (DMA Read)	$\overline{\text{IOW}}$
ISA	DRAM	Memory to I/O (DMA Read)	$\overline{\text{IOW}}$

10.4.3 DMA Channel Mapping

DMA requests may originate from the following sources:

- Infrared port (always 8 bits)
- PC Card bus (8 bits or 16 bits) using WP_A, WP_B, BVD2_A or BVD2_B (ÉlanSC400 microcontroller only)
- ISA bus using PDRQ1–PDRQ0 and $\overline{\text{PDACK1}}$–$\overline{\text{PDACK0}}$ (8 bits or 16 bits)

Note that any channel mapped for use with the infrared port must not be programmed for block mode.

Table 10-6 shows the microcontroller resource and the DMA channels to which the resource can be mapped.

All DMA channel mapping in the ÉlanSC400 and ÉlanSC410 microcontrollers is programmable using CSC index DBh and DCh. The DMA Resource Channel Map Registers A and B should be programmed consecutively to prevent two resources from being mapped to the same channel.

Table 10-6 DMA Channel Mapping

Microcontroller Resource	DMA Channel							
	0	1	2	3	4	5	6	7
Infrared Port	X	X						
PC Card Controller (Sockets A and B) (ÉlanSC400 microcontroller only)			X	X		X		
PDRQ0/$\overline{\text{PDACK0}}$ Programmable DMA Channel	X	X	X	X		X	X	X
PDRQ1/$\overline{\text{PDACK1}}$ Programmable DMA Channel	X	X	X	X		X	X	X

10.4.4 DMA Latency

The following requests could delay a DMA acknowledgment.

- A higher priority DMA request
- A cache write-back, if the DMA target is in a dirty cache line
- A high-priority PMU request

The DMA Hold request is prevented from reaching the CPU when the CPU is in the Stop Grant state. Latency for this can be 1 ms.

Once a demand transfer or block transfer has started, if the DMA is trying to read from a memory region that is in the cache, the transfer will be paused while a cache line write-back occurs. If the cache holds data that the DMA controller is overwriting, a cache line invalidate cycle will also occur.

On the ÉlanSC400 microcontroller, when the internal graphics controller is enabled and the graphics FIFOs get starved, the DMA transfer will be held off while the graphics controller gets more data from DRAM.

10.5 INITIALIZATION

The DMA controller is enabled at power-on reset, but all channels are masked off. This is also the state after the Software Reset Register is written.

10.6 POWER MANAGEMENT

To conserve power, the DMA clock is gated to stop the clock due to DMA controller inactivity. Operation of the DMA controller is affected by the power-management functions shown in Table 10-7.

Table 10-7 Power Management in the DMA Controller

DMA Controller Event	Description	Power Management Effect			
		Wake-Up	Activity	SMI	NMI
External DMA request	Triggered by rising edge of PDRQ0 or PDRQ1 if PDRQ is enabled and mapped to a DMA channel and Pin Mux Register A (CSC index 38h[0] selects the DMA function of the pin.	Yes	Programmable		

CHAPTER

11 PROGRAMMABLE INTERRUPT CONTROLLER

11.1 OVERVIEW

Dual, cascaded, 8259-compatible programmable interrupt controllers support 15 user interrupt levels. The two internal devices are internally connected on the ÉlanSC400 and ÉlanSC410 microcontrollers and must be programmed to operate in Cascade mode.

Eight external interrupt requests (PIRQ7–PIRQ0) can be mapped to any of the 15 internal IRQ inputs. The programmable sources for interrupts going into the programmable interrupt controller (PIC) block are controlled through the CSC and PC Card index registers.

The interrupt controller block includes these features:

- Software-compatibility with PC/AT interrupt controllers
- 15-level priority controller
- Programmable interrupt modes
- Individual interrupt request mask capability
- Accepts requests from peripherals
- Resolves priority on pending interrupts and interrupts in service
- Issues interrupt request to processor
- Provides interrupt vectors for interrupt service routines
- Tied into the PMU for power management

The interrupt controller block is functionally compatible with the standard cascaded 8259A controller pair as implemented in the PC/AT system. The master controller drives the CPU's interrupt input signal based on the highest priority interrupt request pending at the master controller's IRQ7–IRQ0 inputs. The master IRQ2 input is configured for Cascade mode and is driven only by the slave controller's interrupt output pin. The highest pending interrupt at the slave's IRQ inputs will therefore drive the IRQ2 input of the master.

The interrupt controller has programmable sources for interrupts that are controlled using CSC indexed registers and (on the ÉlanSC400 microcontroller) using PC Card indexed registers.

11.2 REGISTERS

The following types of registers are used to configure the PIC on the ÉlanSC400 and ÉlanSC410 microcontrollers.

- **Direct-mapped initialization words**—These registers set the PIC to a known state.
- **Direct-mapped operation control words**—These registers set up any special operating modes for the PIC.
- **Direct-mapped status registers**—The Interrupt Request Register indicates which internal IRQs are requesting service.The In-Service Register indicates which internal IRQs are being serviced. The Interrupt Mask Register sets the mask bits for the internal IRQs.

■ **Indexed configuration registers**

A summary listing of the CSC and PC Card indexed registers used to control the PIC is shown in Table 11-1. Complete register descriptions for all the registers used to configure the PIC can be found in the *Élan™SC400 Microcontroller Register Set Reference Manual* (order #21032).

Table 11-1 Programmable Interrupt Controller Register Summary

Register	I/O Address	Programmable Interrupt Controller Function Keyword	Description in Register Set Manual
Chip Setup and Control (CSC) Index Registers			
Keyboard Configuration Register A	22h/23h Index C0h	XT keyboard IRQ1 control, SCP mouse emulation IRQ12 control	page 3-146
Interrupt Configuration Register A	22h/23h Index D4h	PIRQ1–PIRQ0 mapping to IRQ15–IRQ1	page 3-170
Interrupt Configuration Register B	22h/23h Index D5h	PIRQ3–PIRQ2 mapping to IRQ15–IRQ1	page 3-171
Interrupt Configuration Register C	22h/23h Index D6h	PIRQ5–PIRQ4 mapping to IRQ15–IRQ1	page 3-172
Interrupt Configuration Register D	22h/23h Index D7h	PIRQ7–PIRQ6 mapping to IRQ15–IRQ1	page 3-173
Interrupt Configuration Register E	22h/23h Index D8h	Mapping of UART, infrared port, parallel port, and cursor high/low address register IRQs; IRQ3, IRQ4, IRQ5, IRQ7, IRQ9	page 3-174
PC Card Index Registers			
Interrupt and General Control Register	3E0h/3E1h Index 03h (Socket #A) and 43h (Socket #B)	IRQ mapping for RDY_X	page 6-11
Card Status Change Interrupt Configuration Register	3E0h/3E1h Index 05h (#A) and 45h (#B)	IRQ mapping for card status change interrupt	page 6-13

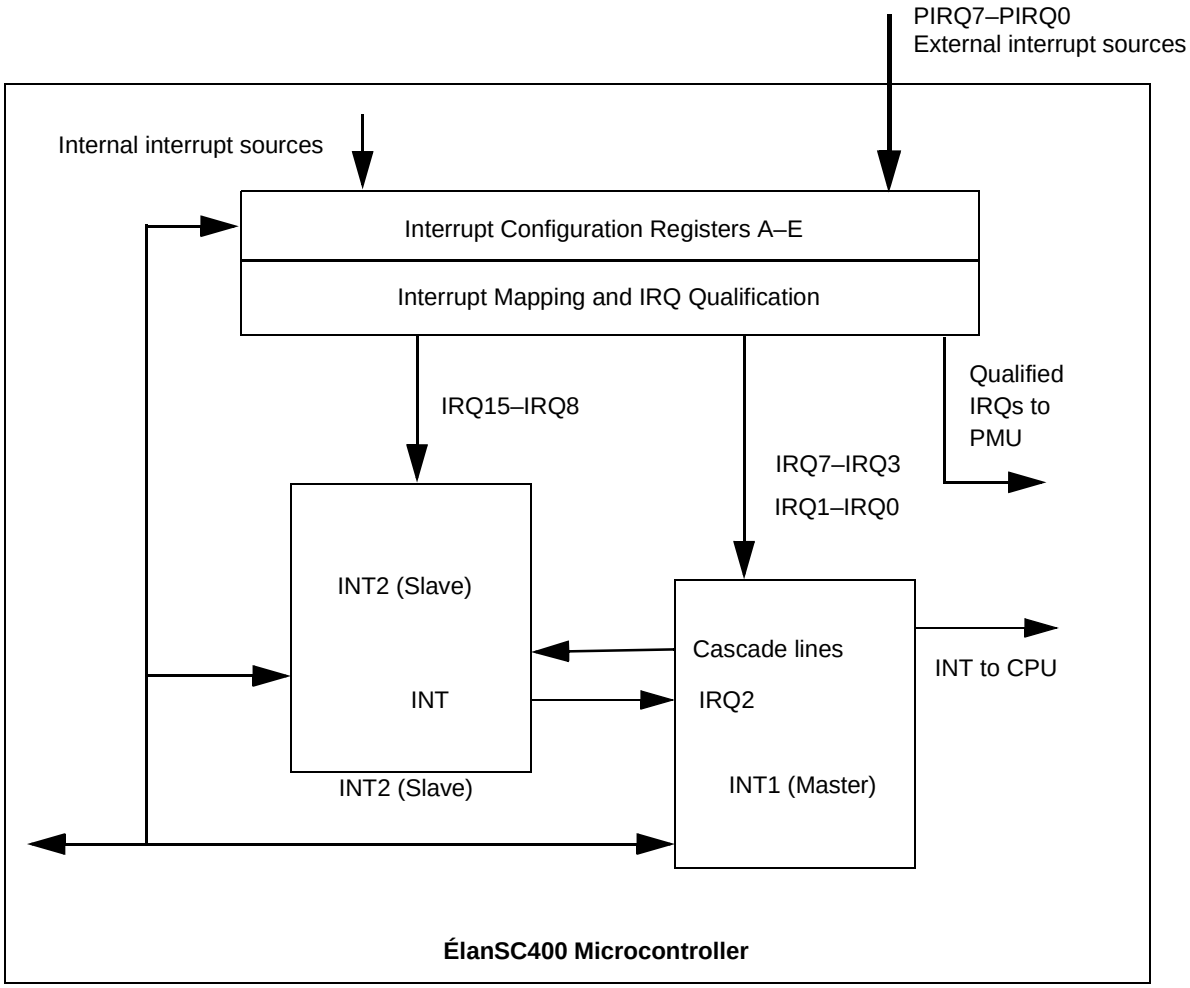
11.3 BLOCK DIAGRAM

A block diagram of the PIC on the ÉlanSC400 and ÉlanSC410 microcontrollers is shown in Figure 11-1.

The interrupt controller block on the ÉlanSC400 and ÉlanSC410 microcontrollers is functionally compatible with the standard cascaded 8259A controller pair, as implemented in the PC/AT system.

Interrupt Requests 0–7 are configured for master operation in Cascade mode, with IRQ2 dedicated to cascading the slave interrupt controller. Interrupt Requests 8–15 are configured for slave operation.

Figure 11-1 Programmable Interrupt Controller Block Diagram



11.4 OPERATION

The PIC as implemented on the ÉlanSC400 and ÉlanSC410 microcontrollers is different from the standard 8259 part in the following ways.

- Cascade mode is hardwired internally, using INT2 for the cascade.
- 8080/8085 mode is not supported.
- Automatic End-of-Interrupt (AEOI) is not supported in the slave. However, AEOI is supported in the master.
- After initialization, the PIC always comes up in fully nested mode. EOIs should already be defined.

11.4.1 IRQ Mapping

Table 11-2 shows the resources of the ÉlanSC400 and ÉlanSC410 microcontrollers and the IRQs that these peripherals can be mapped to. IRQ mapping in the ÉlanSC400 and ÉlanSC410 microcontrollers is programmable using CSC index registers and PC Card index registers.

Note that sharing interrupts (i.e., steering two IRQ sources into the same IRQ line) is not recommended and may lead to unpredictable system behavior.

Table 11-2 IRQ Mapping

Microcontroller Resource	IRQ Number															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Programmable Interval Timer	X															
Matrix Keyboard Controller (Keyboard Output Buffer Full)		X														
XT Keyboard Controller (Shift Buffer Full)		X														
UART (8-Pin Serial and Infrared Ports)				X	X											
Parallel Port						X		X								
Real-Time Clock									X							
Graphics Controller (Cursor Control Address Register Accesses)										X						
Matrix Keyboard Controller (Mouse Output Buffer Full)													X			
PC Card (Sockets A and B):[1] —I/O and Memory mode ($\overline{\text{IREQx}}$ pin) —Memory-only mode (status change/RI)				X	X	X		X		X	X	X	X		X	X
PIRQ0 Programmable IRQ I/O Pin		X		X	X	X	X	X	X	X	X	X	X	X	X	X
PIRQ1 Programmable IRQ I/O Pin		X		X	X	X	X	X	X	X	X	X	X	X	X	X
PIRQ2 Programmable IRQ I/O Pin		X		X	X	X	X	X	X	X	X	X	X	X	X	X
PIRQ3 Programmable IRQ I/O Pin		X		X	X	X	X	X	X	X	X	X	X	X	X	X
PIRQ4 Programmable IRQ I/O Pin		X		X	X	X	X	X	X	X	X	X	X	X	X	X
PIRQ5 Programmable IRQ I/O Pin		X		X	X	X	X	X	X	X	X	X	X	X	X	X
PIRQ6 Programmable IRQ I/O Pin		X		X	X	X	X	X	X	X	X	X	X	X	X	X
PIRQ7 Programmable IRQ I/O Pin		X		X	X	X	X	X	X	X	X	X	X	X	X	X

Note:

1. PC Card IRQ mapping is fully compatible with the 82365SL PC Card controller and is controlled by the PC Card index registers. The PC Card controller is not supported on the ÉlanSC410 microcontroller.

11.4.2 Interrupt Vectors

Table 11-3 lists the vector returned to the CPU for each IRQ during the internal interrupt-acknowledge sequence.

Table 11-3 Interrupt Vectors

IRQ	Vector Value
IRQ0	8h
IRQ1	9h
IRQ2	Not available (used for cascading)
IRQ3	Bh
IRQ4	Ch
IRQ5	Dh
IRQ6	Eh
IRQ7	Fh
IRQ8	70h
IRQ9	71h
IRQ10	72h
IRQ11	73h
IRQ12	74h
IRQ13	75h
IRQ14	76h
IRQ15	77h

11.5 INITIALIZATION

The PIC is enabled at power-on reset. However, it is not reset by a power-on reset.

None of the direct-mapped PIC (8259) registers have power-on reset values. These registers must go through an initialization sequence before being used.

Note that all four initialization control words are required on the ÉlanSC400 and ÉlanSC410 microcontrollers. The Initialization Control Word (ICW) registers 1–4 are programmed in sequence. Writing to Port 20h with bit 4 = 1 causes the ICW1 Register to be written and resets the PIC's internal state machine and ICW register pointer. Master ICW2–4 are programmed via Port 21h. Each time Port 21h is written to (following ICW1), the register pointer points to the next internal ICW register.

11.6 POWER MANAGEMENT

The interrupt controller provides interrupt information to the on-chip power management unit to allow the monitoring of the system activity. A qualified interrupt is sent to the PMU when an interrupt request is active (and not masked in the PIC), or when an interrupt in-service bit is set. These signals are implemented as combinatorial paths to allow speeding up or starting of the system clocks depending on which device generates the interrupt request.

Operation of the programmable interrupt controller is affected by the power-management functions shown in Table 11-4.

Table 11-4 Power Management in the Programmable Interrupt Controller

PIC Event	Description	Power Management Effect			
		Wake-Up	Activity	SMI	NMI
External interrupt request	Triggered by a rising edge of any of the three PIRQ2–PIRQ0 signals if the PIRQ is enabled, mapped to an internal IRQ, and the IRQ function is selected via CSC index 38h[1,2]	Yes			
Internal interrupt request	Triggered by rising edge of any internal IRQ coming into the PMU		Programmable		

CHAPTER

12 PROGRAMMABLE INTERVAL TIMER

AMD

12.1 OVERVIEW

The programmable interval timer (PIT) on the ÉlanSC400 and ÉlanSC410 microcontrollers is software-compatible with PC/AT 8254 system timers. The PIT provides three 16-bit timer channels (also called counters) that can be operated independently in six different modes. The PIT is generally used for timing external events, counting, and producing repetitive waveforms. It can be programmed to count in binary or in BCD.

All three timer channels are driven from a common clock internally generated from one of the on-chip phase-locked loops (PLL). Alternatively, the CLK_IO pin can be configured as an input to provide an external clock source. When the internal PLL is used for clock generation, the resulting source clock frequency is 1.1892 MHz. The standard PC/AT timer clock source frequency is 1.19318 MHz. Section 12.4.2.1 describes how this affects DOS-compatible systems.

12.2 REGISTERS

A summary listing of the chip configuration and control (CSC) index registers used to control the programmable interval timer is shown in Table 12-1. Complete register descriptions can be found in the *Élan™ SC400 Microcontroller Register Set Reference Manual* (order #21032).

12.2.1 Direct-Mapped Registers

The direct-mapped registers provide a common set of controls to load, read, and configure each timer channel. The following direct-mapped registers are available.

- **Programmable Interval Timer #1 Mode Control Register (Port 0043h)**—Stores the control word used to define the operation of the channels, including mode.
- **Programmable Interval Timer #1 Channel Count Registers (Ports 0040–0042h)**—Store the current count values for each channel.
- **Programmable Interval Timer #1 Counter Latch Command Register (Port 0043h)**—When the counter latch command is valid, the value in the status register plus the output signal of the counter is latched into this status latch register. The status in this register is cleared only after the status is read by the CPU.
- **Programmable Interval Timer #1 Read-Back Command Register (Port0043h)**—Allows the status and current mode of each channel to be read.
- **Programmable Interval Timer #1 Status Registers (Ports 0040–0042h)**—Contain the programmed mode and the null count value for each timer channel.
- **System Control Port B/ NMI Status Register (Port 0061h)**—Controls the gate input for Timer Channel 2 and reflects the output signal state for Channel 2.

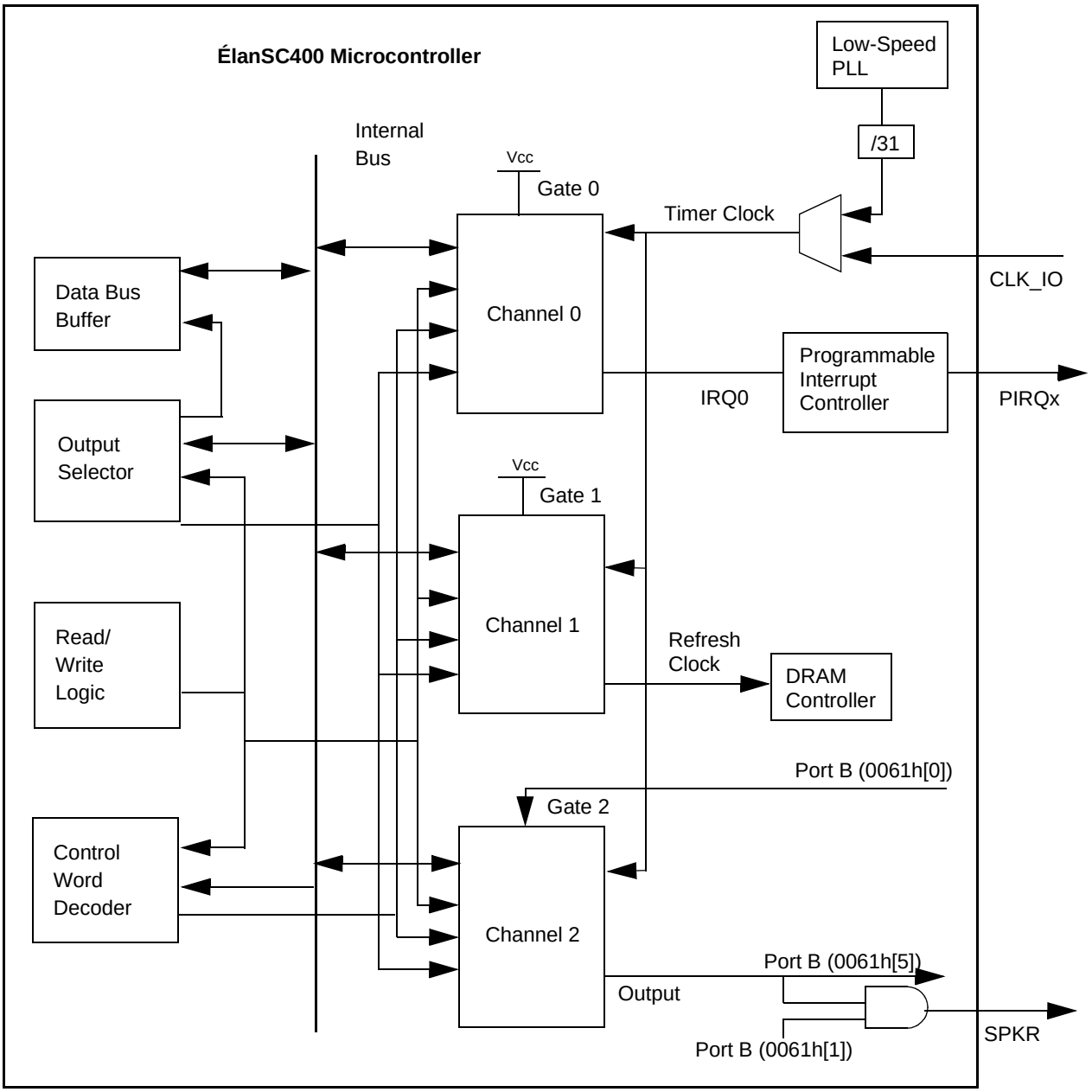
Table 12-1 Programmable Timer Register Summary

Register	I/O Address	Programmable Timer Function	Description in Register Set Manual
DRAM Refresh Control Register	22h/23h Index 05h	PIT as DRAM refresh clock	page 3-14
Pin Mux Register A	22h/23h Index 38h	CLK_IO as PIT clock input	page 3-44

12.3 BLOCK DIAGRAM

Figure 12-1 shows a block diagram of the programmable interval timer.

Figure 12-1 Programmable Interval Timer Block Diagram



12.4 OPERATION

Each of the three 16-bit timer channels can be operated independently.

- Timer Channel 0 is the primary system timer. It is used for generating interrupt requests. Its output is hardwired internally to drive IRQ0 of the microcontroller's programmable interrupt controller.
- Timer Channel 1 is used for memory refresh. It is programmed as a rate generator to produce a refresh pulse to the microcontroller's DRAM controller. The refresh source (either the PIT or 32 KHz) can be read in the System Control Port B/NMI Status Register (Port 0061h).
- Timer Channel 2 is available for general system use. It is also used in conjunction with a bit (SPKD) in Port B to drive the SPKR output pin.

12.4.1 Modes of Operation

The six timer modes are shown in Table 12-2. Channel 0 and Channel 1 operate in four modes only. Channel 2 supports all six modes of operation of the timer. Mode selection is performed in the PIT #1 Mode Control Register (Port 0043h).

Table 12-2 Timer Modes

Mode	Function	Supported Channels		
		Channel 0	Channel 1	Channel 2
0	Interrupt on Terminal Count	Yes	Yes	Yes
1	Hardware Retriggerable One-Shot	No	No	Yes
2	Rate Generator	Yes	Yes	Yes
3	Square Wave Generator	Yes	Yes	Yes
4	Software Triggered Strobe	Yes	Yes	Yes
5	Hardware Triggered Strobe	No	No	Yes

12.4.1.1 Mode 0: Interrupt on Terminal Count

Mode 0 is used to cause an event after a predetermined interval.

- The initial count is loaded into the count register and the output of the counter goes Low.
- If the gate input is held High, the count value gets decremented by one for each input clock pulse. If the gate input is held Low, the count will maintain its state until after a rising edge of the clock after the gate goes High again.
- The output of the counter is initially Low and will remain Low until the counter reaches zero.
- The output then goes High until a new count or a new Mode 0 control word is loaded into the Counter.

12.4.1.2 Mode 1: Hardware-Retriggerable One-Shot

Mode 1 is used to create a fixed duration output.

- After an initial count is loaded into the count register, a rising edge on the gate input causes the output of the counter to go Low.

- The count value gets decremented with each successive clock pulse.
- The gate trigger begins the one-shot pulse with the output going Low until the count reaches zero.
- Output then goes High and remain High until the clock pulse after the next trigger.

The duration of the one-shot pulse is the initial count multiplied by the period of the clock input. This mode is called hardware retriggerable because, once an output pulse has started, if a rising edge is experienced at the gate input, the counter is reloaded with the initial count and the pulse continues until the new count expires.

12.4.1.3 Mode 2: Rate Generator

Mode 2 is used to generate a short periodic pulse. PC/AT-compatible BIOS programs (including the ones available for the ÉlanSC400 and ÉlanSC410 microcontrollers) will program Channel 0 to operate in Mode 2 to provide the standard 55-ms timer tick.

When programmed in this mode, the counters operate as divide by N counters, where N is the initial count.

- The output signal starts off High until the initial count is decremented to one.
- The output then goes Low for one clock pulse and goes High again; the counter is reloaded with the initial count; and the counting sequence is repeated.

One clock pulse appears at the output for every N clock cycles.

12.4.1.4 Mode 3: Square Wave Mode

Mode 3 is used to generate a periodic square wave. Timer Channels 1 and 2 use this mode by default to drive DRAM refresh and speaker, respectively.

In this mode, the output of the counter has a 50% duty cycle whenever the counter is loaded with an even count.

- The output is initially High.
- The count decrements by two with each clock cycle when the gate is held High.
- When the count reaches zero the output toggles state, the initial count is reloaded and the sequence is repeated.

The period of the output signal is equal to the input clock period multiplied by the initial count loaded into the counter. If the initial count is an odd number, the output is High for (N+1)/2 cycles and is Low for (N-1)/2 cycles.

12.4.1.5 Mode 4: Software Triggered Strobe

Mode 4 generates a strobe under software control.

In this mode, the counter automatically begins to decrement one clock pulse after it is loaded with the initial count through software.

- The output signal is initially High.
- The count decrements at the rate set by the clock input signal.
- At the moment the terminal count is reached, the counter generates a single strobe pulse on the output for one clock pulse duration.

If the counter is loaded with a count of N, then a strobe pulse is produced at the output after N+1 clock cycles.

12.4.1.6 Mode 5: Hardware Triggered Strobe

Mode 5 generates a strobe under hardware control.

The counting in this mode is initiated by a signal at the gate input.

- The output will be initially High.
- Counting begins at the rising edge of the gate input. The output remains High until the count has expired.
- The output goes Low for one clock cycle and goes High again.
- After writing the control word and the initial count, the counter is loaded at the next clock pulse after the trigger.

The strobe pulse occurs N+ 1 clock pulses after the Low-to-High transition (trigger) on the gate input. This count sequence is retriggerable.

12.4.2 Timer Configuration

12.4.2.1 Configuring Timer Channel 0

Timer Channel 0 is used for generating interrupt requests. Its output is hardwired internally to drive IRQ0 of the interrupt controller. For DOS-compatible systems, system BIOS usually programs the PIT #1 Channel 0 Count Register (Port 0040h) to a value of FFFFh. DOS relies on this periodic interrupt in order to keep accurate time of day. Because the timer clock source is 1.1892 MHz in the ÉlanSC400 and ÉlanSC410 microcontrollers, the IRQ0 is generated every 55.11 ms. Historically, the timer clock source has been 1.19318 MHz. This translates into an IRQ0 generation rate of 54.93 ms. This IRQ0 generation rate difference causes the time keeping function of DOS to be inaccurate.

There are two possible ways to address this issue. One method involves modifying Port 0040h via the system BIOS. The second method involves driving the timer from an external clock source.

- Modifying PIT #1 Channel 0 Count Register (Port 0040h)—If the system BIOS programs Port 0040h to a value of FF23h, the desired IRQ0 generation rate of 54.93 ms can be achieved.
- Driving an external 1.19318 MHz clock on the CLK_IO pin—A system designer may choose to supply an external clock source frequency of 1.19318 MHz on the microcontroller's CLK_IO pin. This pin must be specifically configured for this functionality by the system BIOS during the system boot process prior to configuring Port 0040h.

12.4.2.2 Configuring Timer Channel 1

Timer Channel 1 can be programmed as the system memory (DRAM) refresh clock source. It is programmed as a rate generator to produce a refresh pulse to the DRAM controller.

In the ÉlanSC400 and ÉlanSC410 microcontrollers, the 32-KHz oscillator clock source is the default memory refresh clock source. If Timer Channel 1 is configured as the refresh clock source, the 32-KHz clock source is always enabled as the refresh clock source when the system enters the Suspend mode of operation and $\overline{\text{CAS}}$-before-$\overline{\text{RAS}}$ refresh is enabled in Suspend. In this case, the refresh clock source will switch back to the timer Channel 1 upon resuming from Suspend. This is required because the timer clock source is disabled during Suspend.

12.4.2.3 Configuring Timer Channel 2

The gate line for Timer Channel 2 is controlled by Port 0061h[0]. The output of Timer Channel 2 is read at Port 0061h[5]. The output goes to the speaker (SPKR) when Port 0061h[1] is set.

12.4.3 Programming the Timer Channels

The timer channels are programmed by first writing a control word into the PIT #1 Mode Control Register and then writing an initial count into the count register of the timer channel being programmed. The control word determines the format of the initial count.

A new initial count can be written at any time without affecting the programmed mode. The mode definitions describe how counting is handled in each mode. The new count must follow the programmed count format.

The channel must be read without disturbing the count in progress. There are three possible methods to accomplish this: a simple read operation, counter latch command, and read-back command.

- Simple read operation—The count value in the count latch of the counter is read. It should be noted that simple reads will not always return a correct value. The two methods that follow are the preferred way of reading the current count.
- Counter latch command—This command is written to the PIT #1 Mode Control Register and acts like a control word. The SC1–SC0 bits select one of the three channels; two other bits, RW1 and RW0, distinguish this command from a control word.
- Read-back command—Also written to the PIT #1 Mode Control Register. It allows the user to check the count value, programmed mode, and current state of the output of the chosen channel.

12.5 INITIALIZATION

The programmable interval timer is enabled at power-on reset. After power-up, the state of the timer itself is undefined. The mode, count value, and output of all channels are undefined. Each timer channel must be programmed before it can be used.

The timer clock is either the Low-Speed PLL divided by 31, or it is an external oscillator brought in on the CLK_IO pin. The default is to use the PLL to generate the timer clock.

If the pin-multiplexing registers select CLK_IO to be active as an input, then the PIT gets its clock from this input. For DOS applications, the pin should have a stable 1.19218 MHz frequency on it, because it will be switched in immediately as the timer clock.

12.6 POWER MANAGEMENT

Operation of the programmable interval timer is affected by the power-management functions shown in Table 12-3.

Table 12-3 Power Management in the Programmable Interval Timer

PIT Event	Description	Power Management Effect			
		Wake-Up	Activity	SMI	NMI
Timer tick (IRQ0)	Triggered by the rising edge of internal IRQ0		Programmable		

CHAPTER

13 REAL-TIME CLOCK

13.1 OVERVIEW

The RTC designed into the ÉlanSC400 and ÉlanSC410 microcontrollers is compatible with the MC146818A device used in PC/AT systems. The RTC consists of time-of-day clock with alarm and a 100-year calendar. The clock/calendar has a programmable periodic interrupt and 114 bytes of static user RAM, and can be represented in either binary or BCD. The RTC includes the following features:

- Counts seconds, minutes, and hours of the day
- Counts days of the week, date, month, and year
- 12–24 hour clock with AM and PM in 12 hour mode
- 14 bytes of clock and control registers
- 114 bytes of general purpose RAM
- Three interrupts are separately software-maskable and testable
  - — Time-of-day alarm is programmable to occur from once-per-second to once-per-day
  - — Periodic interrupts can be continued to occur at rates from 122 μs to 500 ms
  - — Update-ended interrupt provides cycle status

The RTC has its own reset and power pin separate from the rest of the core supplies. When the chip is powered off, the RTC can remain powered up and in full functional mode, maintaining time, calendar, and user RAM data.

The RTC includes ten registers for time, calendar, and alarm data and four general-purpose registers, named A, B, C, and D. Register D has a status bit that indicates the validity of the contents of the RAM, time registers, and the calendar. This status bit is set based on the power supply level on the RTC V_{CC} supply pin (VCC_RTC). The RTC alarm function is supported.

The RTC interrupt request is connected internally to IRQ8. This, along with other IRQs, may be configured as the system power management unit's wake-up activity.

Note: *The RTC must be initialized correctly to provide proper function of the matrix keyboard timer and, on the ÉlanSC400 microcontroller, the internal graphics controller. This initialization must occur, regardless of whether the internal RTC or an external device will be used for the RTC function in a system design.*

13.2 REGISTERS

Two different sets of index registers are used to configure the RTC.

- The chip setup and control (CSC) index registers are accessed via the 22h/23h index/data I/O scheme.
- The standard RTC index registers are accessed via the PC/AT I/O space at Ports 0070h and 0071h.

A summary listing of the chip setup and control (CSC) and RTC index registers used to control the real-time clock is shown in Table 13-1. Complete register descriptions can be found in the *Élan™ SC400 Microcontroller Register Set Reference Manual* (order #21032).

13.2.1 RTC and Configuration RAM Index Registers

These indexed registers function as the configuration, setup, and status for the Real-Time Clock (RTC), as well as user-configurable RAM locations.

- RTC index registers 00–09h contain RTC seconds, minutes, hours, day of week, date of months, months of year, and year status, as well as second, minute, and hour alarm configuration control. Both binary and BCD formats are supported for these registers.
- RTC registers 0A–0Dh are used to configure the RTC.
- All index values from 0E–7Fh can be used as read/write RAM locations.

The 114 general-purpose RAM bytes are not dedicated to the RTC. They can be used by system- or application-level software and are fully available during the update cycle. These user RAM bytes provide low-power CMOS battery-backed storage and extend the RAM available to the program.

Table 13-1 Real-Time Clock Register Summary

Register	I/O Address	Real-Time Clock Function Keyword	Description in Register Set Manual
Chip Setup and Control (CSC) Index Registers			
Wake Up Source Enable Register A	22h/23h Index 52h	Wake-up source enable: RTC alarm (IRQ8)	page 3-59
Wake Up Source Status Register A	22h/23h Index 56h	Wake-up source status: RTC alarm	page 3-63
Miscellaneous SMI/NMI Enable	22h/23h Index 90h	SMI/NMI enable: RTC alarm (IRQ8)	page 3-94
Miscellaneous SMI/NMI Status Register A	22h/23h Index 94h	SMI/NMI status: RTC alarm	page 3-99
SMI/NMI Select Register	22h/23h Index 98h	SMI or NMI selection: RTC alarm	page 3-104
Internal I/O Device Disable/Echo Z-Bus Configuration Register	22h/23h Index D0h	RTC enable	page 3-164
RTC and Configuration RAM Index Registers			
RTC Current Second Register	70h/71h Index 00h	Seconds	page 4-5
RTC Alarm Second Register	70h/71h Index 01h	Seconds alarm	page 4-6
RTC Current Minute Register	70h/71h Index 02h	Minutes	page 4-7
RTC Alarm Minute Register	70h/71h Index 03h	Minutes alarm	page 4-8
RTC Current Hour Register	70h/71h Index 04h	Hours, 12- and 24-hour mode	page 4-9

Table 13-1 Real-Time Clock Register Summary (continued)

Register	I/O Address	Real-Time Clock Function Keyword	Description in Register Set Manual
RTC Alarm Hour Register	70h/71h Index 05h	Hours alarm, 12- and 24-hour mode	page 4-10
RTC Current Day of Week Register	70h/71h Index 06h	Day of the week	page 4-11
RTC Current Day of Month Register	70h/71h Index 07h	Date of the month	page 4-11
RTC Current Month Register	70h/71h Index 08h	Month	page 4-12
RTC Current Year Register	70h/71h Index 09h	Year	page 4-13
Register A	70h/71h Index 0Ah	Update status, internal oscillator control, rate selection	page 4-16
Register B	70h/71h Index 0Bh	Update override (SET); periodic interrupt, alarm interrupt, and update-ended interrupt enables; date mode, 24/12 hour control, and daylight savings enable	page 4-18
Register C	70h/71h Index 0Ch	Interrupt request, periodic interrupt, alarm interrupt, and update-ended interrupt flags	page 4-19
Register D	70h/71h Index 0Dh	External backup battery condition, RTC reset, BBATSEN	page 4-20
Configuration RAM	70h/71h Index 0E–7Fh	General-purpose CMOS RAM bytes	page 4-15

13.3 BLOCK DIAGRAM

A block diagram of the real-time clock is shown in Figure 13-1. Backup battery considerations, along with system diagrams, are described in Section 13.4.5.

13.3.1 Voltage Monitoring

The voltage monitor for the RTC block provides a reset signal to the RTC block when it detects a low backup battery voltage and provides an early warning signal when the system is powering down. A diagram of the RTC voltage monitor is shown in Figure 13-2. The internal RTC reset signal is asserted on power-up if the backup battery voltage drops below 2.4 V. Internal circuitry prevents multiple resets during power-on. An internal power-down signal is used by the RTC to isolate the RTC core from the rest of the microcontroller. The RTC voltage monitor uses the $\overline{\text{RESET}}$ assertion to detect a power down.

The band gap block generates the bias currents for the four PLLs and provides the 2.4-V reference source for the RTC voltage monitor. The current sources, constant over V_{CC}, temperature, and process variations, are used by the four PLL charge pumps for adjusting the PLL operating frequency.

Figure 13-1 Real-Time Clock Block Diagram

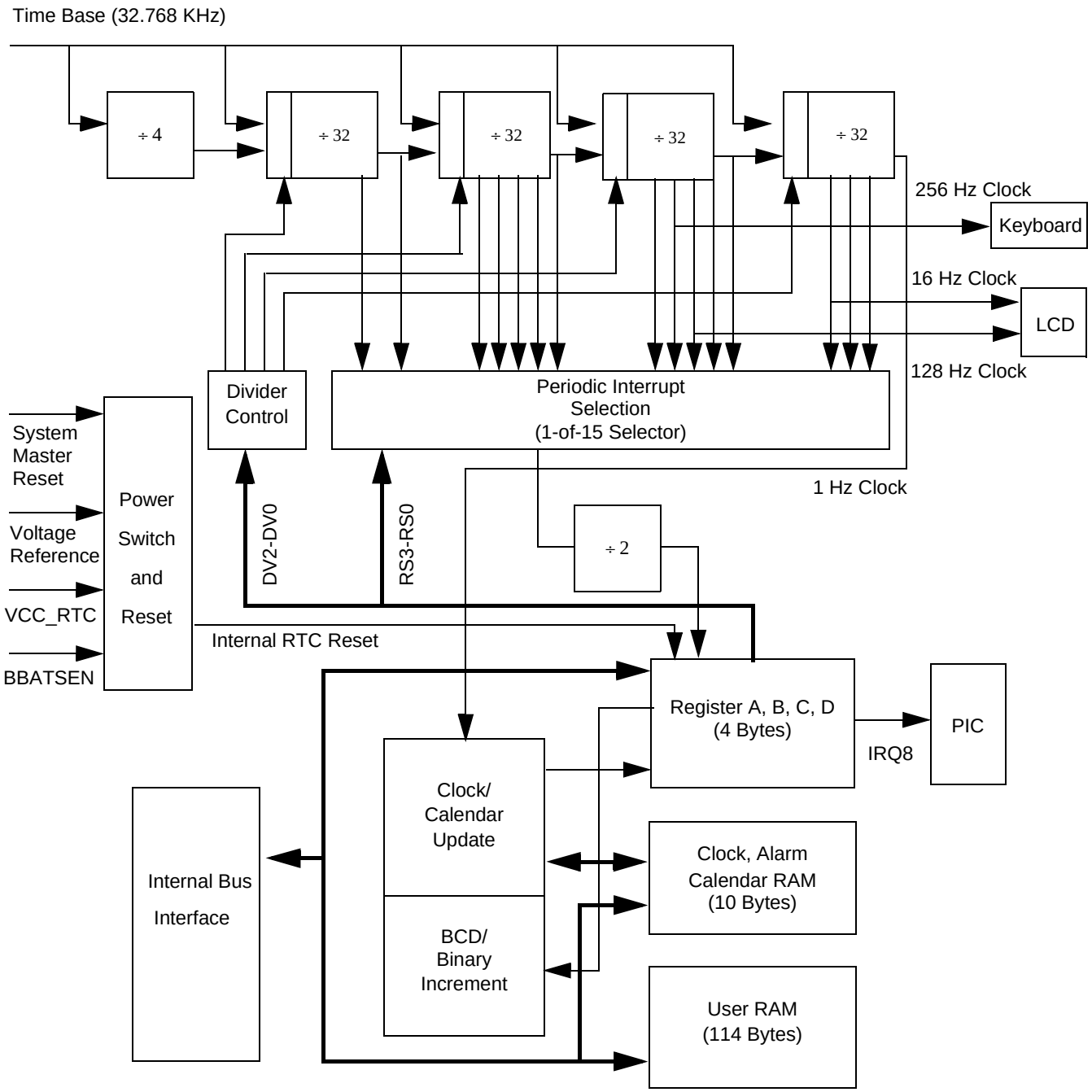
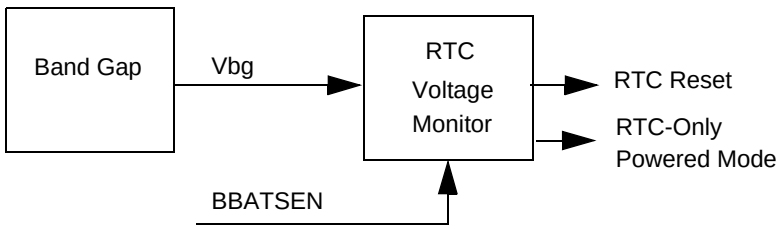


Figure 13-2 RTC Voltage Monitor



13.4 OPERATION

Programs can retrieve time and calendar information from the RTC by reading the appropriate RTC index registers. Programs can also change the time, calendar, and alarm information in the RTC by writing to these registers.

The 24/12 bit in Register B establishes whether the hour locations represent 1-to-12 or 0-to-23. The 24/12 bit cannot be changed without re-initializing the hour registers. When the 12-hour format is selected, the high-order bit of the hours byte represents PM when it is a 1.

The three alarm bytes can be used in two different ways.

- If the alarm enable bit is set, the alarm interrupt occurs at the time specified in the appropriate hours, minutes, and seconds alarm registers.
- If a “don’t care” state (any hexadecimal byte from C0–FFh) is written to one or more of three alarm registers.

13.4.1 Interrupts

The RTC provides three different interrupt sources. All three are connected internally to IRQ8. The three interrupt sources are:

- Periodic interrupt—Can be set at rates from 500 ms to 122 µs.
- Alarm interrupt—Can be set at rates from once-per-second to once-per-day.
- Update-ended interrupt—Provides update cycle status.

These three interrupts are enabled in Register B (RTC index 0Bh[6,5,4]). Table 13-2 lists the values of RS3–RS0 in Register A (RTC index 0Ah[3–0]) used to specify different periodic interrupt rates.

Table 13-2 Using RS3–RS0 to Specify a Periodic Interrupt Rate

Periodic Interrupt Rate	RS3	RS2	RS1	RS0
None	0	0	0	0
3.90625 ms	0	0	0	1
7.8125 ms	0	0	1	0
122.070 µs	0	0	1	1
244.141 µs	0	1	0	0
488.281 µs	0	1	0	1
976.562 µs	0	1	1	0
1.953125 ms	0	1	1	1
3.90625 ms	1	0	0	0
7.8125 ms	1	0	0	1
15.625 ms	1	0	1	0
31.25 ms	1	0	1	1
62.5 ms	1	1	0	0
125 ms	1	1	0	1
250 ms	1	1	1	0
500 ms	1	1	1	1

13.4.2 RTC Clock

The RTC clock is the 32.768 KHz generated by the internal oscillator. This clock is used by many cores and is always available (as long as there is power).

13.4.3 Internal Oscillator Control Bits

The normal operational setting for the internal oscillator control bits DV2–DV0 in Register A is '010b'. This turns the oscillator on, uses an internal time base of 32768 Hz, and enables the countdown chain to run at the internal time base frequency.

A value of '11xb' turns the oscillator on, but holds the countdown chain in reset. In this mode, the time and date update cycles do not occur. This mode is useful for precision setting of the clock. If entering this mode from the oscillator-off mode, a 200-ms delay must be observed to allow for oscillator stabilization prior to attempting to set the time. Time and date update cycles begin 500 ms after the countdown chain reset is removed.

Programming DV2–DV0 to any value except '010b' or '11xb' disables the input clock from the oscillator circuit. In this mode, time and date update cycles do not occur, but the RTC draws slightly less power.

Upon exiting this mode, a 200-ms delay should be observed before reconfiguring or using the time and date information to allow for oscillator stabilization. DV2–DV0 are not affected by a reset of the RTC subsystem.

13.4.4 Update Cycle

The RTC executes an update cycle once per second, assuming the DV2–DV0 divider is not clear and the SET bit in Register B is clear. When the SET bit is 1, the program can initialize the time and calendar bytes by stopping an existing update and preventing a new one from occurring.

With a 32.768-KHz time base, the update cycle takes 1984 µs. During the update cycle, the time, calendar, and alarm bytes are not available because they are taken off the bus for the entire update cycle. If a program reads these RAM locations before the update is complete, the output is undefined. The update in progress (UIP) status bit is set during this time.

There are three ways to handle nonavailability during an RTC update.

- Use the update-ended interrupt. If enabled, this interrupt occurs after every update cycle. This means that over 999 ms are available to read the time and date registers. Before leaving the interrupt service routine, clear the IRQF bit in Register C.
- Use the Update-in-Progress bit (UIP) in Register A. The UIP bit changes once per second. The update cycle begins 244 µs after the UIP bit goes High. This means that, if a 0 is read on the UIP bit, there are at least 244 µs before the time or calendar data will be changed. If a 1 is read in the UIP bit, the time or calendar data may not be valid. Note that the time allocated to read time or calendar data should not exceed 244 µs.
- Use a periodic interrupt to determine if an update cycle is occurring.

Note that, to ensure correct data, the time should not be set on the last day of the month within two seconds of the rollover to the next day.

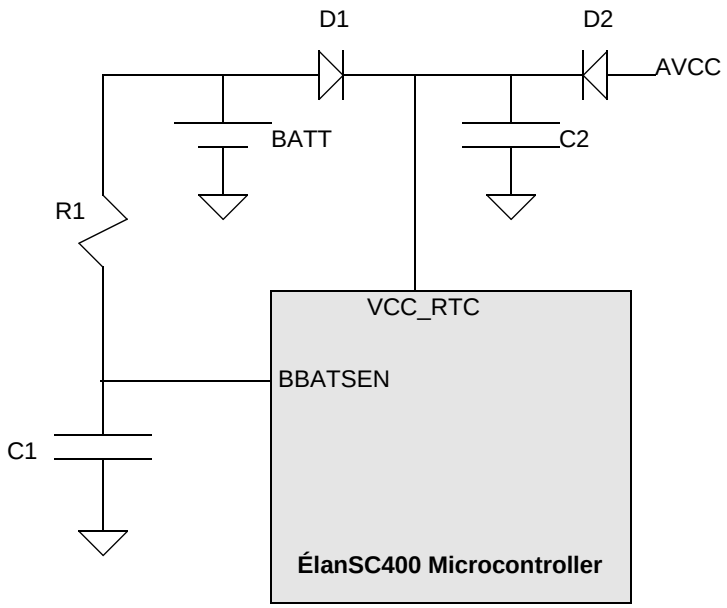
13.4.5 Backup Battery Considerations

The behavior of the RTC when the primary power supply is turned off depends on whether or not an external backup battery is included in the system design.

13.4.5.1 Using an External RTC Backup Battery

Figure 13-3 shows a specific system implementation with the ÉlanSC400 microcontroller using an external backup battery to keep the 32-KHz oscillator, RTC, and RAM powered on when the primary system power supply is turned off (i.e., the AVCC source is removed). In the circuit shown, both D1 and D2 are required to have a maximum forward voltage drop of 0.25 V at a forward current of 100 µA.

Figure 13-3 Backup Battery Used to Power RTC



RTC index 0Dh contains the VRT (Valid RAM and Time) bit. This bit can be sampled at system boot time by the BIOS to determine whether or not the RTC time, date, and user RAM are valid since the last boot.

The operation of the RTC reset and VRT bit is outlined below for the circuit in Figure 13-3:

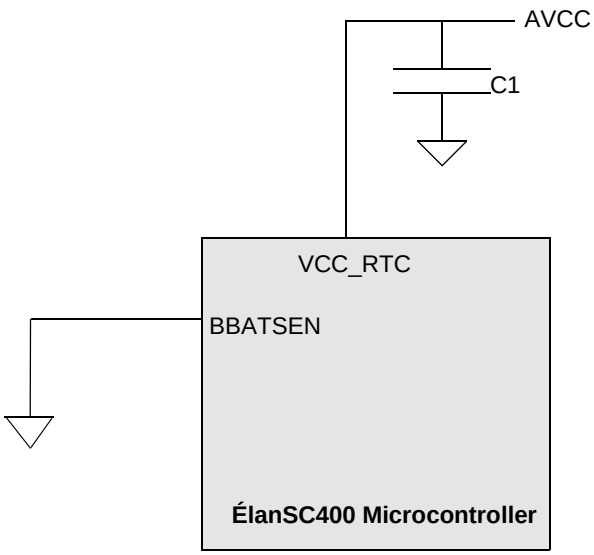
1. The VCC_RTC pin is a dedicated power supply pin for the 32-KHz crystal oscillator and the RTC.
2. When the primary system power supply is turned on, the analog V_{CC} pin (AVCC) drives the VCC_RTC pin through an external diode.
3. When the primary power supply is turned off or non-functional, VCC_RTC is driven by the backup battery through a second external diode.
4. An on-chip voltage monitor circuit monitors the voltage level of the backup battery through the BBATSEN pin every time the system primary power supply is initially applied (i.e., the AVCC pin has power applied to it) and the ÉlanSC400 microcontroller's master reset ($\overline{\text{RESET}}$ pin) is deasserted.
5. If the backup battery is sampled below 2.4 V, the RTC logic is completely reset. The read-only VRT bit (RTC index 0Dh[7]) is cleared and latched in this state until the bit is read. After this bit is initially read, it always reads back a value of 1 for all subsequent reads prior to a RTC reset.

6. When the main system power supply is off and the backup battery is initially installed, the external RC circuit consisting of R1 and C1 causes a slow rising edge on the BBATSEN input, causing the RTC to be reset via an internal power-on-reset circuit. The RTC is then reset (or not) as described in items 4 and 5.

13.4.5.2 Not Using an External RTC Backup Battery

Figure 13-4 shows a specific system implementation with the ÉlanSC400 Microcontroller that does not use an external backup battery to keep the RTC and RAM powered on when the primary system power supply is turned off (i.e., the AVCC source is removed).

Figure 13-4 Implementation with No Backup Battery Used



Referring to the description of the operation of the RTC reset and VRT bit as outlined above, this implementation will always reset the RTC (and therefore clear the VRT bit) whenever the primary system power supply is turned on and a master reset is performed.

13.4.5.3 Overall System Implications

Using the scheme described above allows the BIOS to detect the state of the backup battery independently of the actual V_{CC} level that is applied to the RTC (i.e., when the system has booted and firmware reads the VRT bit). The state of the VRT bit will reflect the state of the RTC power supply prior to the application of the primary power supply and not the state of the RTC power supply in real time.

13.5 INITIALIZATION

The real-time clock is enabled at power-on reset; however, it is not reset by a power-on reset.

1. Before initializing the internal registers, set the SET bit in Register B to prevent time or calendar updates from occurring.
2. Initialize the ten time, calendar, and alarm registers in either binary or BCD data format.
3. Specify the format in the data mode (DM) bit of Register B. All ten time, calendar, and alarm registers must use the same data mode, either binary or BCD.
4. Clear the SET bit to enable updates.

When initialized, the RTC makes all updates in whatever data mode has been programmed. To change the data mode, the ten data bytes must be re-initialized.

13.6 POWER MANAGEMENT

Operation of the programmable interrupt controller is affected by the power-management functions shown in Table 13-3.

Table 13-3 Power Management in the Real-Time Clock

RTC Event	Description	Power Management Effect			
		Wake-Up	Activity	SMI	NMI
RTC alarm	Triggered by the rising edge of internal IRQ8		Programmable		

CHAPTER

14 PARALLEL PORT

14.1 OVERVIEW

The parallel port on the ÉlanSC400 and ÉlanSC410 microcontrollers is functionally compatible with an IBM PC/AT and PS/2 system, with an optional mode for faster transfers. The microcontroller's parallel port interface provides all the status inputs, control outputs, and the control signals necessary for the external parallel port data buffers.

Communication between the host (microcontroller) and the peripheral is asynchronous. The parallel port datapath is external to the microcontroller. The parallel port can be physically mapped to one of two different I/O locations or can be completely disabled. Only edge-triggered interrupts are supported.

The parallel port interface is shared with the GPIO31–GPIO21 signals and, on the ÉlanSC400 microcontroller, with the PC Card Socket B interface. Only one of these interfaces can be enabled at one time.

The parallel port interface can be configured to operate in one of three different modes of operation:

- **PC/AT Compatible mode**–This mode provides a byte-wide forward (host-to-peripheral) channel with data and status lines used according to their original (Centronics) definitions in the IBM PC/AT.
- **Bidirectional mode**–This mode offers byte-wide bidirectional parallel data transfers between host and peripheral, equivalent to the parallel interface on the IBM PS/2.
- **Enhanced Parallel Port (EPP) mode** –This mode provides a byte-wide bidirectional channel controlled by the microcontroller. EPP mode provides separate address and data cycles over the eight data lines of the interface. EPP mode offers wider system bandwidth and increased performance over both the PC/AT Compatible and Bidirectional modes.

14.2 REGISTERS

The parallel port interface is controlled primarily by software. A summary listing of the chip setup and control (CSC) registers used to control the parallel port interface is shown in Table 14-1. Complete register descriptions can be found in the *Élan™ SC400 Microcontroller Register Set Reference Manual* (order #21032).

14.2.1 Direct-Mapped Registers

The parallel port interface can be mapped to one of the two I/O locations: LPT1 from ports 0378–037Fh or LPT2 from ports 0278–027Fh. The following direct-mapped registers are available for either LPT1 or LPT2.

- **Parallel Port Control Register (Port 037Ah or 027Ah)—**This register sets the various signals that control the data transfer to or from the parallel port peripheral device. These control signals are $\overline{\text{SLCTIN}}$, $\overline{\text{INIT}}$, $\overline{\text{STRB}}$, and $\overline{\text{AFDT}}$. The parallel port's internal interrupt request is enabled or cleared in this register. Bidirectional data direction is controlled through bit 5 of this register.

- **Parallel Port Status Register (Port 0379h or 0279h)**—This register keeps track of the parallel port peripheral device status via the status input signals, BUSY, $\overline{\text{ACK}}$, SLCT, $\overline{\text{ERROR}}$, and PE. The fields of this register vary according to mode of operation.
- **Parallel Port Data Registers (Ports 0378h, 037C–037Fh, or 0278h, 027C–027Fh)**—These internal registers (including the EPP 32-bit data registers) hold the data read from or written to the parallel port.

14.2.2 Chip Setup and Control Registers

The following chip setup and control (CSC) registers are available.

- **Pin Mux Register B**—Setting bit 1 in this register enables the parallel port signals.
- **Parallel/Serial Port Configuration Register**—By default, the internal parallel port is disabled; the port is enabled by setting bit 2 of this register. Bit 3 controls mapping the parallel port interface to one of the two I/O locations: LPT1 from ports 0378–037Fh or LPT2 from ports 0278–027Fh.
- **Parallel Port Configuration Register**—This register is used to configure the operation mode of the parallel port and to enable EPP mode time-outs. The default mode is PC/AT Compatible mode. Bidirectional or EPP mode must be enabled by setting the following bits: To enable bidirectional data transfers, set bit 1 to 1. To enable EPP mode, set bit 0 to 1.
- **Activity Monitor Registers**—For power management, these registers report that the parallel port is the source of an activity.
- **I/O Access SMI Enable and Status Registers**—These registers allow the user to determine that the parallel port is the source of a system management interrupt (SMI). This information can be used to power-up an external peripheral for use before the peripheral is actually accessed by the I/O cycle.
- **Interrupt Configuration Register E**—This register controls the mapping of the parallel port's internal interrupt request to either the PIRQ5 or PIRQ7 output.

Table 14-1 Parallel Port Register Summary

Register	I/O Address	Parallel Port Function Keyword	Description in Register Set Manual
Pin Mux Register B	22h/23h Index 39h	Parallel port signals enable	page 3-45
Activity Source Enable Register D	22h/23h Index 65h	Activity source enable: CPU access to the parallel port	page 3-74
Activity Source Status Register D	22h/23h Index 69h	Activity source status: CPU access to the parallel port	page 3-78
Activity Classification Register D	22h/23h Index 6Dh	Primary or secondary activity classification: CPU access to the parallel port	page 3-82
I/O Access SMI Enable Register A	22h/23h Index 99h	SMI enable for I/O access to LPT1 or LPT2	page 3-105
I/O Access SMI Status Register A	22h/23h Index 9Bh	SMI state for I/O access to LPT1 or LPT2	page 3-107
Parallel/Serial Port Configuration Register	22h/23h Index D1h	Internal parallel port enable, base address configuration (LPT1 or LPT2)	page 3-167

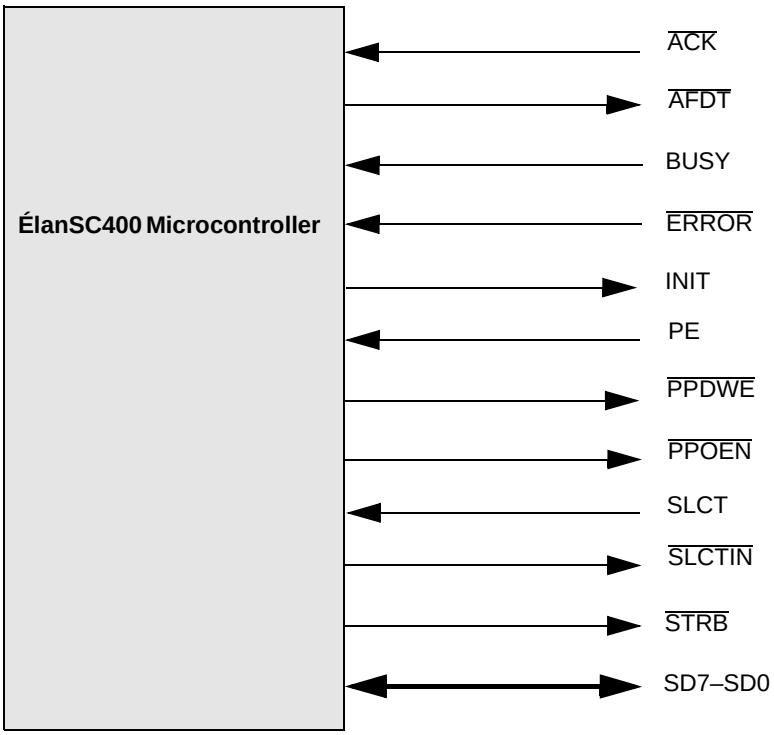
Table 14-1 Parallel Port Register Summary (continued)

Register	I/O Address	Parallel Port Function Keyword	Description in Register Set Manual
Parallel Port Configuration Register	22h/23h Index D2h	PC/AT Compatible, Bidirectional, or EPP mode select, EPP timeouts	page 3-168
Interrupt Configuration Register E	22h/23h Index D8h	IRQ mapping to the programmable interrupt controller	page 3-174

14.3 BLOCK DIAGRAM

The parallel port interface is shared with the GPIO31-GPIO21 signals and, on the ÉlanSC400 microcontroller, with the PC Card Socket B interface. Only one of these interfaces can be enabled at one time. Figure 14-1 shows a block diagram of the parallel port interface.

Figure 14-1 Parallel Port Block Diagram



14.4 PIN DEFINITIONS BY MODE

The pin definitions for the parallel port vary according to mode of operation. Table 14-2 shows the parallel port signals that appear on the pins of the ÉlanSC400 and ÉlanSC410 microcontrollers in PC/AT Compatible, Bidirectional, and EPP modes.

Table 14-2 Parallel Port Signal Definitions by Mode

ÉlanSC400 and ÉlanSC410 Microcontrollers Pin Name	PC/AT Compatible and Bidirectional Mode Signal Name	EPP Mode Signal Name	Function
BUSY	BUSY	$\overline{\text{WAIT}}$	In PC/AT Compatible and Bidirectional modes, this signal is driven by the parallel port device with the state of the printer busy signal. In EPP mode, this signal is used to add wait states to the current cycle.
$\overline{\text{ACK}}$	$\overline{\text{ACK}}$	INTR	In PC/AT Compatible and Bidirectional modes, this signal is driven by the parallel port device with the state of the printer acknowledge signal. In EPP mode, this signal is used to indicate to the microcontroller that the parallel port device has generated an interrupt request.
$\overline{\text{SLCTIN}}$	$\overline{\text{SLCTIN}}$	$\overline{\text{ASTRB}}$	In PC/AT Compatible and Bidirectional modes, this signal is driven by the microcontroller to select the parallel port device. In EPP mode, this signal is driven active by the microcontroller when selecting the parallel port device and writes to the EPP address register.
$\overline{\text{AFDT}}$	$\overline{\text{AFDT}}$	$\overline{\text{DSTRB}}$	In PC/AT Compatible and Bidirectional modes, this signal is driven by the microcontroller indicating to the parallel port device to insert a line feed at the end of every line (i.e., carriage return). In EPP mode, this signal is driven active by the microcontroller during reads or writes to the EPP data registers.
$\overline{\text{STRB}}$	$\overline{\text{STRB}}$	$\overline{\text{WRITE}}$	In PC/AT Compatible and Bidirectional modes, this signal is used to indicate to the parallel port device to latch the data on the parallel port data bus. In EPP mode, this signal is driven active during writes to the selected parallel port device and writes to the internal EPP data or the EPP address register.

Note:

The initialization ($\overline{\text{INIT}}$), error ($\overline{\text{ERROR}}$) and the paper end(PE) signals have the same function in PC/AT Compatible, Bidirectional, and EPP modes.

14.5 OPERATION

The parallel port can be configured in hardware as either a PC/AT Compatible port or a Bidirectional/EPP port.

In any mode, a read or write to or from the data registers will generate the parallel port data write enable signal $\overline{\text{PPDWE}}$ and the output enable signal $\overline{\text{PPOEN}}$.

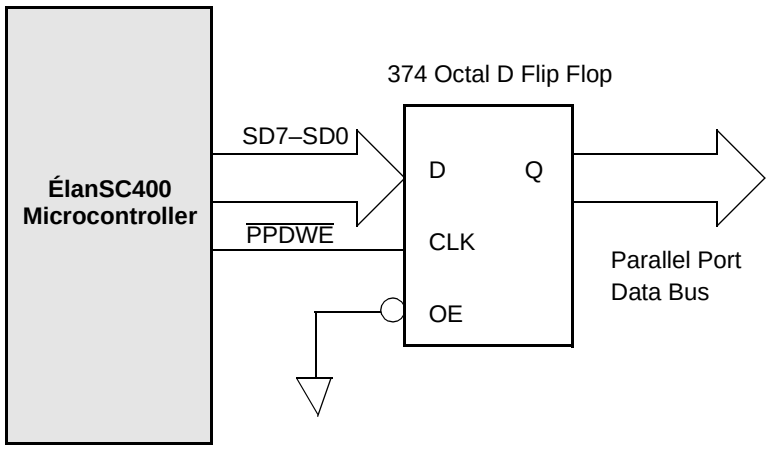
- In PC/AT Compatible mode, $\overline{\text{PPDWE}}$ is used to drive data to the external parallel port data bus.
- In the Bidirectional or EPP mode of operation, the $\overline{\text{PPDWE}}$ signal is reconfigured via firmware to function as an address decode for the Parallel Port Data Register.

14.5.1 Minimal System Design

14.5.1.1 PC/AT Compatible Mode

The PC/AT Compatible parallel port requires an external 374 Octal D Flip-Flop to latch the data from the SD data bus and drive the data onto the external parallel port data bus, as shown in Figure 14-2.

Figure 14-2 Parallel Port Data Control in PC/AT Compatible Mode

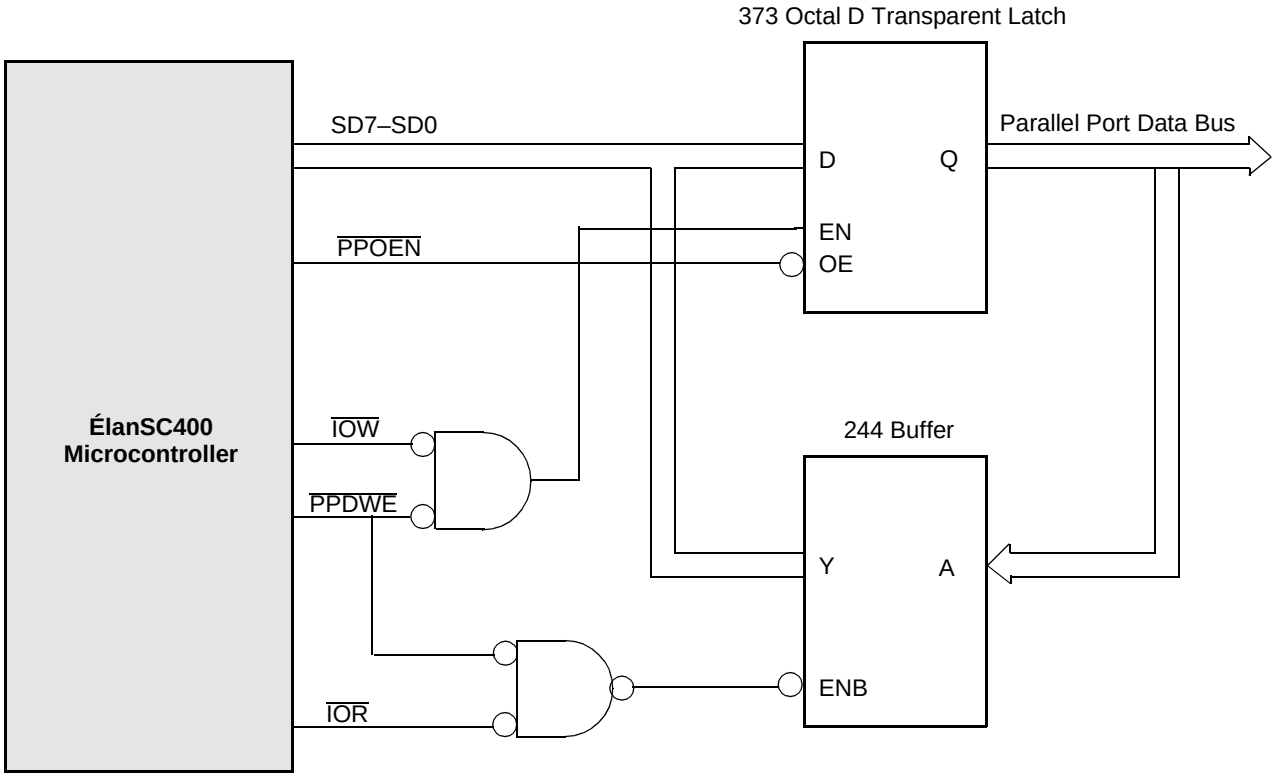


The $\overline{\text{PPDWE}}$ signal is the parallel port data write enable signal. In PC/AT Compatible mode, a write operation to the Parallel Port Data Register causes SD7–SD0 data to be latched and driven onto the parallel port data bus. A read operation causes the internal Parallel Port Data Register to return the last value that was written to it.

14.5.1.2 Bidirectional and EPP Modes

The Bidirectional and EPP mode configuration requires two external devices, one 373 Octal D Transparent Latch and one 244 Octal Buffer, as shown in Figure 14-3.

Figure 14-3 Parallel Port Data Control in Bidirectional and EPP Modes



When the parallel port is configured in either Bidirectional or EPP mode, the parallel port data write enable pin ($\overline{\text{PPDWE}}$) is redefined to function as the Parallel Port Data Register address decode.

The parallel port output enable ($\overline{\text{PPOEN}}$) signal from the microcontroller is controlled through the bidirectional data transfer (DIR) bit 5 of the Parallel Port Control Port Register. $\overline{\text{PPOEN}}$ controls the output enable of the external parallel port data latch. Table 14-3 outlines the operation of the parallel port data transfers to and from the internal Parallel Port Data Register when Bidirectional or EPP mode is enabled.

Table 14-3 Parallel Port Data Register Transactions in Bidirectional and EPP Modes

DIR Bit	Transaction Type	Result
0	Write	Data is driven out on the external parallel port data bus and latched into the external 373 and into the internal data register.
1	Write	Data written is latched into the external 373 and into the internal data register.
0	Read	Data is read from the internal data register.
1	Read	Data is read from the external parallel port data bus.

Note:

In EPP mode, the read or write cycles refer to EPP address, ports 027Bh or 037Bh, and data registers of address 027C–027Fh or 037C–037Fh.

14.5.2 Operating Modes

14.5.2.1 PC/AT Compatible Mode

This unidirectional mode provides a byte-wide forward (host-to-peripheral) channel with data and status lines used according to their original (Centronics) definitions in the IBM PC/AT.

14.5.2.2 Bidirectional Mode

This mode offers byte-wide bidirectional parallel data transfers between host and peripheral, equivalent to the parallel interface on the IBM PS/2. It is similar to Enhanced Parallel Port (EPP) mode described below, without the external command strobes and without wait state insertion.

14.5.2.3 Enhanced Parallel Port (EPP) Mode

The Enhanced Parallel Port mode allows the host faster data transfers through direct register addressing of the peripheral devices. This is achieved by automatically generating the address and data strobes.

The data transfer can be either an 8-bit, 16-bit, or 32-bit data transfer. For a 32-bit data transfer, a 32-bit I/O write to Port 027Ch causes four back-to-back 8-bit bus cycles to occur to the four EPP data registers (ports 027C–027Fh).

The timing for EPP mode described in the following sections is illustrated in Figure 14-4 and Figure 14-5.

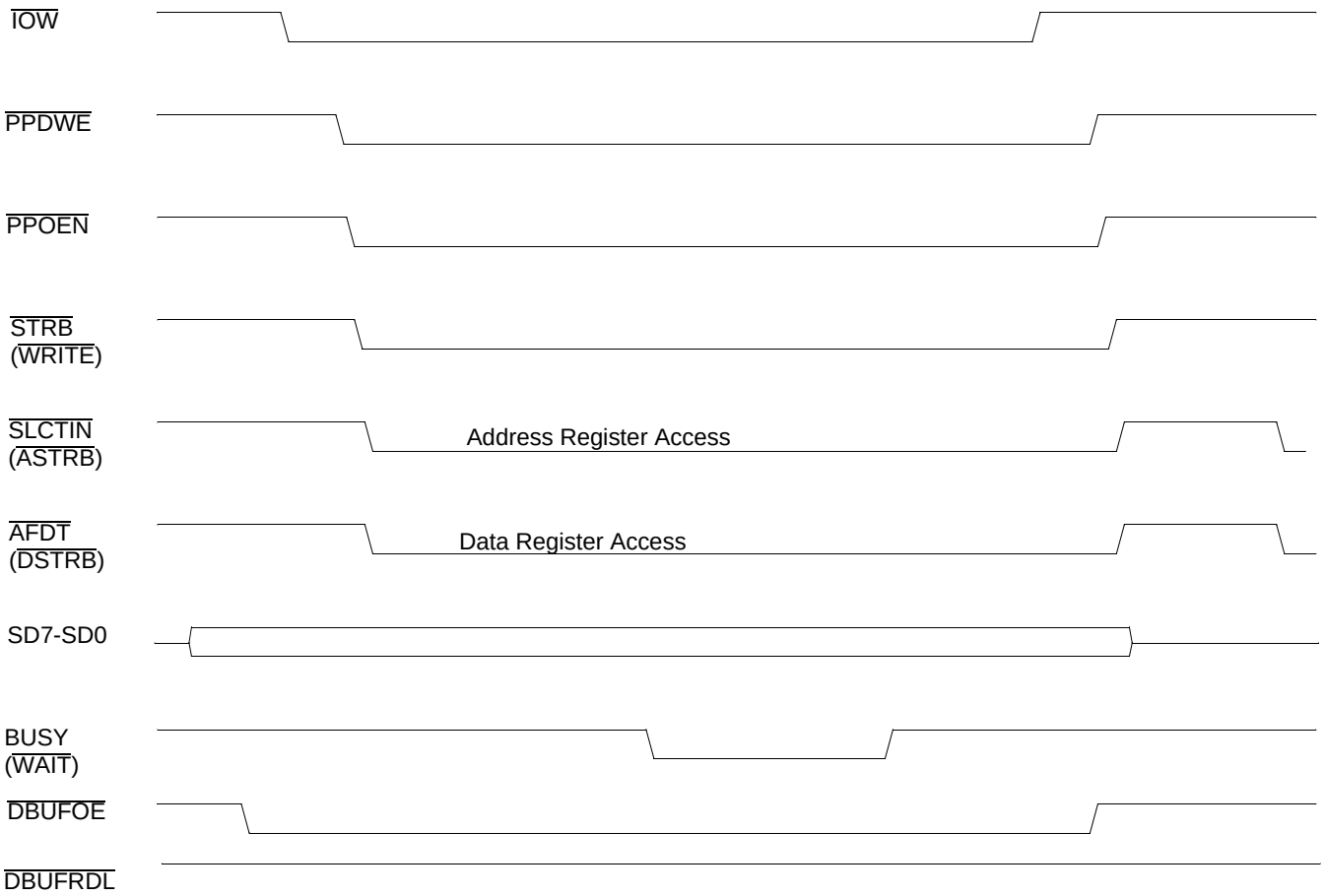
14.5.2.3.1 EPP Address Write

To begin an address write cycle, the host asserts $\overline{\text{WRITE}}$, places the register address on the data signals, and asserts $\overline{\text{ASTRB}}$. The peripheral responds by deasserting $\overline{\text{WAIT}}$ to indicate that it is ready to receive the address byte. When the host recognizes $\overline{\text{WAIT}}$ as inactive, it deasserts $\overline{\text{ASTRB}}$ to latch the address byte into the device. The peripheral acknowledges the end of the cycle and indicates that it is ready for the next cycle to begin by asserting $\overline{\text{WAIT}}$. The host can then modify the address/data on the data signals and change the state of the $\overline{\text{WRITE}}$ signal.

14.5.2.3.2 EPP Address Read

To begin an address read cycle, the host deasserts $\overline{\text{WRITE}}$, places the data signals in a high-impedance state, and then asserts $\overline{\text{ASTRB}}$. The peripheral responds by driving the data signals with the address byte and then deasserting $\overline{\text{WAIT}}$ to indicate that the address is valid. When the host recognizes $\overline{\text{WAIT}}$ as inactive, it reads the address from the data signals and deasserts $\overline{\text{ASTRB}}$. The peripheral places the data signals in a high-impedance state, acknowledges the end of the cycle, then indicates that it is ready for the next cycle to begin by asserting $\overline{\text{WAIT}}$. The host can then drive the data signals and change the state of the $\overline{\text{WRITE}}$ signal.

Figure 14-4 EPP Write Cycle



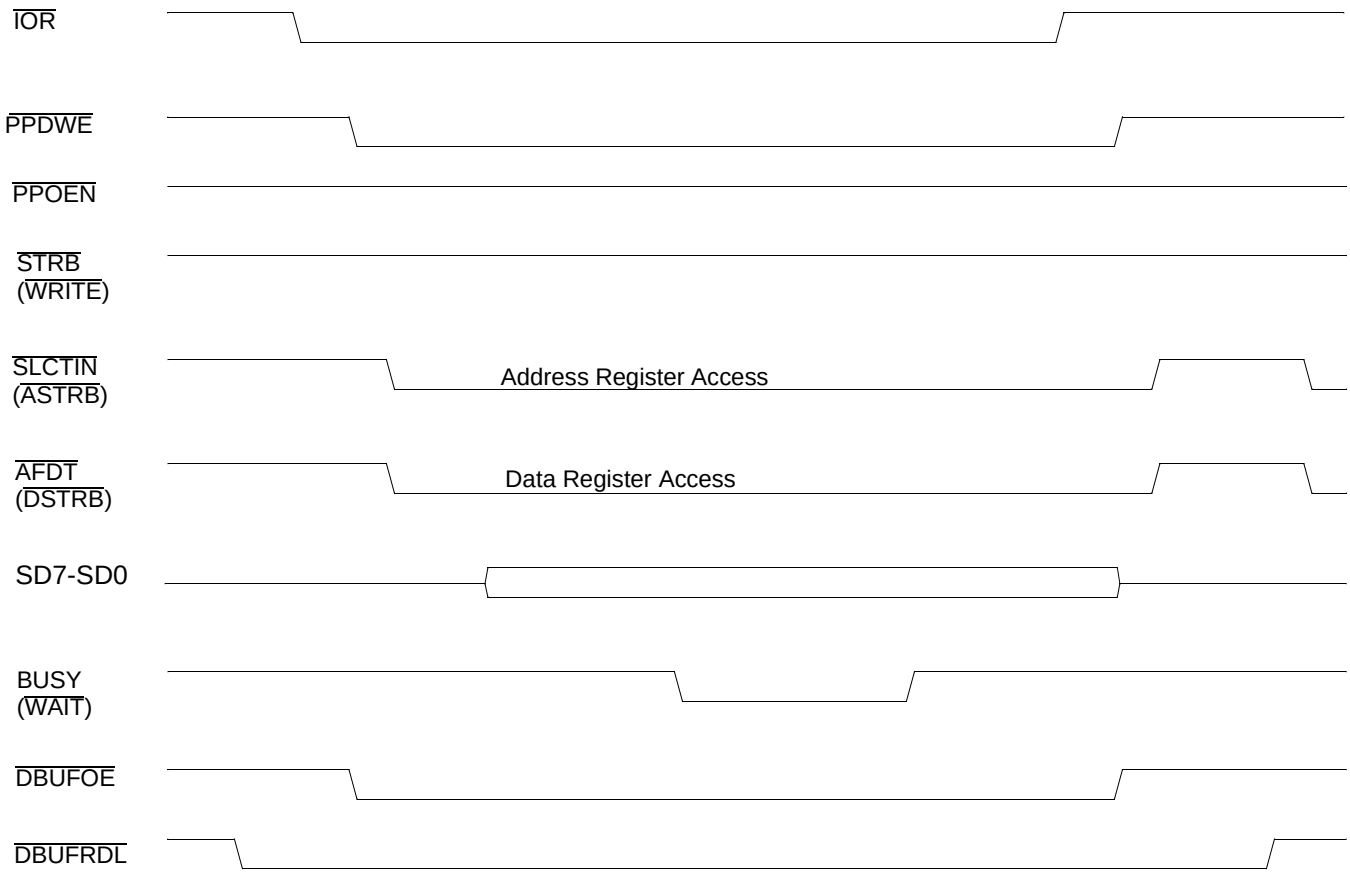
14.5.2.3.3 EPP Data Write

To begin a data write cycle, the host asserts WRITE, drives the data signals, and asserts DSTRB. The peripheral responds by deasserting WAIT to indicate that it is ready to receive the data byte. When the host recognizes WAIT as inactive, it deasserts DSTRB to latch the data byte into the device. The peripheral acknowledges the end of the cycle and indicates that it is ready for the next cycle to begin by asserting WAIT. The host can then modify the address/data on the data signals and change the state of the WRITE signal.

14.5.2.3.4 EPP Data Read

To begin a data read cycle, the host deasserts WRITE, places the data signals in a high-impedance state, and then asserts DSTRB. The peripheral responds by driving the data signals and deasserting WAIT to indicate that the data is valid. When the host recognizes WAIT as inactive, it reads the data from the data signals and deasserts DSTRB. The peripheral places the data signals in the high-impedance state, acknowledges the end of the cycle, and indicates that it is ready for the next cycle to begin by asserting WAIT. The host can then drive the data signals and change the state of the WRITE signal.

Figure 14-5 EPP Read Cycle



14.5.2.3.5 EPP Time-Out

The EPP time-out feature ensures that an external peripheral does not hangup the host. A 10 µs time-out counter is implemented in case the peripheral asserts BUSY/WAIT to insert wait states but then fails to deassert the signal back to High during an EPP data/address read or write cycle. A clock of frequency 1.47456 MHz from the clock divider block is used to provide the source for the 15 clock counts.

Setting bit 2 to 1 in the Parallel Port Configuration Register enables this time-out function. Reading bit 0 in the Parallel Port Status Register shows whether an EPP time-out has occurred; when bit 0 is a 1, a time-out has occurred. Consecutive reads of the Parallel Port Status Register always return a 0; bit 0 of this register is reset after each read.

14.6 INITIALIZATION

The parallel port is disabled at power-on reset. The parallel port must be configured by software before the parallel port is enabled. After it is enabled, the parallel port defaults to PC/AT Compatible mode.

14.7 POWER MANAGEMENT

Operation of the parallel port is affected by the power-management functions shown in Table 14-4.

Table 14-4 Power Management in the Parallel Port

Parallel Port Event	Description	Power Management Effect			
		Wake-Up	Activity	SMI	NMI
Parallel port access	Triggered by the falling edge of an address decode qualified with the command (I/O read/write)		Programmable		
Parallel port access	Accesses to LPT1 (378-37Fh) or LPT2 (278-27Fh) can cause an SMI through an I/O trap			Yes	

CHAPTER

15 SERIAL PORT (UART)

15.1 OVERVIEW

The ÉlanSC400 and ÉlanSC410 microcontrollers include a single industry-standard 16550A UART. The UART can be used to drive either a standard eight-pin serial interface or a two-pin infrared interface using the chip setup and control (CSC) index registers. The infrared port is fully documented in Chapter 18.

The UART powers up as a 16450-compatible device. It can be switched to and from the 16550-compatible mode under software control. In 16650-compatible mode, the receive and transmit sections are each aided by 16-byte FIFOs to off-load the CPU from repetitive service routines.

The serial port includes the following features:

- Eight-pin interface: serial in, serial out, six modem control lines
- Separately enabled receiver line status, receiver data, character timeout, transmitter holding register, and modem status interrupts
- Programmable UART transfer rates, up to 115 Kbit/s.
- Baud-rate generator provides input clock divisor from 1 to 65535 to create 16x clock
- The programmable serial interface includes:
  - — 5-, 6-, 7-, or 8-bit data
  - — Even, odd, no, or stick parity generation and checking
  - — 1, 1-1/2 or 2 stop-bit generation
  - — Break generation/detection
- Internal diagnostics:
  - — Serial loopback—transmit to receive
  - — Error simulation
- Receive line noise filter

15.2 REGISTERS

15.2.1 Direct-Mapped Registers

Note that, because the ÉlanSC400 and ÉlanSC410 microcontrollers include only one serial port, the on-board UART can only be mapped to either COM1 or COM2 at any time. The SP_CONFIG bit in the Parallel/Serial Port Configuration Register (CSC index D1h[1]) controls this selection. IRQ levels are mapped separately using the Interrupt Configuration Register E (CSC index D8h[6–5]).

The following direct-mapped registers are available for COM1 and COM2.

- **COMx Line Control Register (Ports 02FBh/03FBh)**—Used to configure the format of the UART frame for data transfer, including character length, stop bits, and parity. Set the DLAB bit in this register to gain access to the baud-rate divisor latches. Clear the

DLAB bit to gain access to the Transmit Holding and Receive Buffer registers at Port 0xF8h and the Interrupt Enable Register at Port 0xF9h.

- **COMx Baud Clock Divisor Latch LSB (Ports 02F8h/03F8h)**—Holds the least significant byte of a 16-bit baud-rate clock divisor that is used to generate the 16x baud clock (when COMx DLAB is 1).
- **COMx Baud Clock Divisor Latch MSB (Ports 02F9h/03F9h)**—Holds the most significant byte of the clock divisor (when COMx DLAB is 1).
- **COMx Transmit Holding Register (Ports 02F8h/03F8h)**—The byte to be transmitted is written to this write-only register (when COMx DLAB is 0).
- **COMx Receive Buffer Register (Ports 02F8h/03F8h)**—The received byte is read from this read-only register (when COMx DLAB is 0). This register shares an address with the Transmit Holding Register.
- **COMx Interrupt Enable Register (Ports 02F9h/03F9h)**—Enables the following serial port interrupts: modem status, receiver line status, transmitter holding empty, received data available, and time-out interrupts (when COMx DLAB is 0).
- **COMx Interrupt ID Register (Ports 02FAh/03FAh)**—A read-only register used to identify UART interrupts.
- **COMx FIFO Control Register (Ports 02F3h/03F3h)**—A write-only register used to enable and control the FIFO in 16650-compatible mode.
- **COMx Line Status Register (Ports 02FDh/03FDh)**—Shows the status of the data transfer, including parity and framing errors, as well as break and empty indicators
- **COMx Modem Control Register (Ports 02FCh/03FCh)** —Used to enable COMx interrupts and loopback diagnostic mode, and to assert $\overline{\text{RTS}}$ and $\overline{\text{DTR}}$.
- **COMx Modem Status Register (Ports 02FEh/03FEh)**—Contains both real-time and latched status bits for $\overline{\text{DCD}}$, $\overline{\text{RIN}}$, $\overline{\text{DSR}}$, and $\overline{\text{CTS}}$.
- **COMx Scratch Pad Register (Ports 02FFh/03FFh)**—This general-purpose I/O location can be used to hold temporary data and is not required for serial data transfer.

15.2.2 Chip Setup and Control (CSC) Index Registers

A summary listing of the chip setup and control (CSC) index registers used to control the serial port interface is shown in Table 15-1. Complete register descriptions can be found in the *Élan™ SC400 Microcontroller Register Set Reference Manual* (order #21032).

Table 15-1 Serial Port Register Summary

Register	I/O Address	UART Function Keyword	Description in Register Set Manual
Wake Up Source Enable Register A	22h/23h Index 52h	Wake-up source enable: $\overline{\text{RIN}}$ and SIN pins	page 3-59
Wake Up Source Status Register A	22h/23h Index 56h	Wake-up source status: $\overline{\text{RIN}}$ and SIN pins	page 3-63
Activity Source Enable Register A	22h/23h Index 62h	Activity source enable: CPU access to UART at COM1 or COM2	page 3-71
Activity Source Enable Register C	22h/23h Index 64h	Activity source enable: $\overline{\text{RIN}}$ and SIN pins	page 3-73

Table 15-1 Serial Port Register Summary (continued)

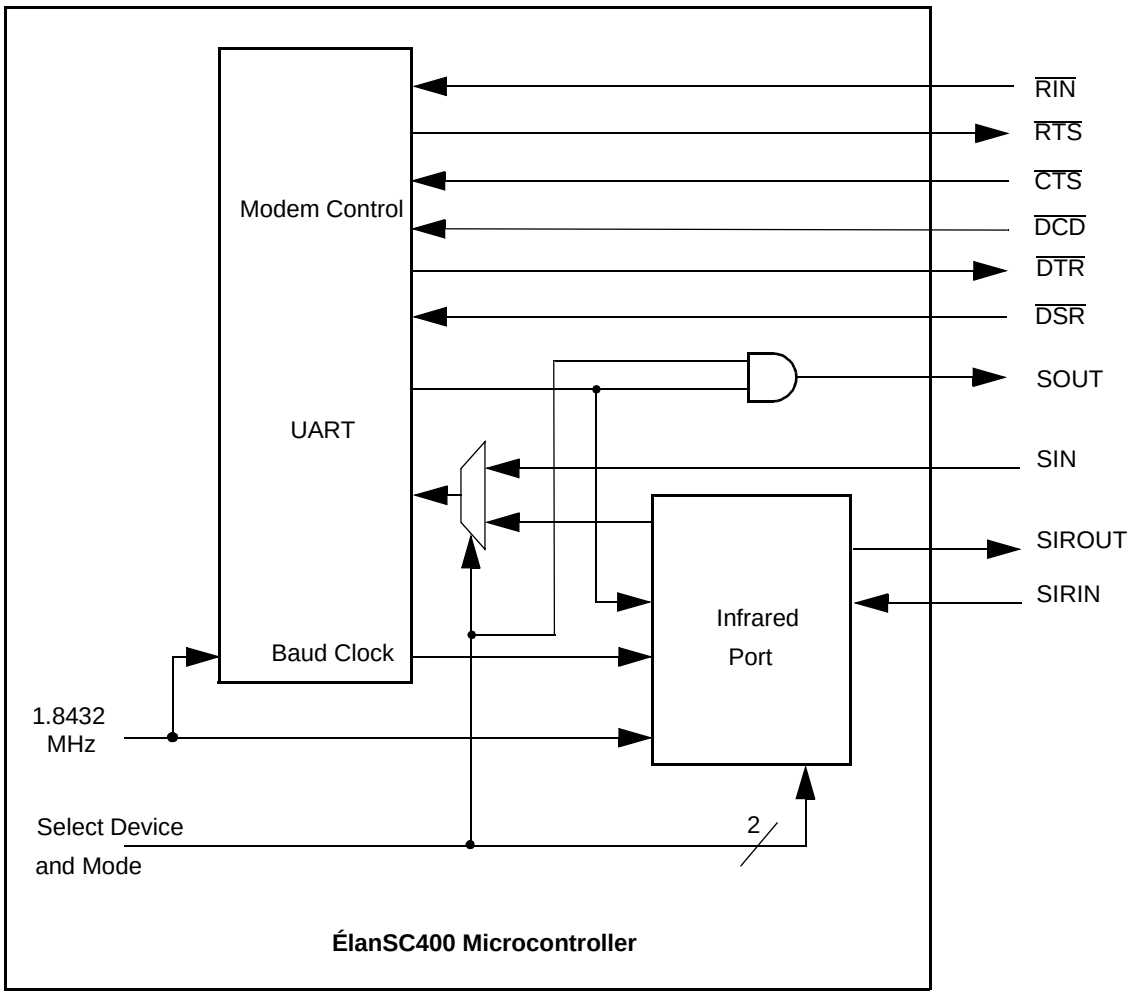
Register	I/O Address	UART Function Keyword	Description in Register Set Manual
Activity Source Status Register A	22h/23h Index 66h	Activity source status: CPU access to UART at COM1 or COM2	page 3-75
Activity Source Status Register C	22h/23h Index 68h	Activity source status: $\overline{RIN}$ and SIN pins	page 3-77
Activity Classification Register A	22h/23h Index 6Ah	Primary or secondary activity classification: CPU access to UART at COM1 or COM2	page 3-79
Activity Classification Register C	22h/23h Index 6Ch	Primary or secondary activity classification: $\overline{RIN}$ and SIN pins	page 3-81
CLK_IO Pin Output Clock Select Register	22h/23h Index 83h	UART clock output on CLK_IO pin	page 3-91
Miscellaneous SMI/NMI Enable Register	22h/23h Index 90h	SMI/NMI enable: $\overline{RIN}$ and SIN pins	page 3-94
Miscellaneous SMI/NMI Status Register	22h/23h Index 94h	SMI/NMI status: $\overline{RIN}$ and SIN pins	page 3-99
SMI/NMI Select Register	22h/23h Index 98h	Select SMI or NMI: $\overline{RIN}$ and SIN pins	page 3-104
I/O Access SMI Enable Register A	22h/23h Index 99h	SMI enable for I/O access to UART COM1 or COM2	page 3-105
I/O Access SMI Status Register A	22h/23h Index 9Bh	SMI status for I/O access to UART COM1 or COM2	page 3-107
Parallel/Serial Port Configuration Register	22h/23h Index D1h	COM1 or COM2 base address configuration, UART enable	page 3-167
UART FIFO Control Shadow Register	22h/23h Index D3h	Shadow FIFO control, 16550-compatible mode enable, FIFO buffer clear, trigger for received-data-available interrupt pending	page 3-169
Interrupt Configuration Register E	22h/23h Index D8h	IRQ mapping: UART (IRQ3 or IRQ4)	page 3-174
Suspend Pin State Register A	22h/23h Index E3h	Suspend state of serial port or infrared interface	page 3-184
IrDA Control Register	22h/23h Index EAh	UART or infrared mode select	page 3-188

15.3 BLOCK DIAGRAM

A block diagram of the serial port on the ÉlanSC400 and ÉlanSC410 microcontrollers is shown in Figure 15-1.

Both the serial interface pins and the infrared interface pins are available on the ÉlanSC400 and ÉlanSC410 microcontrollers at all times, although only one interface is available at any given time, because they both share the same internal UART. This means that both a serial device and an IrDA device can be designed into the same system; the ÉlanSC400 and ÉlanSC410 microcontrollers support real-time switching between the two ports.

Figure 15-1 Serial Port Block Diagram



15.4 OPERATION

The UART converts serial data received on the serial input line (SIN) into parallel data that can be processed by the microcontroller. The UART also converts parallel data into serial data for transmission off the chip on the serial output line (SOUT). Data can be transmitted and received at the same time.

15.4.1 Baud-Rate Generation

The serial data can be transferred from or to the UART on the microcontroller at baud rates up to 115,200, for a transfer rate of 115 Kbit/s. The transmit and receive sections can be operated at different baud rates.

The UART clock on the ÉlanSC400 and ÉlanSC410 microcontrollers runs at 1.8432 MHz. To generate the baud rate of the transfer, the UART clock is divided by a divisor value chosen by the programmer. The UART's baud-rate generator automatically calculates the baud rate from the divisor value programmed into the two COMx Baud Rate Divisor Registers (MSB and LSB). These registers are read at initialization to set the baud rate for the transfer. Table 15-2 lists some typical baud rates and their divisors. The divisor for any baud rate can be calculated by dividing 115,200 by the baud rate.

Table 15-2 Baud Rates at 1.8432 MHz

Desired Baud Rate	Decimal Divisor	Hexadecimal Divisor	Error (Percentage) Difference Between Desired Baud Rate and Actual
50	2304	900h	
75	1536	600h	
110	1047	417h	0.026
150	768	300h	
300	384	180h	
600	192	C0h	
1200	96	60h	
1800	64	40h	
2000	58	3Ah	0.69
2400	48	30h	
3600	32	20h	
4800	24	18h	
7200	16	10h	
9600	12	0Ch	
19200	6	6h	
38400	3	3h	
57600	2	2h	
115200	1	1h	

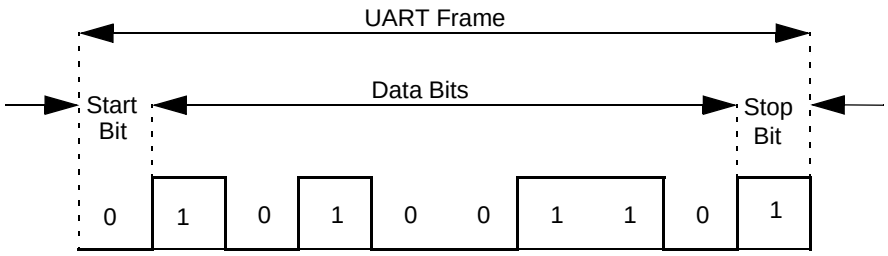
15.4.2 UART Frame

Each byte of data is transferred using a format called a *frame*. Figure 15-2 shows the format of a typical UART frame. The transmitter and receiver must agree on the frame format (as well as the baud rate), or transmission will not be successful. The frame format is determined by the value written into the Line Control Register (ports 03FBh/02FBh). A frame consists of a start bit, 5–8 data bits, an optional parity bit, and 1, 1.5, or 2 stop bits.

Transmission of a frame is initiated when software writes a byte to the Transmit Holding Register (ports 03F8h/02F8h). First, the SOUT output is driven Low for one baud-rate clock period. This is the start bit. Next, 5, 6, 7, or 8 data bits from the Transmit Holding Register are driven out on SOUT, one bit per clock period, starting with bit 0 (the LSB). If parity has been enabled in the Line Control Register, a parity bit is then clocked out. Finally, 1, 1.5, or 2 stop bits are clocked out, again according to the frame format chosen in the Line Control Register.

Reception of a frame is initiated when a start bit is received (the SIN input is driven Low for one baud-rate clock period). This start bit allows the receiver to synchronize its clock with the sender's clock. The receiver then clocks the next 5–8 bits into the Receive Buffer Register (ports 03F8h/02F8h), and then validates that the received parity is correct (if enabled) and that at least one stop bit is received. Any errors are reported in the Line Status Register (ports 03FDh/02FDh).

Figure 15-2 UART Frame



15.4.3 Operating Modes

The UART on the ÉlanSC400 and ÉlanSC410 microcontrollers supports two different modes of operation.

15.4.3.1 16450-Compatible Mode (No FIFOs)

In this mode, there is storage for only one byte to be transmitted and for only one byte of received data.

If a second transmit byte is written by the CPU before the first is moved from the Transmit Holding Register to the Transmit Serializer, the second byte will be lost. This situation can be avoided by waiting for a Transmit Holding Register Empty (THRE) interrupt or by polling the THRE bit.

If a received character is not read by the CPU before a second character is completely received, the first character is lost and an overrun error occurs, generating an interrupt.

15.4.3.2 16550-Compatible Mode (FIFOs)

In this mode, there are two 16-byte FIFOs for transmitting and receiving.

The CPU can write 16 bytes to the transmit FIFO and use the THRE interrupt or poll the THRE bit to trigger another 16 bytes. The receive FIFO has a programmable trigger level that can interrupt the CPU at 1, 4, 8 or 16 bytes present.

Writing a byte to a full transmit FIFO results in the last byte being lost.

If the receive FIFO is full, receipt of one more character generates an overrun error. The latest character is the one lost; the 16 bytes in the FIFO are unchanged.

15.4.4 Interrupts

The serial port on the ÉlanSC400 and ÉlanSC410 microcontrollers supports the standard UART interrupts. These include the Received Data Available, Transmit Holding Register Empty, Modem Status, and Receiver Line Status interrupts. In 16650-compatible mode, enabling the Received Data Available interrupt also enables time-out interrupts.

The priority of these interrupts is shown in Table 15-3. If two interrupt sources are pending simultaneously, only the highest priority interrupt will be indicated by the ID2–ID0 field of the COMx Interrupt ID Register (ports 03FAh/02FAh[3–0]). When the interrupt source is cleared, a subsequent read from this port will return the next highest priority interrupt source.

In 16650-compatible mode, a FIFO time-out occurs when the receive FIFO is not empty, and more than four continuous character times have transpired without more data being placed into or read out of the receive FIFO. Reading a character from the receive FIFO clears the time-out interrupt.

Table 15-3 Serial Port Interrupt Priority

ID2–ID0	Interrupt	Priority
0 1 1	Receive Line Status	First (Highest)
0 1 0	Received Data Available/ Receiver FIFO trigger (16550-compatible mode)	Second
1 1 0	FIFO time-out	Second
0 0 1	Transmitter Holding Register Empty/Transmit FIFO Empty (16550-compatible mode)	Third
0 0 0	Modem status	Fourth (Lowest)

Note: *In 16450-compatible mode, ID2 always reads back '0b'.*

The UART interrupts are enabled in ports 03F9h/02F9h and read in ports 03FAh/02FAh.

The serial port on the ÉlanSC400 and ÉlanSC410 microcontrollers has one internal IRQ that can be mapped to either IRQ3 or IRQ4. The Interrupt Configuration Register E (CSC index D8h[6–5]) controls which of these two IRQs is input to the programmable interrupt controller. Table 15-4 shows the IRQ and I/O address assignments for the serial port.

Table 15-4 Serial Port IRQ Assignments

Serial Port	Interrupt	I/O Address
COM1	IRQ4	03F8–03FFh
COM2	IRQ3	02F8–02FFh

15.5 INITIALIZATION

The serial port is disabled at power-on reset and must be configured by software before being enabled. When the internal UART is disabled, accesses to I/O locations in the 3F8–3FFh and 2F8–2FFh ranges go off the chip to the ISA bus.

- Enable the UART by setting the UART_ENB bit in the Parallel/Serial Port Configuration Register (CSC index D1h[0]).
- Select either COM1 or COM2. The SP_CONFIG bit in the Parallel/Serial Port Configuration Register (CSC index D1h[1]) controls this selection.
- Select UART mode (instead of infrared mode) by writing the SELDEVICE bit to 0 in the IrDA Control Register (CSC index EAh[0]).
- Configure the UART by programming the required registers.

After the UART is enabled, it powers up as a 16450-compatible device. It can be switched to and from 16650-compatible mode under software control.

- Enable 16650-compatible mode by setting the FIFOEN bit in the COMx FIFO Control Register (ports 03FAh/02FAh[0]). Note that the contents of either of these write-only registers can be read back in the UART FIFO Control Shadow Register (CSC index D8h).

15.6 POWER MANAGEMENT

The internal UART clock is turned off if the UART_ENB bit (CSC index D1h[0]) is 0. Operation of the serial port is affected by the power-management functions shown in Table 15-5.

Table 15-5 Power Management in the Serial Port

Serial Port Event	Description	Power Management Effect			
		Wake-Up	Activity	SMI	NMI
UART Ring Indicate ($\overline{RIN}$) signal	Triggered by the falling edge of $\overline{RIN}$	Yes		Yes	Yes
UART Receive (SIN) signal	Triggered by the falling edge of SIN	Yes		Yes	Yes
CPU access to UART (internal or external)	Triggered by the falling edge of the address decode qualified with commands		Programmable		
UART access	Accesses to COM1 (3F8–3FFh) or COM2 (2F8–2FFh) can cause an SMI or NMI through an I/O trap			Yes	Yes

CHAPTER

16 KEYBOARD INTERFACES

16.1 OVERVIEW

The integrated keyboard controller on the ÉlanSC400 and ÉlanSC410 microcontrollers has the following features:

- Matrix keyboard support with up to 15 rows and 8 columns
- Hardware support for software emulation of the System Control Processor (SCP) emulation logic
- XT keyboard interface

In addition to the keyboard interfaces provided on the ÉlanSC400 and ÉlanSC410 microcontrollers, any one of the GPIO_CSx pins can be enabled to output an external 8042 chip select.

16.1.1 Matrix Keyboard Interface

The integrated matrix keyboard controller directly interfaces to the rows and columns of a key matrix, eliminating the need for external keyboard logic.

The custom matrix keyboard interface on the ÉlanSC400 and ÉlanSC410 microcontrollers offers the following features:

- 15-row Schmitt trigger input signals with built-in pull-up resistors
- 8-column open-drain output signals with built-in pull-up resistors
- The SUS_RES signal appears as a key in the Keyboard Row Register B (CSC index C9h)
- Keyboard Column Register (CSC index C7h) for setting the column signals
- Keyboard Row Registers A and B for reading the row signals
- An interrupt for signaling when a key is pressed
- A timer for interrupting the CPU to service the keyboard
- A status register to get information about the state of the controller
- Keyboard Configuration Registers A and B for customizing the controller

Note that anytime the interface (DRAM, VL-bus, or ROM) is programmed for 32 bits, the matrix keyboard interface is not available.

16.1.2 SCP Emulation

In a typical PC/AT-compatible system, the keyboard has a processor to map the pressed key into a make-and-break code that it sends to the SCP in the computer. (The SCP is the System Control Processor, another processor connected to the ISA bus, originally the 8042.) Each key in the matrix has a unique make-and-break code. The SCP takes the codes from the keyboard and maps them to a scan code. The SCP puts this scan code in its output buffer (which may cause an IRQ1). The CPU can then read the scan code at Port 0060h. This scan code is programmable. One of three tables can be used to determine a key's scan code. The scan codes reside in ROM memory and are selectable by the BIOS or software.

It would be very complex to design a hardware keyboard interface that exactly duplicated the SCP function. Because the SCP function relies on the key matrix layout and scan code set selected, the hardware keyboard interface would differ for every system design and would differ depending on the scan code programmed. This would require dictating the keyboard matrix layout (which keys at each row/column intersection) or requiring hardware ROM fetches to get the scan code maps for each key press.

Due to these size and complexity constraints, the matrix keyboard interface described in this chapter is custom to the ÉlanSC400 and ÉlanSC410 microcontrollers and not hardware-compatible with the PC/AT. However, PC/AT compatibility can still be achieved by using SMIs to capture the keystrokes and map them to the correct scan code for the CPU.

The ÉlanSC400 and ÉlanSC410 microcontrollers provide software and hardware support for SCP emulation and PC/AT compatibility with the following features:

- The SCP Input Buffer/Output Buffer/Status Register for SCP software emulation
- An interrupt for signaling that the Input Buffer has been written
- An interrupt for signaling that the Output Buffer has been read
- Hardware for generating the IRQ1 signal
- Hardware for emulating the SCP A20GATE command
- Hardware for emulating the SCP RESET CPU command

16.1.3 XT Keyboard Interface

The XT keyboard interface in the ÉlanSC400 and ÉlanSC410 microcontrollers is compatible with IBM's PC-XT keyboard, consisting of clock and data inputs (XT_CLK and XT_DATA) to the ÉlanSC400 and ÉlanSC410 microcontrollers.

The XT keyboard interface includes the following features:

- Compatible with IBM's PC-XT keyboard
- Operates at speeds up to 250 KHz

16.2 REGISTERS

A summary listing of the chip setup and control (CSC) indexed registers used to control the keyboard interface on the ÉlanSC400 and ÉlanSC410 microcontrollers is shown in Table 16-1. Complete register descriptions can be found in the *Élan™ SC400 Microcontroller Register Set Reference Manual* (order #21032).

Table 16-1 Keyboard Interface Register Summary

Register	I/O Address	Keyboard Interface Function Keyword	Description in Register Set Manual
Pin Mux Register B	22h/23h Index 39h	Keyboard Row (KBD_ROW12–KBD_ROW7) or ISA signals enable, Keyboard Column (KBD_COL1–KBD_COL0) or XT keyboard (XT_CLK, XT_DATA) signals enable	page 3-45
Pin Mux Register C	22h/23h Index 3Ah	Matrix keyboard usage state for proper pin termination during Suspend	page 3-46
Wake-Up Source Enable Register A	22h/23h Index 52h	Wake-up source enable: matrix key press	page 3-59
Wake-Up Source Status Register A	22h/23h Index 56h	Wake-up source status: matrix key press	page 3-63
Activity Source Enable Register B	22h/23h Index 63h	Activity source enable: matrix keyboard key press, keyboard timer time-out, and CPU access to keyboard registers	page 3-72
Activity Source Status Register B	22h/23h Index 67h	Activity source status: matrix keyboard key press, keyboard timer time-out, and CPU access to keyboard registers	page 3-76
Activity Classification Register B	22h/23h Index 6Bh	Primary or secondary activity classification: matrix keyboard key press, keyboard timer time-out, and CPU access to keyboard registers	page 3-80
PC Card and Keyboard SMI/NMI Enable Register	22h/23h Index 91h	SMI/NMI enable: matrix keyboard key press, keyboard timer, and Input Buffer Written and Keyboard Output Buffer Read interrupts	page 3-95
PC Card and Keyboard SMI/NMI Status Register	22h/23h Index 95h	SMI/NMI status: matrix keyboard key press, keyboard timer, and Input Buffer Written and Keyboard Output Buffer Read interrupts	page 3-100
SMI/NMI Select Register	22h/23h Index 98h	SMI or NMI select	page 3-104
I/O Access SMI Enable Register A	22h/23h Index 99h	SMI enable for I/O access to keyboard	page 3-105
I/O Access SMI Status Register A	22h/23h Index 9Bh	SMI state for I/O access to keyboard	page 3-107
Standard Decode to GPIO_CS Map Register	22h/23h Index B1h	External SCP chip select mapping to one of the GPIO_CS pins	page 3-131

Table 16-1 Keyboard Interface Register Summary (continued)

Register	I/O Address	Keyboard Interface Function Keyword	Description in Register Set Manual
Keyboard Configuration Register A	22h/23h Index C0h	Keyboard configuration; SMI/NMI generation for SCP reset, GateA20 command, and SUS_RES/KBD_ROW14; IRQ12 and IRQ1 generation for SCP emulation and XT interface, reset disable, GateA20 disable, and keyboard transmit time-out	page 3-146
Keyboard Configuration Register B	22h/23h Index C1h	XT keyboard interface enable, XT keyboard select SMI/NMI or IRQ1, keyboard timer SMI/NMI status and clear, internal SCP emulation registers or external SCP chip select	page 3-149
Keyboard Input Buffer Read-Back Register	22h/23h Index C2h	Storage of writes to direct-mapped ports 0060h and 0064h	page 3-151
Keyboard Output Buffer Write Register	22h/23h Index C3h	Output buffer back door, data shifted in from XT_DATA	page 3-152
Mouse Output Buffer Write Register	22h/23h Index C4h	Mouse output buffer back door	page 3-153
Keyboard Status Register Write Register	22h/23h Index C5h	Keyboard status back door, emulated SCP status register	page 3-154
Keyboard Timer Register	22h/23h Index C6h	Time delay before the keyboard timer SMI/NMI occurs	page 3-155
Keyboard Column Register	22h/23h Index C7h	Column pin state, read or write	page 3-156
Keyboard Row Register A	22h/23h Index C8h	Row pin state, read or write	page 3-158
Keyboard Row Register B	22h/23h Index C9h	Row pin state, read or write	page 3-160
Keyboard Column Termination Control Register	22h/23h Index CAh	Pin termination, pull-up or pull-down resistor state, read or write	page 3-162

16.3 OPERATION

16.3.1 Matrix Keyboard Interface

Figure 16-1 shows a block diagram of the matrix keyboard controller. Note that anytime the interface (DRAM, VL-bus, or ROM) is programmed for 32 bits, the matrix keyboard interface is not available. The matrix keyboard signals shown in Table 16-2 are shared with other functions on the ÉlanSC400 and ÉlanSC410 microcontrollers.

Support for up to 112 keys is provided with 14 row and 8 column pins dedicated. The row signals have built-in pull-up resistors (~150 Kilohm), eliminating the need for external/ discrete components. The column pull-ups are programmable to be individually disabled in Suspend mode. This eliminates the current draw when a column has been programmed to remain Low in Suspend mode in order to enable a key-press as a wake-up source.

The SUS_RES signal is also brought into the Keyboard Row registers and the key-pressed interrupt logic. This signal can be individually disabled. With this design, the suspend/ resume functions can be more closely incorporated into the keyboard (i.e., using the SUS_RES key with other key presses to initiate system actions like reset). If the hardware suspend is not needed in the system design, this signal gives another row input, for a total of 15 rows and support for up to 120 keys.

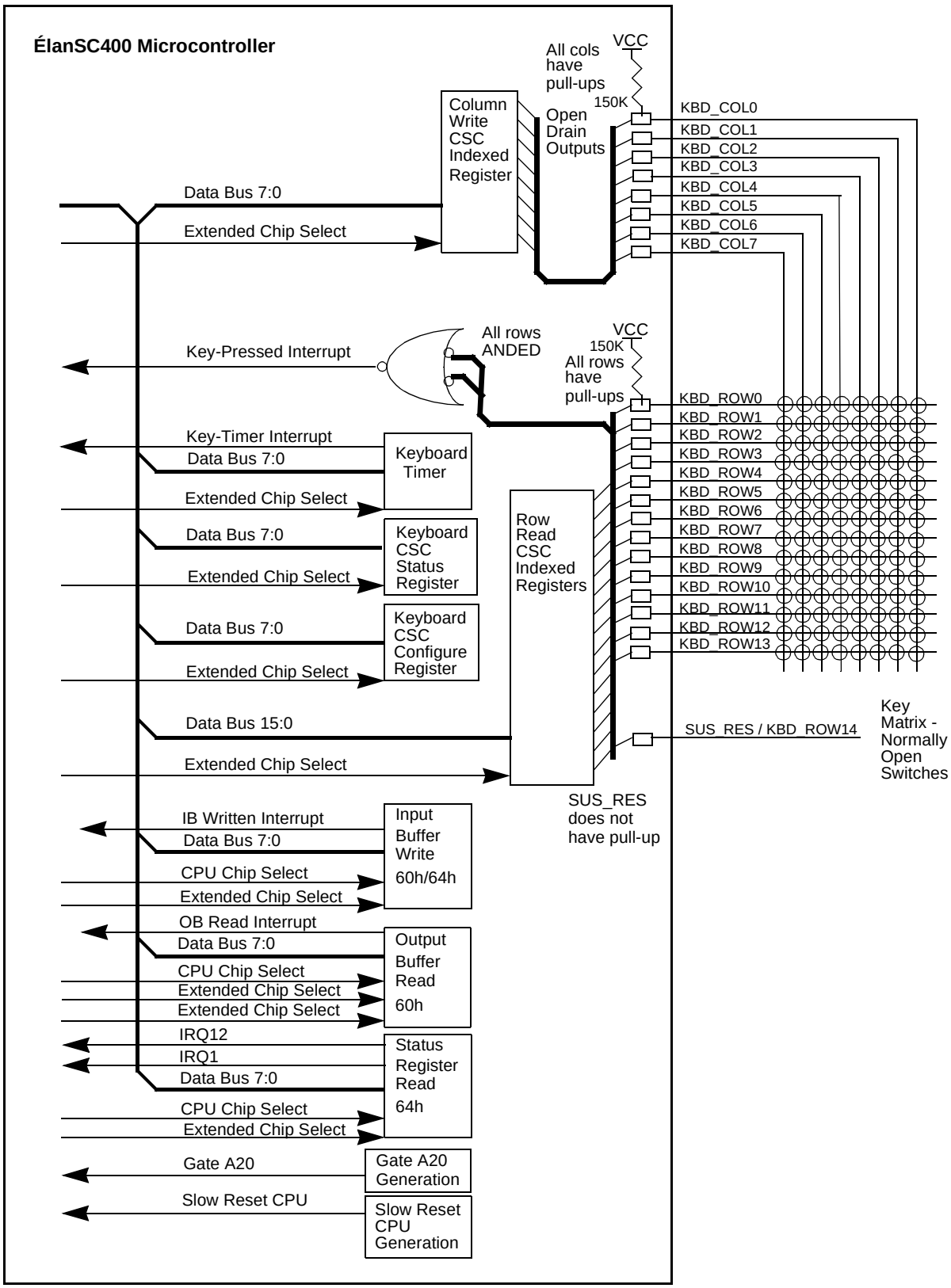
The basic operation of the matrix keyboard interface includes the following steps.

- Write all keyboard columns to 0 (via the Keyboard Column Register at CSC index C7h). This is required so that a key press on any column will generate an interrupt. Note that an SMI or NMI is the only type of interrupt the matrix keyboard interface recognizes as a key-pressed interrupt.
- When the interrupt is received, perform a matrix scan. The scan is performed one column at a time by writing one column control bit to 0, while the other column bits are written to 1. For each column being checked, read back the row inputs (through Keyboard Registers A and B at CSC index C8–C9h). If, for a particular column, a row read-back bit is 0, then the key corresponding to that row and column is currently pressed.
- Clear the interrupt.
- If the interrupt was an NMI, set the NMI_DONE bit in the XMI Control Register (CSC index 9Dh[1]) prior to returning control to the interrupted routine, then return.

Table 16-2 Keyboard Signals Shared with the Other Interfaces

Default Signal	Alternate Function	Control
KBD_ROW13	$\overline{\text{R32BFOE}}$	Do not enable the 32-bit ROM interface on $\overline{\text{ROMCS0}}$.
KBD_ROW12–KBD_ROW7	$\overline{\text{MCS16}}$, $\overline{\text{SBHE}}$, BALE, PIRQ2, PDRQ1, $\overline{\text{PDACK1}}$	CSC index 39h[2]
KBD_ROW6–KBD_ROW0	MA12, $\overline{\text{RAS3}}$–$\overline{\text{RAS2}}$, $\overline{\text{CASH3}}$–$\overline{\text{CASH2}}$, $\overline{\text{CASL3}}$–$\overline{\text{CASL2}}$	CSC index 00–03h[3]
KBD_COL6–KBD_COL2	PIRQ7–PIRQ3	CSC index 3Ah[1]
KBD_COL1–KBD_COL0	XT_CLK, XT_DATA	CSC index 39h[3]

Figure 16-1 Matrix Keyboard Controller Block Diagram



16.3.1.1 N-Key Rollover

N-key rollover is the problem that happens when three keys are pressed at the same time. With two keys in the same row and two keys in the same column, a fourth key will be detected as pressed. Because keyboards no longer incorporate diodes to eliminate current paths through keys, the controller and system designer have to resolve this problem.

- **Example**—Two rows, W and X, and two columns, Y and Z are in the matrix. The keys at (W,Y), (W,Z), and (X,Z) are pressed. When column Z is driven Low and the rows are read (Figure 16-2), rows W and X will be Low, as they should be, because these keys are pressed. When column Y is driven Low and the rows are read (Figure 16-3), rows W and X are Low, which is wrong. Only the key at (W,Y) should be detected; but there is a path to row X through the keys at (W,Z) and (X,Z), so the key at (X,Y) appears as the “Ghost Key”.

N-key rollover is addressed in this design by having many row signals and using several of them for special keys like Shift, Alt, Ctrl, Fn, etc. By putting only one key on each row, there is no path for the Low column signal to drive a row signal it should not. This will limit the total size of the keyboard supported, but an 80-key keyboard can still be supported with four additional keys handled in this special way.

Figure 16-2 N-Key Rollover Example #1

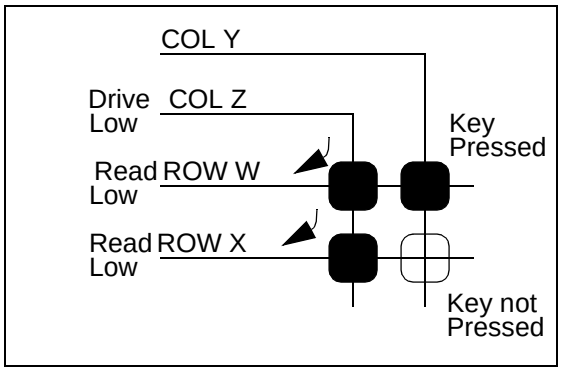
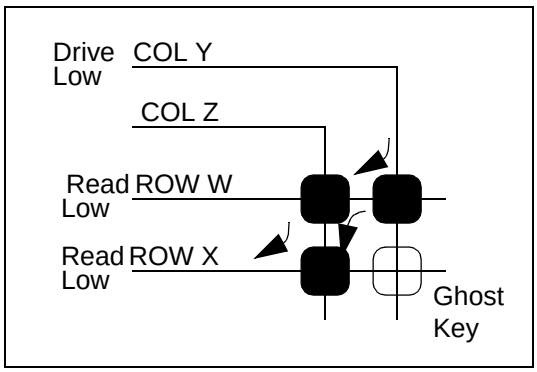


Figure 16-3 N-Key Rollover Example #2



16.3.1.2 Key-Pressed Interrupt

When no keys are pressed, it is not necessary for the CPU to spend time scanning the keyboard (although it could, if the software required it). The ÉlanSC400 and ÉlanSC410 microcontrollers contain hardware designed to cause an SMI or NMI when any key is

pressed. To use it, the CPU writes all the columns to Low. All the rows are ANDed together inside the chip and can be programmed to cause an NMI or SMI on a key press if any row goes Low. This can only be used while no keys are pressed, because as long as a key is held down, the SMI would be active.

In addition, a key press can cause the CPU clock to start back up, if it is stopped and the keyboard is programmed to cause a PMU activity.

As a variation, one or several of the columns can be programmed Low, so only certain keys will cause the interrupt when pressed. This requires careful layout of the key matrix by the system designer to isolate those special keys.

16.3.1.3 Keyboard Wake-Up

The keyboard can be programmed to wake up the system from Suspend mode. This is done by programming the necessary columns Low and using the key-pressed interrupt as the wake-up. As an alternative to using the columns, the SUS_RES signal can be used to do the wake-up. The enables to make these wake-ups are described in Section 5.4.9.

16.3.1.4 CPU-Scanned Keyboard

The CPU handles all scanning of the keyboard. There is no state machine to automatically walk a 0 through the columns and save the pressed key information for the CPU to retrieve later.

The CPU obtains its key-pressed information by writing the column signals Low (through the Keyboard Column Register at CSC index C7h) one at a time and reading the rows (through Keyboard Registers A and B at CSC index C8–C9h) to check if any of the rows are Low. If any row is detected Low, then the key at that row/column intersection is pressed.

To account for key bounce, a software debounce should occur by waiting an appropriate amount of time (several milliseconds—actual time depends on key-switch characteristics and system design) and scanning the keys again to confirm the same keys are pressed.

The software/firmware that is controlling this can then map that row/column intersection into a code indicating which key is pressed.

16.3.1.5 Keyboard Timer

The keyboard controller incorporates its own timer that can be set for 3.91 ms to 1 second in 3.91-ms increments. On a time-out, the timer generates a key-timer interrupt that can be programmed to cause an SMI or NMI and start the CPU clock back up if it has been stopped.

Note: *The internal RTC must be initialized before the keyboard timer function can be used. This is particularly important for those systems that use an external RTC.*

The timer can be used to support key debounce, typematic keys, and to keep the CPU scanning the keyboard. These three different rates are as follows:

- **Debounce**—Typically 5–40 ms depending on the key switch characteristics.
- **Typematic support**—The PC/AT standard calls for a delay (the time a key is held down until the typematic support begins) of 250 ms to 1 second in 250-ms intervals. The typematic period (interval from one key output to the next) is 2 to 30 characters per second (33–500 ms per key output) at a variable rate defined by the following equation:

  $$\text{Period} = (8+A) \times (2^B) \times 0.00417 \text{ seconds}$$

  where A and B are programmable by the system.

The keyboard timer will not support this exact equation, but the resolution of the timer is small enough and the range broad enough to work without a noticeable difference.

- **CPU scanning**—A good touch typist can type 50 words per minute; this equals 250 keystrokes per minute or about 5 keystrokes per second. This indicates the keyboard should be scanned every 200 ms to look for a new key press.

16.3.1.6 Typematic Support

The typematic the feature is the keyboard automatically repeating a key at a programmable rate, as long as a key is held down after it has been pressed a predetermined amount of time. Because the key matrix is scanned by the CPU, there is no specific hardware for typematic, but the timer can be used to aid in typematic support.

16.3.2 SCP Emulation

To facilitate software emulation of a PC/AT keyboard, the keyboard controller provides the SCP Input Buffer, Output Buffer, and Status registers, as well as IRQ generation. Keyboard Configuration Register B at CSC index C1h[3–2] enables the internal SCP emulation registers.

- **Input Buffer—**This CPU write register (ports 0060h and 0064h) can be enabled to cause an SMI/NMI when the CPU writes it. The firmware can then read out the byte at the Keyboard Input Buffer Read-Back Register (CSC index C2h) and use the information for its keyboard code. By writing to the Input Buffer at Port 0060h or 0064h, the IBF flag in the Status Register is set. By reading CSC index C2h, the IBF flag in the Status Register is cleared.
- **Output Buffer—**This CPU read register (Port 0060h) is writable at the Keyboard Output Buffer Write Register (CSC index C3h). This is where the firmware would communicate information back to the CPU (such as key press scan codes). By reading the Output Buffer at Port 0060h, the OBF flag in the Status Register is cleared. By writing CSC index C3h, the OBF flag in the Status Register is set.
- **Status Register—**This CPU read register (Port 0064h) is writable at the Keyboard Status Register Write Register (CSC index C5h). Several of the bits are writable by firmware and some (IBF, OBF, Mouse OBF, Command/Data) are set and cleared automatically when accesses occur (Input Buffer is written or read, Output Buffer is written or read, etc.).
- **IRQ1**—As part of the SCP support, IRQ1 will be generated if it is enabled when the OBF flag is set because of a write to CSC index C3h.
- **IRQ12**—As part of the SCP support, IRQ12 will be generated if it is enabled when the OBF flag is set because of a write to the Mouse Output Buffer Write Register (CSC index C4h).

16.3.2.1 SCP GATEA20 and Reset CPU Command Emulation

The ÉlanSC400 and ÉlanSC410 microcontrollers do not support an A20GATE or RESCPU input pin. These inputs are typically driven by the external SCP in response to a command request that is issued by the main CPU. In the implementation on the ÉlanSC400 and ÉlanSC410 microcontrollers, the A20GATE and RESET CPU command sequences are detected by internal logic, and the appropriate action is taken.

The A20GATE command is detected when the CPU issues the standard command write to Port 0064h of ‘D1h’ followed by a data write to Port 0060h. Bit 1 of the write to Port 0060h drives the A20 control logic. A value of 1 allows the CPU A20 signal to propagate to the core logic, while a value of 0 allows the CPU A20 signal to be driven Low, as long as no other A20GATE control sources are forcing the CPU A20 signal to propagate.

The RESET CPU command is detected when the CPU issues the standard command write to Port 0064h of FEh.

The A20GATE and RESET CPU command emulation can be enabled or disabled independently. Also, the Input Buffer Full SMI/NMI's can be disabled from occurring for both sequences independently.

16.3.3 Keyboard System Scenarios

16.3.3.1 Scenario #1: Simple Matrix Keyboard Support by Interrupting

The following is one possible scenario of how the system would use the keyboard controller with interrupting, if PC/AT compatibility is not required (i.e., the system runs only custom software or guarantees all keyboard accesses go through BIOS and not directly to the keyboard controller):

1. No keys are pressed. Write the Keyboard Column Register all low ('00') and enable the key-pressed interrupt to cause an SMI or NMI on a key press (any row driven Low).

The CPU can continue to run the application software without polling the keyboard now.

2. As soon as a key is pressed, an SMI/NMI occurs and the CPU stops running the application software and jumps to the SMI/NMI code to service the keyboard.
3. The keyboard service code disables the key-pressed interrupt from causing an SMI/NMI; writes the Keyboard Column Register with 'FE' to set only column 0 low; reads the Keyboard Row Registers A and B to see if any of the keys on column 0 are pressed; continues to walk a '0' through all the columns, and reads the rows to identify all the keys that are pressed. The timer is then set for some amount of time and enabled to cause an SMI/NMI; the SMI/NMI routine is exited; and control is returned to the application software (this is for software debounce).
4. On a timer time-out (key-timer interrupt), the SMI/NMI interrupt occurs, and the keyboard service code runs through all the keys to find all that are pressed. These are compared to the keys pressed the first time through, and any that match are reported back to the software for its use.
5. The timer is reset and re-enabled, the SMI/NMI is exited, and control is returned to the software.
6. The next time the timer times-out, the keyboard service code looks for new keys pressed and does the software debounce before reporting them. Any keys that are detected Low for a predetermined amount of time are reported at the programmed typematic rate.
7. When all keys are released. the keyboard service code starts over at the top, programming all columns Low and enabling the key-pressed interrupt to cause an SMI/NMI.

16.3.3.2 Scenario #2: Simple Matrix Keyboard Support by Polling

The following is one possible scenario of how the system would use the keyboard controller with polling if PC/AT compatibility is not require (i.e., the system runs only custom software or guarantees all keyboard accesses go through BIOS and not directly to the keyboard controller):

1. The software running simply goes out and walks a 0 through the columns and reads the rows until a key is detected as pressed.
2. When the key is detected pressed for several milliseconds, it is accepted as a valid hit and used by the software.

16.3.3.3 Scenario #3: Matrix Keyboard Support with PC/AT Compatibility

The following is one possible scenario of how the system would use the keyboard controller if PC/AT compatibility is required (i.e., the system runs standard PC/AT software and has to guarantee that accesses directly to the keyboard controller will work):

1. No keys are pressed.Write the Keyboard Column Register all low (‘00’), and enable the key-pressed interrupt to cause an SMI on a key press (any row goes Low).

The CPU can continue to run the application software without polling the keyboard now.

2. Enable the Input Buffer Full flag (IBF) being set to cause an SMI.
3. Enable the Output Buffer Full flag (OBF) being cleared to cause an SMI.
4. When a key is pressed, an SMI occurs and the CPU stops running the application software and jumps to the SMI code to service the keyboard.
5. The SMI keyboard service code disables the key-pressed interrupt from causing an SMI; writes the Keyboard Column Register with ‘FEh’ to set only column 0 low; reads the Keyboard Row Registers A and B to see if any of the keys on column 0 are pressed; continues to walk a ‘0’ through all the columns, and reads the rows to identify all the keys that are pressed.
6. The timer is then set for some amount of time and enabled to cause an SMI; the SMI routine is exited; and control is returned to the application software (this is for software debounce).
7. On a timer time-out (key-timer interrupt), the SMI interrupt occurs, and the keyboard service code runs through all the columns to identify all keys that are pressed. Those keys found are compared to the keys pressed the first time through, and any that match are translated into the correct PC/AT scan code. The first key scan code is written through the Keyboard Output Buffer Write Register (CSC index C3h) into the Output Buffer.
8. The SMI routine is then exited and control is returned to the application software.
9. When the software reads the Output Buffer to get the keystroke, the OBF being cleared causes an SMI, the code puts the next key scan code into the Output Buffer and exits, and so on, until all pressed keys are reported.
10. While a key is in the “pressed” state, the timer can be used to perform software debounce of the key-press and provide information on the duration of the key-press for Typematic support.
11. When all keys are released, the routine returns to the top, programming all columns Low and a key-pressed interrupt to cause an SMI.
12. If the software writes to the Input Buffer with a command to the keyboard controller, it causes an SMI, and the SMI code can read the byte from the Keyboard Input Buffer Read-Back Register (CSC index C2h) and act accordingly.

16.3.4 XT Keyboard

The XT keyboard interface in the ÉlanSC400 and ÉlanSC410 microcontrollers is compatible with IBM's PC-XT keyboard.

The interface includes the bidirectional clock and data signals, XT_CLK and XT_DATA. These pins are driven by open-drain drivers with optional weak internal pull-up resistors. If a system design requires a reset pin for the XT keyboard interface, an additional output pin, such as one of the GPIO pins, can be used.

16.3.4.1 Interrupts

When a serial keyboard byte has been assembled, an XT Keyboard Byte Received interrupt is generated on IRQ1. The software should respond to the interrupt by reading the byte assembled in the keyboard data shift buffer at Port 0060h. The programmer also has the option of driving the clock pin Low as an additional handshake indication. After reading the byte at Port 0060h, the program clears the keyboard data shift buffer and interrupt by writing Port 0061h[7] High, then Low again. This action not only clears the shift buffer and interrupt, but also releases the data line to be an input again.

The Keyboard Configuration Register A (CSC index C0h[4]) provides IRQ1 control for the XT keyboard interface. Table 16-3 shows the effect of setting this bit on IRQ1 generation.

Table 16-3 IRQ1 Generation

SCP Support	XT Keyboard Enabled	XT Interrupt Type	Effect of Setting CSC Index Bit C0h[4]
External	N/A	N/A	No effect
None	No	N/A	No effect
None	Yes	XMI	No effect
None	Yes	IRQ1	Allows IRQ1 to be generated as a result of data being received from the XT keyboard interface.
Internal	No	N/A	Allows IRQ1 to be generated as a result of the Keyboard Output Buffer Write Register (CSC index C3h) being written to.
Internal	Yes	XMI	Allows IRQ1 to be generated as a result of CSC index C3h being written to.
Internal	Yes	IRQ1	Allows IRQ1 to be generated as a result of data being received from the XT keyboard interface or as a result of CSC index C3h being written to. When configured like this, if either IRQ1 source is being asserted, the other source will not be able to generate an IRQ1. Care must be taken in the IRQ1 handler for this specialized case because if both sources of IRQ1 are asserted simultaneously (i.e., a write to C3h is quickly followed by arrival of data from the XT keyboard interface). The handler must not exit until one of the following has occurred: — Both IRQ1 sources are cleared. — CSC index C0[4] has been toggled after one of the IRQ1 sources has been cleared to generate an edge for the remaining IRQ source. Failure to perform one of the above can result in the loss of further IRQ1 requests being detected by the PIC, as an edge is required for this.

16.3.4.2 Enabling the XT Keyboard Interface

The XT keyboard interface is enabled by setting CSC index C1h[4]. Setting this bit does the following:

- Allows the pins, XT_DATA and XT_CLK, to become available as keyboard signals, because their function is shared
- Allows Port 0060h to be read as an internal XT por
- Allows IRQ1 to be used by the XT interface

16.3.4.3 Controlling the XT Keyboard Interface

Two control bits (Port 0061h[7, 6] are provided for control of the XT keyboard interface.

- Bit 7 is used to clear the keyboard interrupt, clear the keyboard data shift buffer, and force the data line XT_DATA Low (which can be used as a busy signal to the keyboard). Two writes are required for the proper operation of this bit: the first to set it, and the second to clear it. If it is not cleared, then the shift buffer will be held in a “clear” configuration.
- Bit 6, when 0, forces the keyboard clock line XT_CLK Low, which can also be used as a busy signal to the keyboard.

Once a serial keyboard byte has been assembled, it can be read at Port 0060h.

16.3.4.4 Timing

The XT keyboard clock typically runs at roughly 100 KHz, or 10 µs per bit. The falling edge of the XT_CLK input (after being delayed by two CPUCLKS/6) is what clocks the shift buffer. Therefore, XT_DATA should be changed on the rising edge of the XT_CLK signal. The XT keyboard interface will run at speeds up to 250 KHz.

16.4 INITIALIZATION

Both the matrix keyboard interface and the XT keyboard interface are disabled at power-on reset, and must be configured by software before being enabled. Note that the internal RTC must be initialized before the keyboard timer function can be used. This is particularly important for those systems that use an external RTC.

16.5 POWER MANAGEMENT

Operation of the keyboard interfaces on the ÉlanSC400 and ÉlanSC410 microcontrollers is affected by the power-management functions shown in Table 16-4.

Table 16-4 Power Management in the Keyboard Interfaces

Keyboard Interface Event	Description	Power Management Effect			
		Wake-Up	Activity	SMI	NMI
Matrix keyboard key press	Triggered by the falling edge of the internal keyboard controller's key-pressed interrupt	Yes	Programmable	Yes	Yes
PU access to internal keyboard (ports 60h and 64h)	Triggered by the falling edge of the internal keyboard controller's chip select		Programmable		
Keyboard timer time-out	Triggered by keyboard controller's timer time-out interrupt			Yes	Yes
Keyboard input buffer write	Triggered by keyboard controller's input buffer write interrupt			Yes	Yes
Keyboard output buffer read	Triggered by keyboard controller's output buffer read interrupt			Yes	Yes
Keyboard access	Reads and writes to ports 0060h and 0064h can cause an SMI through a trap			Yes	

CHAPTER

17 GENERAL-PURPOSE INPUT/OUTPUT AND PROGRAMMABLE CHIP SELECTS

17.1 OVERVIEW

The ÉlanSC400 and ÉlanSC410 microcontrollers support 32 general-purpose I/O pins (GPIOs) that can be used on the system board. There are two classifications of GPIO available:

- GPIOx signals (where 'x' is a number)—These signals are programmable to be inputs or outputs only. There are 17 GPIOx pins on the ÉlanSC400 and ÉlanSC410 microcontrollers.
- GPIO_CSx signals—These signals can be programmed to be inputs, outputs, chip selects, or power management functions. There are 15 GPIO_CSx pins on the ÉlanSC400 and ÉlanSC410 microcontrollers.

Two general-purpose I/O pins are dedicated: GPIO_CS0 and GPIO_CS1. The rest are shared with other functions, including external buffer control, the ISA bus interface, the parallel port, and, on the ÉlanSC400 microcontroller, PC Card power control and the PC Card Socket B interface.

The GPIO_CSx signals can be programmed for the following functions:

- PMU mode change outputs, activities, wake-ups, or SMI/NMI
- I/O or memory address decode outputs
- $\overline{\text{ROMCS2}}$ (ROM Chip Select 2)
- External 8042 (or similar) keyboard controller chip select (called $\overline{\text{SCP_CS}}$ in this chapter.)

17.1.1 External Pins

The ÉlanSC400 and ÉlanSC410 microcontrollers support 32 general-purpose I/O pins (GPIOs). Except for two pins (GPIO_CS0 and GPIO_CS1), all the GPIO pins share pins with other functions. The designer should carefully consider the system implications of using a pin as a GPIO instead of its alternate function.

In addition to their general-purpose I/O functions, 15 of the GPIO signals (GPIO_CS14–GPIO_CS0) can be used as chip selects, power management unit (PMU) I/Os, or to signal an SMI or NMI.

17.1.2 Internal Chip-Select Logic

The ÉlanSC400 and ÉlanSC410 microcontrollers contain internal chip-select logic that provides two fixed chip selects ($\overline{\text{ROMCS2}}$ and $\overline{\text{SCP_CS}}$) and four programmable chip selects (GP_CSA–GP_CSD).

Each of these chip selects can optionally be mapped to any one of the 15 GPIO_CSx pins. Additionally, the programmable chip selects (GP_CSA–GP_CSD) can be used for power management or to generate SMIs, whether or not they are physically mapped to external GPIO pins. This is fully discussed in Section 17.7.

17.2 REGISTERS

A summary listing of the chip setup and control (CSC) indexed registers used to control the GPIO signals is shown in Table 17-1. Complete register descriptions can be found in the *Élan™ SC400 Microcontroller Register Set Reference Manual* (order #21032).

Table 17-1 GPIO Register Summary

Register	I/O Address	GPIO Function Keyword	Description in Register Set Manual
Pin Strap Status Register	22h/23h Index 20h	External buffer controls ($\overline{\text{DBUFOE}}$, $\overline{\text{DBUFRDH}}$, $\overline{\text{DBUFRDL}}$) enable on GPIO_CS4–GPIO_CS2, ROM0 data bus width, ROM0 or PC Card boot vector decode	page 3-25
Pin Mux Register A	22h/23h Index 38h	GPIO_CS8–GPIO_CS5 or ISA signals enable	page 3-44
Pin Mux Register B	22h/23h Index 39h	PC Card power controls or GPIO_CSx signals, keyboard columns or XT keyboard signals; $\overline{\text{LBL2}}$; parallel port, PC Card Socket B, or GPIOx signals	page 3-45
Pin Mux Register C	22h/23h Index 3Ah	PC Card Socket A second card detect or GPIO signal	page 3-46
GPIO Termination Control Registers A–D	22h/23h Index 3B–3Eh	GPIOx and GPIO_CSx pull-ups and pull-downs	page 3-47–page 3-50
GPIO as a Wake Up or Activity Source Status Registers A–B	22h/23h Index 5A–5Bh	Wake-up or activity source status: GPIO_CSx signals	page 3-67–page 3-68
GP_CS Activity Enable Register	22h/23h Index 60h	Activity enable for GP_CSA–GP_CSD signals, primary and secondary activity classification	page 3-69
GP_CS Activity Status Register	22h/23h Index 61h	Activity status: GP_CSA–GP_CSC signals	page 3-70
Mode Timer SMI/NMI Status Register	22h/23h Index 96h	SMI/NMI status: GPIOx signals	page 3-96
I/O Access SMI Enable Register B	22h/23h Index 9Ah	SMI enable: I/O access to GP_CSA or GP_CSB address range	page 3-106
I/O Access SMI Status Register B	22h/23h Index 9Ch	SMI status: I/O access to GP_CSA or GP_CSB address range	page 3-108
GPIO_CS Function Select Registers A–D	22h/23h Index A0–A3h	GPIO_CSx signals: activity, wake-up, input, or output	page 3-110–page 3-113
GPIO Function Select Registers E–F	22h/23h Index A4–A5h	GPIOx signals: inputs or outputs	page 3-114–page 3-115
GPIO Read-Back/Write Registers A–D	22h/23h Index A6–A9h	GPIO_CSx status and control	page 3-116–page 3-119
GPIO_PMUx Mode Change Registers	22h/23h Index AA–ADh	Drive GPIO_PMUA–GPIO_PMUD signals in PMU modes	page 3-120–page 3-126
GPIO_PMU to GPIO_CS Map Registers A–B	22h/23h Index AE–AFh	GPIO_PMUA–GPIO_PMUD mapping to GPIO_CSx pins	page 3-128–page 3-129
GPIO_XMI to GPIO_CS Map Register	22h/23h Index B0h	GPIO_CSx pin to the internal GPIO_XMI signal, SMI or NMI selection	page 3-130

Table 17-1 GPIO Register Summary (continued)

Register	I/O Address	GPIO Function Keyword	Description in Register Set Manual
Standard Decode to GPIO_CS Map Register	22h/23h Index B1h	Keyboard controller chip select ($\overline{\text{SCP_CS}}$) and $\overline{\text{ROMCS2}}$ mapping to GPIO_CSx pins	page 3-131
GP_CS to GPIO_CS Map Registers A–B	22h/23h Index B2–B3h	GP_CSA–GP_CSD mapping to GPIO_CSx pins	page 3-132–page 3-133
GP_CSA I/O Address Decode Register	22h/23h Index B4h	Chip select A address	page 3-134
GP_CSA I/O Address Decode and Mask Register	22h/23h Index B5h	Chip select A address, SA3–SA0 mask	page 3-135
GP_CSB I/O Address Decode Register	22h/23h Index B6h	Chip select B address	page 3-136
GP_CSB I/O Address Decode and Mask Register	22h/23h Index B7h	Chip select B address and SA3–SA0 mask	page 3-137
GP_CSA/B I/O Command Qualification Register	22h/23h Index B8h	GP_CSA and GP_CSB qualified with $\overline{\text{IOR}}$/$\overline{\text{IOW}}$, GP_CSA and GP_CSA ISA cycle data bus widths and timing selectors	page 3-138
GP_CSC Memory Address Decode Register	22h/23h Index B9h	Chip select C address	page 3-140
GP_CSC Memory Address Decode and Mask Register	22h/23h Index BAh	Chip select C address, SA3–SA0 mask	page 3-141
GP_CSD Memory Address Decode Register	22h/23h Index BBh	Chip select D address	page 3-142
GP_CSD Memory Address Decode and Mask Register	22h/23h Index BCh	Chip select D address, SA3–SA0 mask	page 3-143
GP_CSC/D Memory Command Qualification Register	22h/23h Index BDh	GP_CSC and GP_CSD qualified with $\overline{\text{IOR}}$/$\overline{\text{IOW}}$, GP_CSA and GP_CSA ISA cycle data bus widths and timing selectors	page 3-144
Suspend Mode Pin State Override Register	22h/23h index E5h	Pin termination latch	page 3-186

17.3 BLOCK DIAGRAM

Figure 17-1 shows all the GPIO signals available on the ÉlanSC400 and ÉlanSC410 microcontrollers and their shared functions, if any. Figure 17-2 shows a block diagram of the GPIO_CSx signals.

Figure 17-1 General-Purpose Input/Output Block Diagram

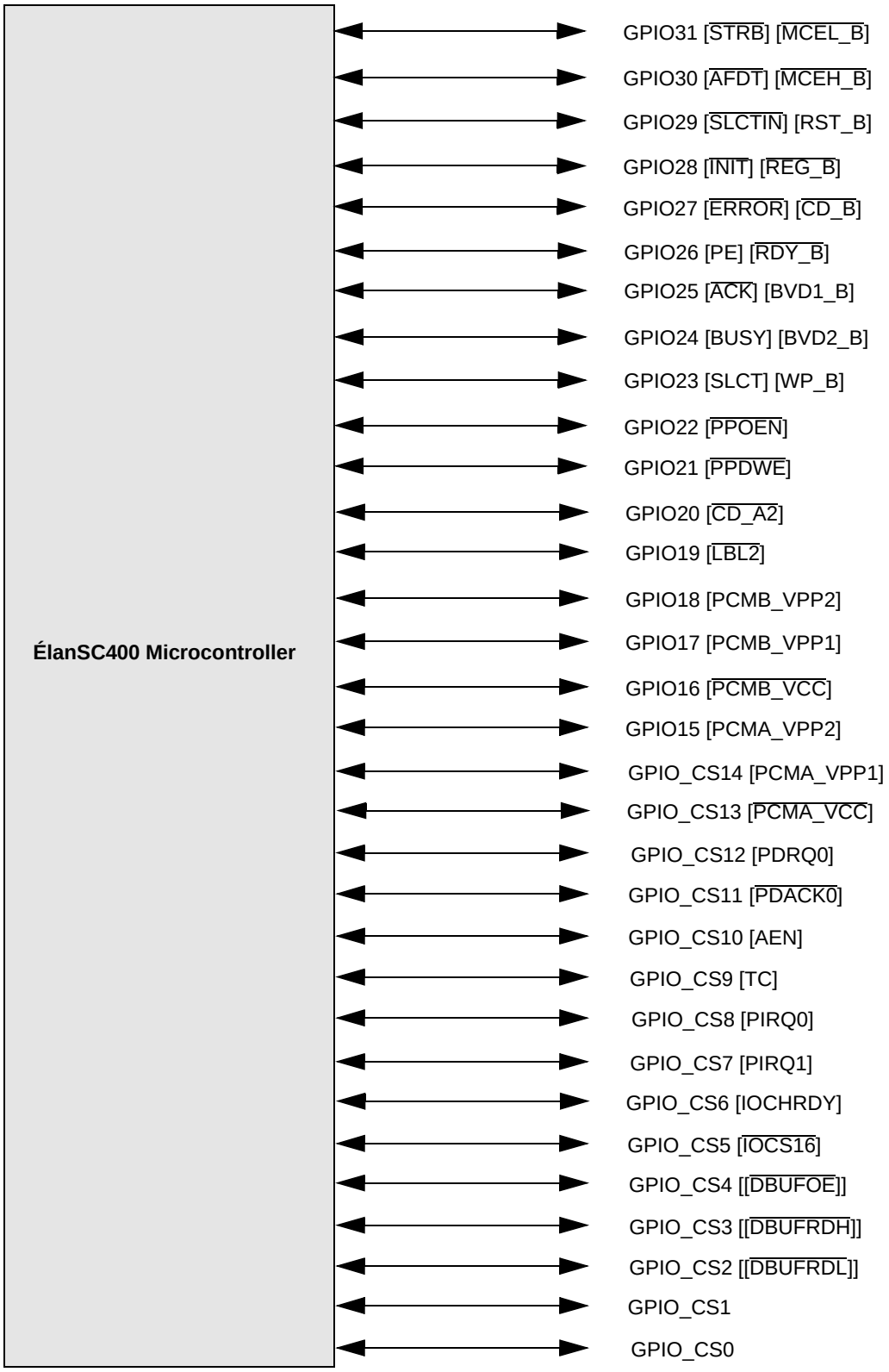
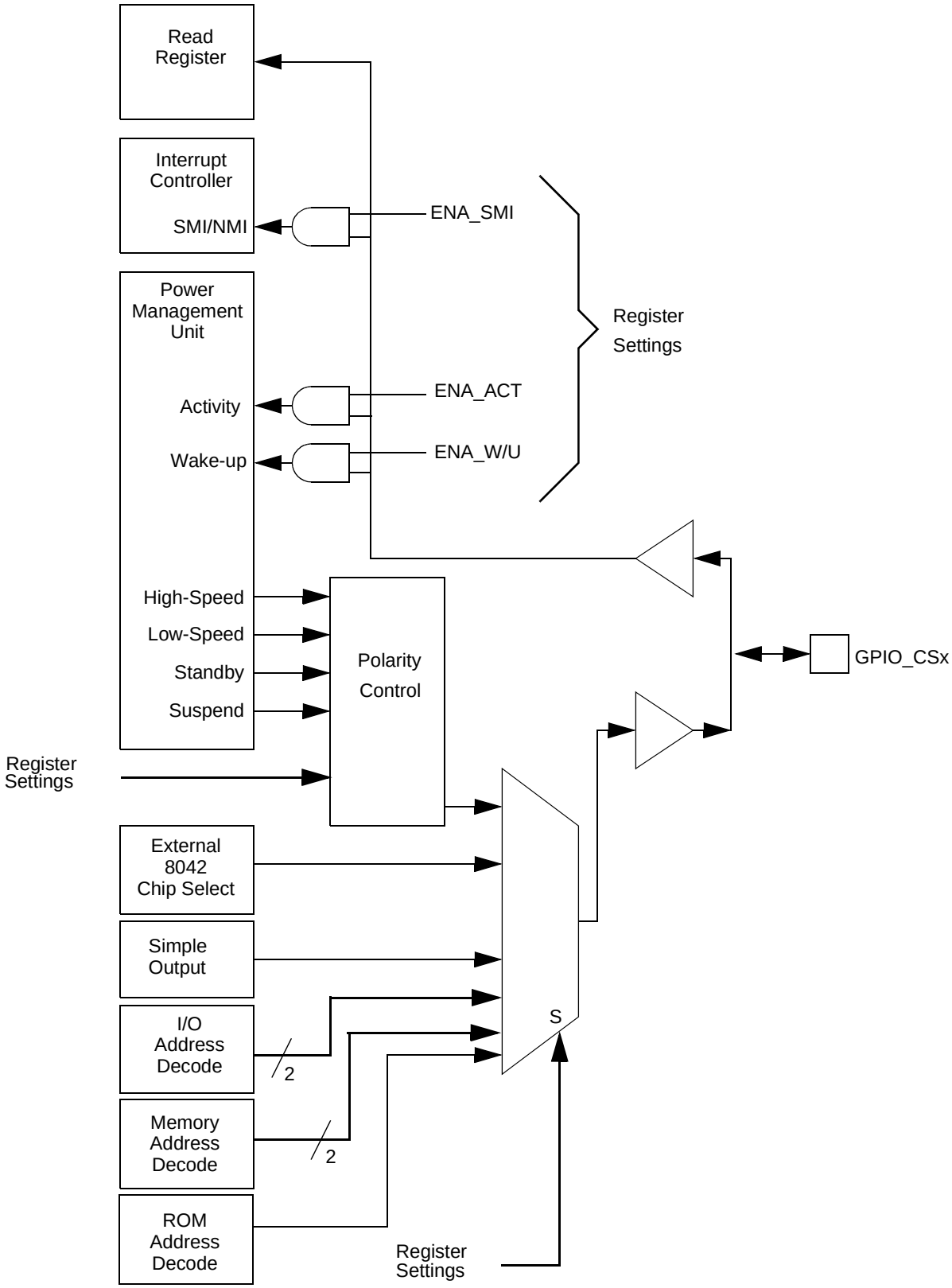


Figure 17-2 GPIO_CSx Signals Block Diagram



17.4 GPIO SYSTEM IMPLICATIONS

Because all of the GPIOs (except GPIO_CS0 and GPIO_CS1) trade off against other functionality, the designer will usually be constrained in choosing which GPIO pins to use for which functions. Figure 17-1 shows the mapping of GPIO pins to alternate functions. Choosing between GPIOs and alternate functions is done by functional groups within the Pin Mux Registers A–C (CSC indexed registers 38–3Ah), except for the buffer control group (GPIO_CS2–GPIO_CS4), which is selected via pin strapping at reset.

In addition to the alternate function trade-offs, the following should also be considered when selecting which GPIO pins to use:

- All GPIOs are, by default, terminated by either pull-ups or pull-downs (depending on alternate function). The termination can be disabled, but should be considered when deciding which GPIO to use. For example, if a GPIO that is pulled down by default is to be used for a chip select, the internal pull-down will have to be overridden by a stronger external pull-up resistor, or else the external device will see its chip select active at reset. This also has power implications: when the chip select is active, current will be flowing through the pull-up resistor. See Section 2.4.2 and Appendix B for more information on pin termination.
- GPIO31–GPIO15 are only capable of simple I/O. They can be set to be High, Low, or not driven, and can be read back.
- GPIO_CS14–GPIO_CS0 have the I/O capabilities of GPIO31–GPIO15, and additional chip select, PMU, and SMI/NMI capabilities.

17.5 INITIALIZATION

All 32 GPIO signals can be programmed as inputs or outputs, or to support their alternate function. They are enabled as GPIO inputs at power-on reset, with pin-dependent pull-ups or pull-downs enabled.

- To change a GPIO to be an output, set the appropriate bit in GPIO Function Select Registers A–F (CSC index A0–A5h).
- To select the alternate (non-GPIO) pin function, set the appropriate bit in Pin Mux Registers A–C (CSC index 38–3Ah).
- To disable the pull-up or pull-down, reset the appropriate bits in GPIO Termination Control Registers A–D (CSC index 3B–3Eh).

Note: *After changing to or from an alternate function, or enabling or disabling a pull-up/ pull-down, be sure to set the Pin Termination Latch Command Bit in the Suspend Mode Pin State Override Register (CSC index E5h[0]).*

17.5.1 GPIO Pins and Simple Input

GPIO pins are selected for simple input at power-up, with the exception of GPIO_CS4–GPIO_CS2, which can be selected as buffer control signals via a strapping option. The input value of the pins can be read using the GPIO Read-Back/Write Registers A–D (CSC index A6–A9h).

Any of the following actions will disable simple input on the GPIO pin:

- Selecting the pin's alternate function via the Pin Mux Registers A–C (CSC index 38–3Ah)
- Setting the GPIO's output bit in CSC index A0–A5h to turn the GPIO into an output

17.5.2 GPIO Pins and Simple Output

If the GPIO pin's alternate function has not been selected with the appropriate Pin Mux Register, and the GPIO's output bit in CSC index A0–A5h is set, the GPIO will now be an output. The value of the pin can be set by writing to its bit in CSC index A6–A9h.

17.5.3 GPIO_CS Pins and Automatic Output

Automatic outputs are outputs that change state automatically, based on hardware events, without explicit software attention.

Fifteen of the GPIOs, GPIO_CS14–GPIO_CS0, support automatic output, which can be used for two different functions: PMU state information output and chip select output.

To use an automatic output function, the pin must be set to output mode (using CSC index A0–A5h), the output VALUE must be set to 0 (CSC index A6–A9h), and the desired function must be steered to the correct pin (CSC index AEh, AFh, and B1–B3h).

Note that, in many cases, automatic output must be programmed very carefully to insure that no glitches occur. Consider programming GPIO_CS0 to be $\overline{\text{ROMCS2}}$. By default, it will be pulled up, so the ROM will not be driving the data bus. The programming must be done in such a way as to keep this true for the entire sequence:

- (If it was one of the GP_CSx selects instead of $\overline{\text{ROMCS2}}$, its registers would be initialized here to make sure it is not selecting continuously. See Section 17.7.)
- Write 0000 to bits 7–4 of the Standard Decode to GPIO_CS Map Register (CSC index B1h) to steer $\overline{\text{ROMCS2}}$ to GPIO_CS0.
- Output a 0 to bit 0 of the GPIO Read-Back/Write Register A (CSC index A6h) to allow $\overline{\text{ROMCS2}}$ to propagate.
- Output a 1 to bit 0 of the GPIO_CS Function Select Register A (CSC index A0h) to change the GPIO to being an output from being an input (it should now be driven High, because $\overline{\text{ROMCS2}}$ is not being driven).

17.5.3.1 Automatic PMU Information Output

Up to four GPIO_CS pins can be programmed to inform external hardware of internal PMU states. The internal signal names associated with this information are PMUA, PMUB, PMUC, and PMUD. Each of these signals has a register, GPIO_PMUx Mode Change Register (CSC index AA–ADh), that defines its value during every distinct PMU state, and each of these signals has a 4-bit field in the GPIO_PMU to GPIO_CS Map Registers A and B (CSC index AE–AFh) that defines which, if any, GPIO_CS pin it drives. As noted above, the GPIO's output bit in CSC indexed registers A0–A5h must be 1 to set the pin to output mode, and the GPIO's I/O bit in CSC indexed registers A6–A9h must be 0 to allow the PMU signal to propagate.

17.5.3.2 Automatic Chip Select Outputs

Up to six GPIO_CS pins can be programmed as chip selects for external hardware devices. The correct sequence for initializing a pin for use as a chip select is shown above in Section 17.5.3.

Two of these chip selects, $\overline{\text{ROMCS2}}$ and $\overline{\text{SCP_CS}}$, select hard-coded addresses, with $\overline{\text{ROMCS2}}$ selecting any memory operation to the $\overline{\text{ROMCS2}}$ space, and $\overline{\text{SCP_CS}}$ selecting any I/O operation to ports 60h and 64h. These two selects can be independently mapped to any one of the GPIO_CS pins using the Standard Decode to GPIO_CS Map Register (CSC index B1h).

The other four chip selects (GP_CSA, GP_CSB, GP_CSC, GP_CSD) can be independently mapped to any one of the GPIO_CS pins using the GP_CS to GPIO_CS Map Registers A and B (CSC index B2–B3h).

GP_CSA and GP_CSB decode I/O addresses and GP_CSC and GP_CSD decode memory addresses. These signals can be used for internal functions in addition to or instead of being used for external chip selects. See Section 17.7 for details on selecting I/O and memory regions for decode.

17.6 GPIO_CS SIGNALS AS PMU ACTIVITIES AND SMI/NMI GENERATION

As noted in Section 17.5.3.1, PMU state information can be output on GPIO_CS pins. GPIO_CS pins can also be used to input information to the PMU, or to generate an SMI or NMI. Chapter 5 contains a discussion of the PMU and SMI generation.

Note that a GPIO_CS pin can be configured to provide information to the PMU or to generate an SMI or NMI, independent of whether the pin has been configured as an input or as an output. For example, an SMI could be generated by external hardware (input), or by writing to a GPIO_CS register (output), or by accessing a particular device or memory region (automatic output).

17.6.1 GPIO_CS PMU Activity and Wake-Up

By setting the appropriate bits in the GPIO_CS Function Select Registers A–C (CSC index A0–A3h), any GPIO_CS pin (or set of pins) can be programmed to be a primary activity and wake-up. A low-going edge on the pin will cause a wake-up to occur if the system is in Suspend mode, or a primary activity if the system is already running. PMU code can detect which pin caused the activity by examining the GPIO as a Wake-Up or Activity Source Status Registers A–B (CSC index 5A–5Bh).

17.6.2 GPIO_CS Signals and SMI/NMI Generation

The GPIO_XMI to GPIO_CS Map Register (CSC index B0h) can be configured to allow any one GPIO_CS signal to generate an SMI or NMI on the falling edge. The SMI or NMI handler can notice and reset this condition by checking and resetting bit 5 in the Mode Timer SMI/NMI Status Register (CSC index 96h).

17.7 GENERAL-PURPOSE CHIP SELECTS (GP_CSA–GP_CSD)

The ÉlanSC400 and ÉlanSC410 microcontrollers contain four internal general-purpose chip select signals.

- GP_CSA and GP_CSB are intended for use as I/O chip selects. They decode the lower 15 bits of the address bus and can optionally qualify the address with $\overline{\text{IOR}}$ and/or $\overline{\text{IOW}}$. (To avoid aliasing, address bits A15–A10 are compared with 0s.) GP_CSA and GP_CSB are configured using CSC indexed registers B4–B8h.
- GP_CSC and GP_CSD are intended for use as memory chip selects. They decode the upper 12 bits of the address bus, and can optionally qualify the address with $\overline{\text{MEMR}}$ and/or $\overline{\text{MEMW}}$, or CPU address valid. They are configured via CSC indexed registers B9–BDh.

CSC indexed registers B4–BDh also allow any combination of the lowest four bits of the address to be ignored during decode (SA3–SA0 for GP_CSA and GP_CSB, SA17–SA14 for GP_CSC and GPC_CSD), and also allow automatic forcing of 16-bit ISA cycles, on a per-chip select basis.

17.7.1 Using DMA with General-Purpose Chip Selects

The memory chip selects GP_CSC and GP_CSD can be used for DMA cycles. I/O chip selects GP_CSA and GP_CSB are asserted for CPU-initiated cycles only. The GP_CSC and GP_CSD memory chip selects behave as follows:

- Raw address decode (CPU or DMA)
- Qualified with $\overline{\text{MEMR}}$ assertion (CPU or DMA)
- Qualified with $\overline{\text{MEMW}}$ assertion (CPU or DMA)
- Qualified with $\overline{\text{MEMW}}$ or $\overline{\text{MEMR}}$ assertion (CPU or DMA)
- Qualified with CPU address valid (The chip select would not be asserted for DMA cycles.)

17.7.2 Mapping a General-Purpose Chip Select to a GPIO_CS Pin

As discussed in Section 17.5.3, each chip select can be independently mapped to any one of the GPIO_CS pins for use as an external device chip select, and/or to generate an SMI or NMI via CSC index B0h. Many external devices require no additional logic to use this scheme. CSC indexed registers B1h and B2h perform this mapping. Do not map two different GP_CS signals to the same GPIO_CS pin, or to a pin to which PMUx has been mapped.

17.7.3 Using General-Purpose Chip Selects as PMU Activities

The GP_CS Activity Enable Register (CSC index 60h) allows any of the general-purpose chip selects to be programmed to be primary or secondary activities. The GP_CS Activity Status Register (CSC index 61h) allows software to determine which general-purpose chip select activity occurred.

17.7.4 Using General-Purpose Chip Selects to Force an SMI

I/O accesses decoded by GP_CSA and GP_CSB can be trapped by setting bits 5 and/or 6 in the I/O Access SMI Enable Register B (CSC index 9Ah). The SMI handler can determine and clear the cause of the SMI by examining and resetting bits 5 and/or 6 in the I/O Access SMI Status Register B (CSC index 9Ch). The SMI handler can emulate the I/O or restart the instruction. See Chapter 3 for SMI handler details.

In addition, the GPIO_XMI to GPIO_CS Map Register (CSC index B0h) can be used in conjunction with any one GPIO_CS pin to cause either an SMI or NMI. This works with output pins as well as input pins, so even GP_CSC and GP_CSD could be programmed to cause an SMI or NMI by programming them to drive the pin that CSC index B0h is sampling.

17.8 POWER MANAGEMENT

Operation of the GPIOs is affected by the power-management functions shown in Table 17-2.

Table 17-2 Power Management in the GPIOs

GPIO Event	Description	Power Management Effect			
		Wake-Up	Activity	SMI	NMI
GPIO_CS14–GPIO_CS0	Triggered by falling edge on the signal	Yes	Primary	Yes	Yes

CHAPTER

18 INFRARED PORT

18.1 OVERVIEW

The ÉlanSC400 and ÉlanSC410 microcontrollers provide an infrared port designed for systems that need to support an infrared communications port compliant with the Infrared Data Association (IrDA) standard. The infrared port on the ÉlanSC400 and ÉlanSC410 microcontrollers provides a reliable, half-duplex, wireless communications link to other systems that support the IrDA standard using light pulses in the Infrared spectrum to carry the data.

On the ÉlanSC400 and ÉlanSC410 microcontrollers, the industry-standard 16550A UART is shared between RS-232 and infrared operations. Special modifications have been made to the UART to support infrared operation. The UART can be used to drive either the standard eight-pin RS-232 interface or a two-pin infrared interface.

The infrared port has dedicated transmit and receive data pins, called SIROUT and SIRIN respectively. These pins are designed to be connected gluelessly to common IrDA transmit and receive LED modules to support Slow-Speed (up to 115 Kbit/s) or High-Speed (1.152 Mbit/s) Infrared mode operation. The UART and the infrared interface pins are not multiplexed with each other, or with any other interfaces, and are therefore available on the microcontroller at all times. However, because the two interfaces share the internal UART, only one interface can be enabled at any given time. This means that both a serial device and an IrDA device can be designed into the same system, and the microcontroller will support real-time switching between the two ports.

The infrared port on the ÉlanSC400 and ÉlanSC410 microcontrollers is capable of half-duplex operation only. The port operates in either Slow-Speed or High-Speed Infrared modes.

- **Slow-Speed Infrared mode** —Supports a variable (programmable) baud rate in exactly the same way as a standard 16550 UART, using the same registers and controls. Either interrupt-driven or polled-I/O operation is possible in Slow-Speed Infrared mode, but DMA is not supported in this mode. The serialized data format that is emitted from the SIROUT pin in this mode is identical to what is found on a standard RS-232 SOUT signal (i.e., programmable length start, data, and stop bit fields), but the pulses are inverted and shortened.
- **High-Speed Infrared mode** —Supports a fixed transfer rate of 1.152 Mbit/s. This mode is characterized by a continuous data stream; the data bytes are not separated from each other with individual start and stop bits. DMA is always used for transferring High-Speed Infrared mode data between system DRAM and the UART's transmit and receive I/O ports.

18.2 REGISTERS

A summary listing of the chip setup and control (CSC) registers used to control the infrared port interface is shown in Table 18-1. Complete register descriptions can be found in the *Élan*™SC400 Microcontroller *Register Set Reference Manual* (order #21032).

CSC index registers for power management and SMI/NMI control in the UART are listed in Chapter 15 in Table 15-1.

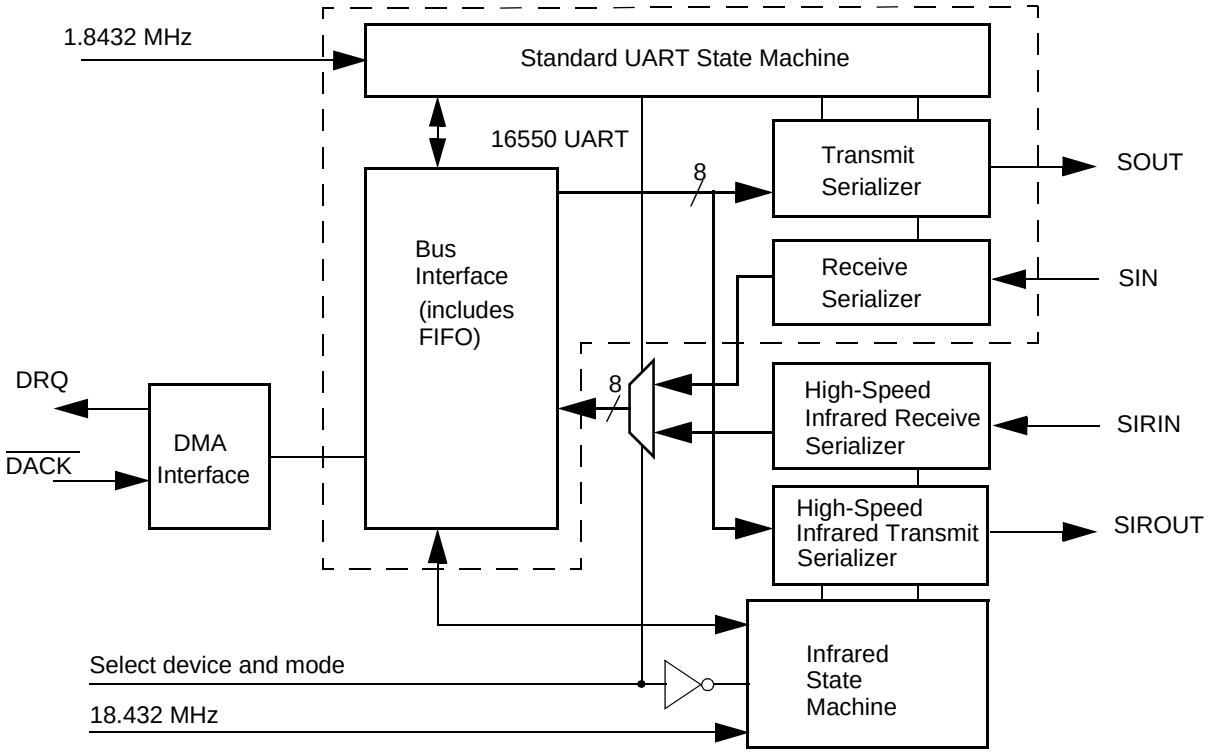
Table 18-1 Infrared Port Register Summary

Register	I/O Address	Infrared Port Function Keyword	Description in Register Set Manual
Clock Control Register	22h/23h Index 82h	DMA clock frequency select for High-Speed Infrared mode	page 3-90
Parallel/Serial Port Configuration Register	22h/23h Index D1h	COM1 or COM2 base address configuration, UART enable	page 3-167
UART FIFO Control Shadow Register	22h/23h Index D3h	Shadow FIFO control, 16550-compatible mode enable, FIFO buffer clear, trigger for received-data-available interrupt pending	page 3-169
Interrupt Configuration Register E	22h/23h Index D8h	IRQ mapping for infrared port	page 3-174
DMA Resource Channel Map Register A	22h/23h Index DBh	DMA controller channel mapping for infrared port	page 3-177
IrDA Control Register	22h/23h Index EAh	Infrared mode enable, infrared data rate, Slow-Speed and High-Speed mode, DMA start-up, interrupt requests, data direction, receive blocking, SIRIN pull-down disable, and end-of-transmission status	page 3-188
IrDA Status Register	22h/23h Index EBh	Transmit and receive FIFO status, transmit and receive underflow, terminal count/end-of transmission status, and High-Speed interrupt request status	page 3-190
IrDA CRC Status Register	22h/23h Index ECh	CRC error detect and receive abort	page 3-192
IrDA Own Address Register	22h/23h Index EDh	Assigned address	page 3-193
IrDA Frame Length Register A	22h/23h Index EEh	Transmit mode: Length of transmitted infrared data frame (first part). Receive mode: Length of received infrared data frame (first part)	page 3-194
IrDA Frame Length Register B	22h/23h Index EFh	Transmit mode: Length of transmitted infrared data frame (second part). Receive mode: Length of received infrared data frame (second part)	page 3-195

18.3 BLOCK DIAGRAM

A block diagram of the infrared port is shown in Figure 18-1. Note that the UART SOUT and SIN pins become disabled when the infrared interface is enabled. To complete the serial infrared implementation, optical infrared transceivers and their support circuitry (e.g., drivers) must be added externally to the chip.

Figure 18-1 Infrared Port Block Diagram



Note: *Blocks inside the dashed box are part of the standard UART.*

18.4 OPERATION

The Infrared Data Association (IrDA) consists of member companies that have an interest in generating hardware and software standards for infrared communications. Supporting the IrDA standard, the infrared port on the ÉlanSC400 and ÉlanSC410 microcontrollers provides a reliable, half-duplex, wireless communications link to other IrDA-compatible systems.

The hardware designed into the ÉlanSC400 and ÉlanSC410 microcontrollers is not a generic infrared port implementation. What is provided is an infrared port designed to support an IrDA-compatible system implementation. Most of the features of the infrared port on the ÉlanSC400 and ÉlanSC410 microcontrollers were derived directly from either from the requirements of the IrDA specifications, or, at the system level, from the goals of the IrDA specifications.

A complete understanding of the IrDA specifications will help the user to better comprehend the features in the ÉlanSC400 and ÉlanSC410 microcontrollers that support those specifications. See the *Infrared Data Association Serial Infrared Physical Layer Link Specification* and the *Infrared Data Association Serial Infrared Link Access Protocol (IrLAP)* for more detail.

Two different modes of operation are provided: Slow-Speed mode and High-Speed mode.

18.4.1 Slow-Speed Infrared Mode

Slow-Speed Infrared mode supports a programmable baud rate in exactly the same way as a standard 16550 UART. When operating in Slow-Speed Infrared mode, the infrared port on the ÉlanSC400 and ÉlanSC410 microcontrollers is like a two-wire virtual RS-232 cable that has transmit and receive signals only and that can operate only in half-duplex mode.

Slow-Speed Infrared mode is similar to High-Speed Infrared mode in terms of the pulse stream from the SIROUT pin. All fields are transmitted with the least significant bit of each byte first, and the data stream is RZI (Return-to-Zero-Inverted).

Besides this, one other observable difference between the output of the infrared interface's SIROUT pin and the UART interface's SOUT pin is that the actual pulses sent out on the SIROUT pin to the external infrared LED module are pulse-shaped to only 3/16 of a standard RS-232 bit-cell time, in order to reduce transmit operation power consumption. The pulse width is not adjustable—it is fixed to be the minimum width allowed by the *IrDA Serial Infrared Physical Layer Link Specification* and is centered in the standard RS-232 bit-cell time slot. In this mode, incoming pulses are detected and stretched to the full RS-232 bit-cell length by the microcontroller prior to being fed to the on-board UART for deserialization.

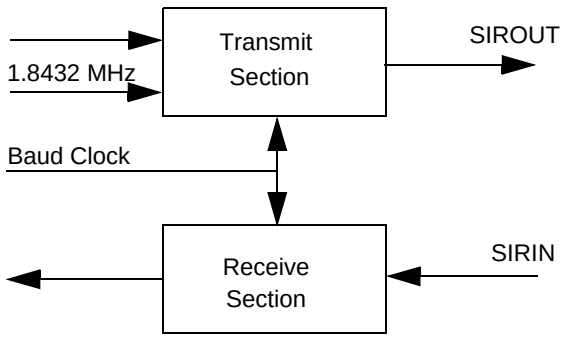
18.4.1.1 Hardware Support

Slow-Speed Infrared mode does not provide any special hardware support (i.e., CRC generation, etc.) for the IrDA IrLAP (Infrared Link Access Protocol) layer like High-Speed infrared mode does. Because of this, software must handle all aspects of IrLAP protocol in Slow-Speed Infrared mode. This also means that the IrLAP need not be implemented if all that is desired is an RS-232 port implemented via infrared.

Slow-Speed Infrared mode does not use DMA. Instead, it uses all of the traditional UART interrupts and controls for data transfer. The standard UART interrupts generated due to Receive Buffer Full, Transmit Holding Register Empty, and status changes do apply and are generated in this mode. As with any conventional 16550 UART, Slow-Speed Infrared mode can operate with the UART FIFOs either enabled (16550 operation) or disabled (16450 operation).

Slow-Speed Infrared mode consists of a transmit section and a receive section, as shown in Figure 18-2. The baud clock is 16 times the bit clock in Slow-Speed Infrared mode (115 Kbit/s), or 1.8432 MHz.

Figure 18-2 Slow-Speed (115 Kbits/s) Infrared Mode



The transmit section accepts the serial data output from the UART and produces an output pulse equivalent to three UART clocks wide on the SIROUT pin. Figure 18-3 shows a unit of serial data (serial data unit or SDU); the corresponding Slow-Speed Infrared mode SDU is shown in Figure 18-4.

The infrared port accepts the serial data input from the external IrDA device that has been squared and conditioned to the appropriate logic level. The incoming pulse on the SIRIN pin is detected and appropriately stretched.

Figure 18-3 UART Serial Data Unit (SDU)

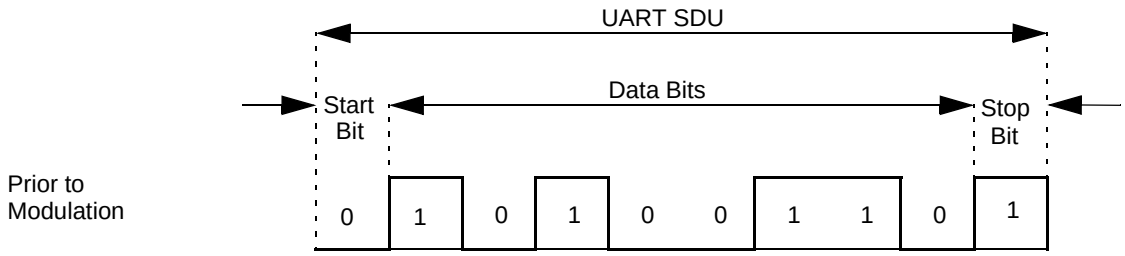
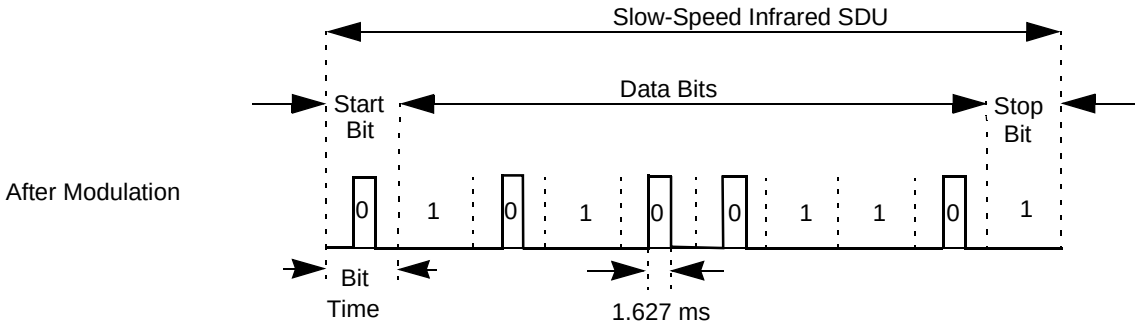


Figure 18-4 Slow-Speed Infrared Mode SDU



18.4.2 High-Speed Infrared Mode

High-Speed Infrared mode supports a fixed transfer rate of 1.152 Mbit/s. This mode is characterized by a continuous data stream and always uses DMA for data transfers.

Since many of the High-Speed Infrared mode features were implemented to address requirements in the IrDA standard for 1.152 Mbit/s operation, a short overview of the high-speed IrDA frame structure is presented in this section to provide a basis for further discussion. The intent of this section is to provide some basic familiarity with a high-speed IrDA frame so that the user will understand how to use the High-Speed Infrared mode controls provided on the ÉlanSC400 and ÉlanSC410 microcontrollers.

18.4.2.1 High-Speed IrDA Frame

The basic unit of data transfer defined by the *Infrared Data Association Serial Infrared Link Access Protocol (IrLAP)* specification is called a frame. As a basic point of reference, the 1.152 Mbit/s IrDA frame is similar to an HDLC frame.

Each 1.152 Mbit/s IrDA frame consists of two pieces: the *payload data*, and the *wrapping layer*. The payload data contains some overhead data used to operate the link along with the user information to be transmitted. The wrapping layer surrounds the payload data with start and end flags which delimit the frame. The wrapping layer also provides CRC data for error detection and recovery.

The payload data consists of three fields: Address (ADDR), Control (CTL), and an optional Information (INFO) field. The following is an in-sequence breakdown of a high-speed (1.152 Mbit/s) IrDA frame shown in Figure 18-5:

- STA (2 bytes) —The STA bytes are part of the wrapping layer. For 1.15 Mbit/s IrDA, a minimum of two STA flags are required at the beginning of each frame. The start flag is set to a constant value of 7Eh (01111110b) that is defined by the IrLAP standard. More than the required minimum of two start flags can be sent since an infrared receiver treats multiple start flags as a single flag. Multiple start flags are depicted in the diagram below. STA flags are alternatively referred to as BOF (Beginning-Of-Frame) flags.
- ADDR (1 byte) —An 8-bit field at the beginning of the payload data specifies the address of the intended receiver. Actually, only bits 7–1 of this field are the receiver's address. Bit 0 of the ADDR byte is the C/R (Command/Response) bit indicates whether the transmission is from a primary (Command) or secondary (Response) station. A receiver can use the remaining bits of the address field to determine whether or not the data being received applies to it. A value of FEh in this field is used to specify a broadcast message that is applicable to all receivers within range of the transmitter. A value of 00h is called the null address, and no receiver should try to respond to this address.
- CTL (1 byte) —The control field follows the address field, and specifies the function of a particular frame. The control byte command encodings are given in the IrLAP specification.
- INFO —The Information field is optional. Whether or not it is present, and the meaning of the bytes it contains, depends on the value in the CTL field since the CTL field determines the frame type. If this field does exist, it can be any power-of-2 size between 64 bytes and 2048 (2K) bytes. The information field does not have to be of fixed length, but must be a multiple of 8 bits.
- FCS (Frame Check Sequence field) (2 bytes)—A 16-bit cyclic redundancy check (CRC) in CCITT format allows the checking of received frames for errors that may have been introduced during frame transmission.
- STO (1 byte)—Minimum one stop flag at the end of each frame. (The receiver treats multiple stop flags as single flag.) The stop flag is set to a constant value of 7Eh or 01111110b. STO flags are alternatively referred to as EOF (End-Of-Frame) flags.

Figure 18-5 High-Speed Infrared Frame Format

18.4.2.2 Frame Sequences

Frames are grouped into *frame sequences*, which may consist of from one to seven frames. The maximum number of frames in a sequence is a parameter that two stations negotiate when they form a connection and is known as the *window size* for the connection.

After the connection has been established, only frame sequences that have less than or equal to the negotiated window size are allowed. The window size may never be greater than seven. When only one frame is sent, the window size is considered to be 1.

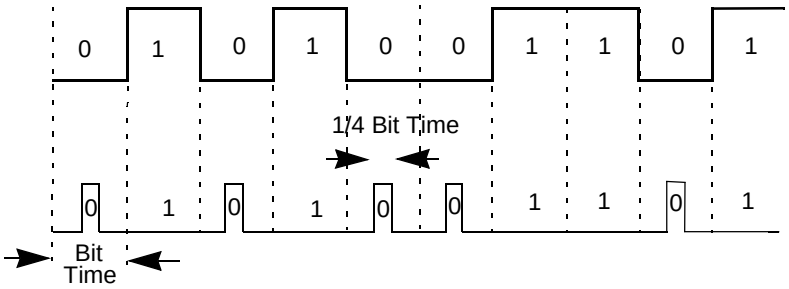
Each time a frame sequence is sent, an acknowledgment must be sent back to the transmitting station by the receiving station to confirm that the data was received. Since the interface is only capable of half-duplex operation, the act of listening for a response after having sent out some data costs some turnaround-time overhead. Thus, a larger window size and the sending of multiple frames per sequence (also known as *back-to-back frames*) may increase performance. The entire frame structure shown above is repeated for each frame in the sequence. Window size can be limited by resources on either the transmitting or receiving station such as transmit/receive buffer space, storage space to temporarily hold received data CRC calculations, etc.

18.4.2.3 High-Speed Infrared Mode

High-Speed Infrared mode is similar in some ways to Slow-Speed Infrared mode in terms of the pulse stream from the SIROUT pin. As mentioned earlier, all fields are transmitted with the least significant bit of each byte first. Of course, the bit-cell times will be shorter to reflect the higher speed, but the data stream is still RZI (Return-to-Zero-Inverted) like Slow-Speed Infrared mode.

Another minor difference is that the bit-cell time for the High-Speed Infrared mode data is 1/4 the actual bit-cell (as opposed to 3/16 of the actual bit-cell in Slow-Speed Infrared mode —see Figure 18-6 for more detail on High-Speed Infrared mode modulation). In terms of the actual data observed in the data stream, High-Speed Infrared mode has some notable differences, as compared to Slow-Speed Infrared mode.

Figure 18-6 High-Speed Infrared Data Modulation



18.4.2.4 Data Stream

In Slow-Speed Infrared mode, the parallel data is converted into individual SDUs, with start and stop bits delimiting the serialized data word. With High-Speed Infrared mode, however, all of the data bytes in an IrDA frame are merged into a contiguous bit stream that is delimited by flag bytes at the start and at the end of the stream (STA/STO flags).

When observing this data stream at the SIROUT pin, the user will see that extra 0 bits have been inserted into the data stream by the infrared transmit hardware for all frame fields except the STA and STO flags. This action, called *zero bit-stuffing* has two purposes:

- Synchronization—This disallows too much time to pass without a light pulse being emitted (remember that a '0' bit is transmitted as a light pulse since the signal is inverted).
- Allowing a value of 7Eh to be part of the normal (non-flag) data— This is required since the STA and STO flags (as defined by the IrDA specification) are merely bytes of 7Eh.

18.4.2.5 FIFO Usage

For performance reasons, the 16550 FIFOs must be enabled via Port 03FAh or 02FAh when operating in High-Speed Infrared mode. Even though DMA to the UART is not allowed when operating the UART in normal RS-232 mode or in Slow-Speed Infrared mode, in High-Speed infrared mode, DMA is used for all data transfers between main system DRAM and the UART's transmit and receive FIFOs.

- When transmitting, data is placed in a buffer located in system DRAM and is then transferred via DMA to the transmit FIFO. The transmit state machine takes data from the transmit FIFO, serializes, bit-stuffs, pulse-shapes and inverts the data before sending it out the SIROUT pin.
- When receiving, the receive state machine takes the incoming bit stream from the SIRIN pin, inverts, pulse-stretches, un-bit-stuffs, and then places it into the receive FIFO on the UART, from which point it is transferred via DMA to DRAM.

18.4.2.6 Receive and Transmit State Machines

In High-Speed Infrared mode, the UART receive and transmit serializers and controlling state machines have some properties that are specific to High-Speed Infrared mode operation.

First, the receiver state machine filters all incoming data before starting to put anything in the receive FIFO. This filtering consists of waiting for a valid STA flag to be detected. Upon seeing this, it enables bit unstuffing to occur, and then starts looking for the address byte which should come right after the STA flag(s).

If the received address does not match the broadcast address (FEh) or the address that has been programmed into the IrDA Own Address Register (CSC index EDh), the receive state machine will not place the data into the receive FIFO, but will instead begin looking for STA flags again. This avoids software from handling frames that were destined for another station.

If a match does occur, the data is deserialized and placed into the receive FIFO. From the data in the payload field, the infrared receive state machine calculates a 16-bit CRC and compares it against the one which was received at the end of the frame.

If the calculated CRC and the received CRC do not match, then a register bit in the IrDA CRC Status Register (CSC index ECh) is set to indicate an error. The CPU can later read this register bit for status information. The error status bit which will be set depends upon how many frames were received after the status bits were last cleared up until the frame which caused the error. For example, if the status bits were just cleared, and then 3 back-to-back frames are received followed by a frame with a CRC error, ECh[2-0] will be clear, and ECh[3] will be set. Thus, it is important to check and clear the CRC error bits after each frame sequence is received.

To support bit-stuffing on the transmit side, the transmit state machine must monitor the outgoing data stream to know when the two required STA flags have been transmitted so

that it can start bit-stuffing, and it must know where the STO flags are so that it can send them without bit-stuffing. The transmit state machine expects exactly two STA flags at the start of a transmitted frame. After transmitting the first two bytes from the transmit buffer (i.e., the STA flags), the transmit state machine begins bit-stuffing.

The point at which to stop bit-stuffing is determined by starting a down-counter with the value found in the IrDA Frame Length Registers A and B after the start flags have been detected. Each time the transmit state machine grabs a byte from the transmit FIFO and sends it out the SIROUT pin, the down-counter is decremented. Bit-stuffing is done on all data from the start of the counter to a counter value of zero. This count must include all of the bytes in the payload field, plus the two CRC bytes.

The infrared transmit state machine does not automatically insert STA or STO flags. It is up to the infrared driver software to load the transmit buffer with all of the flags, CRC bytes, and data, and to load the proper transfer count into the DMA controller prior to initiating the DMA transfer.

For transmit operations, the software should construct the transmit buffer to contain frame data as follows: two STAs, payload data, 16-bit software-generated CRC of the payload data, one STO. The DMA transfer-count must be the sum of all bytes in the transmit buffer.

Failure to properly program the Frame Length Registers will result in the transmit state machine becoming locked up. In order to recover from this type of software error, a reset for the high-speed transmit state machine has been implemented. To activate it, write any data to CSC index ECh. This also clears the frame error status, so be sure to read the error status before resetting the transmit state machine.

18.4.2.7 Frame Abort

A frame abort can occur due to the following:

- Blocking the infrared transmission path in the middle of the frame
- Random introduction of infrared noise
- Intentional termination by the transmitter

Regardless of what caused the aborted frame, the receiver treats a frame as an aborted frame when seven or more consecutive 1s are received. The abort terminates the frame immediately without waiting to receive the FCS field or a STO flag. An abort will cause CSC index ECh[7] to be set.

18.4.2.8 Sending Back-to-Back Frames

Transmission of back-to-back frames is allowed by butting the data (i.e., payload data and wrappers) for up to seven frames up against each other in the transmit buffer. If two consecutive frames are not back-to-back, the time delay between the last ending flag of the first frame and the start of next frame should be separated by at least seven bit-times (refer to frame-abort sequence described in Section 18.4.2.7).

18.4.2.9 Receiving Back-to-Back Frames

When receiving frames, there is no way to tell how big the frame will be before it is received. To handle this, software must allocate a receive buffer that is larger than all of the data that is expected to be received for all frames in the current frame sequence, and set the DMA transfer count to that large number. During receipt, the DMA transfer count should never expire. Software must rely solely on the Received Frame Complete (RFC) interrupt and the Receive Buffer Empty status bit to know when a frame or frame sequence is complete.

In order to support back-to-back frames, the infrared circuitry counts the bytes as they are received. At the end of receipt of a frame, the byte-count can be read from the Frame Length Registers (CSC index EEh and EFh), along with some status information, and stored to DRAM for later analysis. This must be done in a time critical fashion, because the received byte-count read from EEh and EFh must be reset at the start of each received frame. Failure to handle the task in a time-critical fashion will result in data overruns in the receive FIFO.

The status bits provided are to be used for a status information overrun indication. If the software fails to read the byte-count out before two byte-counts are written, the third byte-count written will result in losing byte-count information. This byte-count information is necessary for receiving back-to-back frames, because it allows the CPU to ascertain frame boundaries for back-to-back frames within the DMA buffer. Note that the CPU must be running at 33 MHz or faster while receiving back-to-back frames to avoid getting byte-count overruns.

The process for receiving back-to-back frames follows. Register details can be found in the *Élan*™SC400 Microcontroller *Register Set Reference Manual* (order #21032) and amendments:

1. Set up for receive mode.
2. Read the byte-count latches to clear internal the overrun internal pre-bit.
3. Write the 11 bit byte-count to ’111 1111 1111b’.
4. [Start receiving data.]
5. [Receive first byte.]
6. [Byte transferred to FIFO.]
7. [Count decrements.]
8. [Rest of frame data transferred over, count decremented once per received byte.]
9. [End-of-frame detected by receive state machine.]
10. [Received-frame-complete interrupt occurs.]
11. Read the byte-count latches and the overrun bit (this clears the pre-bit).
12. Invert the byte-count (it reads out in 1’s-complement format from the registers), and save it and the overrun status to some variable location.
13. Write the 11 bit byte-count to '111 1111 1111b' as setup for the next frame.
14. [Starting with Step 4, repeat the steps listed above until the entire sequence is received.]

18.4.2.10 Transmit Data Transfers

For High-Speed Infrared mode transmit operations, as long as the transmit FIFO is not full (i.e., the number of bytes in the FIFO is less than 16) and the START_DMA bit is set, an internal infrared port DMA request is generated so that the DMA controller will transfer another byte from the transmit buffer in DRAM to the transmit FIFO. The internal infrared port DMA request is deasserted after each write transfer. The TC (Terminal Count) signal from the DMA controller signifies that all bytes indicated by the transfer count programmed into the DMA controller have been transferred into the FIFO. When the terminal count has been reached, the START_DMA bit is automatically cleared. Thus, the infrared controller will not issue further DMA requests until the START_DMA bit is set again, even if the transmit FIFO is not full.

The sequence of events for transmitting data in High-Speed Infrared mode follows.

1. Software sets up the transmit buffer in system DRAM with data as required.
2. Software routes the infrared DMA to an 8-bit DMA channel via the DMA Resource Channel Map Register A (CSC index DBh[7-6]). Note that any channel mapped for use with the infrared port must not be programmed for block mode. See Section 10.4.2.1.3.
3. Software ensures the DMA clock is running sufficiently fast to avoid transmit underflow. This is based on system latency issues, and will be worst case if the internal graphics controller on the ÉlanSC400 microcontroller is in use with a high-resolution LCD panel with high color depth. This is because the LCD controller will be accessing system DRAM constantly in order to keep the LCD panel fed with display data. Operation at 8 or 16 Mhz is suggested. See the Clock Control Register (CSC index 82h[6-5]).
4. Software selects infrared mode via EAh[0], selects High-Speed Infrared mode via the IrDA Control Register (CSC index EAh[1]), optionally enables High-Speed Infrared mode IRQs via EAh[3], sets up infrared controller for transmit operation by clearing EAh[4], and then sets the START_DMA bit to begin the DMA operation. Note that all EAh register accesses can be done via one I/O if desired.
5. As a result of the START_DMA bit being set, an internal infrared port DMA request is generated by the infrared interface.
6. DMA issues an internal infrared port DMA acknowledge signal to the requesting IrDA device after the CPU relinquishes the bus.
7. Memory read followed by I/O write signals are generated by the DMA controller.
8. The DMA controller executes the write cycle by moving the byte from the memory to the transmit FIFO.
9. An internal infrared port DMA acknowledge signal is deasserted after the transfer is complete and in turn, the DMA controller surrenders the bus back to CPU.
10. Steps 6–9 are repeated until the DMA transfer is complete. This is indicated by the TC signal from the DMA controller. The end-of-memory transfer indicated when the TC generates an interrupt request (IRQ) (assumes the if the interrupt enable control bit has been enabled). Note that the FIFO is still full when the TC signal occurs. Before changing to receive mode, software must wait until the transmit FIFO is empty. This can be done by polling the IrDA Status Register (CSC index EBh[0]). Alternatively the TC interrupt can be swapped out for a Transmit FIFO Empty interrupt by setting CSC index EAh[7]. In this case, the interrupt will not occur until the transmit FIFO has completely emptied into the transmit serializer, so it is acceptable to change to receive mode immediately to look for the response. This is the suggested operating mode for most situations.

18.4.2.11 Receive Data Transfers

Per the IrLAP specification, software should look for the initial connection between IrDA ports to be performed in Slow-Speed Infrared mode at 9600 baud. During the negotiation phase, if both stations agree to connect at 1.15 Mbit/s, the SELMODE bit is set to 1. In this transfer mode, whenever the receive FIFO is not empty, an internal infrared port DMA request is generated. If the DMA controller has been set up, this will result in DMA transfers of data from receive FIFO to system DRAM.

Sequence of events:

1. Software allocates space in system DRAM for a receive buffer.
2. Same as Transmit Step 2.

3. Same as Transmit Step 3.
4. Software selects infrared mode via EAh[0], selects High-Speed Infrared mode via the IrDA Control Register (CSC index EAh[1]), optionally enables High-Speed Infrared mode IRQs via CSC index EAh[3], and sets up infrared controller for receive operation by setting CSC index EAh[4]. Note that all EAh register accesses can be done via one I/O if desired.
5. As soon as the receive FIFO has any data in it, an internal infrared port DMA request is generated by the infrared controller to request that the data be transferred to system DRAM.
6. The internal DMA controller issues an internal infrared port DMA acknowledge signal to the requesting IrDA device after the CPU relinquishes the bus.
7. Memory write followed by I/O read signals are generated by the DMA controller.
8. The DMA controller executes the read cycle by moving the byte from the receive FIFO to the memory.
9. The internal infrared port DMA acknowledge signal is deasserted after the transfer is complete and in turn the DMA controller surrenders the bus back to the CPU.
10. Steps 5–9 are repeated until the I/O transfer is complete. The transfer can complete in two possible ways: a valid STO flag can be detected, or the transfer can be aborted due to the infrared path becoming obstructed, etc. In either case, it is possible to get an interrupt to notify the software of the event. When in receive mode, CSC index EBh[6] changes meaning from TC/EOT status to RFC/ABORT. RFC stands for Received Frame Complete, and this bit will be set when the receive state machine detects the STO flag. Note that this does not indicate that the data has been transferred to DRAM yet, just that the STO flag has been detected. In order to know when the transfer to DRAM is complete, poll CSC index EBh[2] after receipt of the RFC/ABORT interrupt. If the interrupt was due to an abort rather than RFC, that status will be available in the IrDA CRC Status Register (CSC index ECh[7]).

18.4.2.12 Interrupts

The normal UART interrupts generated due to Receive Buffer Full, Transmit Holding Register Empty, and status changes do not apply and are not generated in High-Speed Infrared mode. Special interrupts are supported for this mode, including DMA Terminal Count/End-of-Transmission, Receive FIFO Overflow, and Transmit FIFO Underflow.

The interrupt request signal from the infrared interface is multiplexed with the IRQ signal of the internal UART. Thus, the IRQ routing to the interrupt controller level for High-Speed Infrared mode IRQs is controlled by the same bits as for the UART in the Interrupt Configuration Register E (CSC index D8h[6-5]). The IRQ_ENABLE bit, along with the SELMODE bit in the IrDA Control Register, acts as the select signal. Upon interrupt request, the interrupt handler can read the infrared port status registers to find the cause and then process the interrupts accordingly.

The RECV_BLOCKING bit (CSC index EAh[5]) is provided to disable the receive section while in transmit mode. This prevents any leakage or erroneous data being captured while transmitting. This feature can be disabled by clearing the RECV_BLOCKING bit.

18.4.2.13 Serial Infrared Interaction Pulse (SIP) Generation

In High-Speed Infrared mode, the IrLAP specification requires the infrared port to be capable of generating a Serial Infrared Interaction Pulse (SIP). A SIP is used to quiet Slow-Speed Infrared mode traffic in the local vicinity of the High-Speed Infrared mode traffic. The SIP

is required to be generated once each 500 ms when the primary station generating the pulses is not actually transmitting.

To do this on the ÉlanSC400 and ÉlanSC410 microcontrollers, software must put the infrared controller into Slow-Speed Infrared mode at 9600 baud with the UART set up for 1 start bit and no parity. Then, a value of FFh must be written to the COMx Transmit Holding Register (Port 02F8h/03F8h). This will effectively send a 1.6-µs light pulse with no other pulses because Slow-Speed Infrared is not bit-stuffed. Note that it takes approximately 108 ns to complete the switch from High-Speed Infrared mode to Slow-Speed Infrared mode, after which time the FFh data may be written. After writing the SIP pulse data, the software will need to wait about 8 µs (one byte-time) after the UART's THRE status bit goes active before switching back to High-Speed Infrared mode, to ensure that the SIP gets sent.

18.5 INITIALIZATION

The infrared port is disabled at power-on reset and must be configured by software before being enabled.

- In Slow-Speed Infrared mode, the port is essentially operating in standard UART mode. For Slow-Speed Infrared mode, set up all of the registers that are required to set up the UART. Slow-Speed Infrared operation requires that the UART be set up for 8 data bits, no parity, and 1 stop bit via the UART COMx Line Control Register at Port 03FBh/02FBh. Write SELMODE to 0 (CSC index EAh[1]) to select Slow-Speed Infrared mode, and set SELDEVICE to 1 (CSC index EAH[0]) to enable the infrared interface. Enable the UART by setting the UART_ENB bit in the Parallel/Serial Port Configuration Register (CSC index D1h[0]). Select the UART/infrared port base address via CSC index D1h[1], and IRQ routing via the Interrupt Configuration Register E (CSC index D8h[6-5]).
- For High-Speed Infrared mode, set the FIFOEN bit to enable the FIFO in COM2 FIFO Control (Port 03FAh/02FAh), and then set up all the infrared registers. Set SELMODE to 1 to select High-Speed Infrared mode, and set SELDEVICE to 1 to enable the infrared interface. Enable the UART by setting the UART_ENB bit in the Parallel/Serial Port Configuration Register (CSC index D1h[0]). Note that configuring the UART registers is not required for this mode.

18.6 POWER MANAGEMENT

Operation of the infrared port is affected by the power-management functions shown in Table 18-2.

Table 18-2 Power Management in the Infrared Port

Infrared Port Event	Description	Power Management Effect			
		Wake-Up	Activity	SMI	NMI
UART Ring Indicate ($\overline{RIN}$) signal	Triggered by the falling edge of $\overline{RIN}$	Yes		Yes	Yes
UART Receive (SIN) signal	Triggered by the falling edge of SIN	Yes		Yes	Yes
CPU access to UART (internal or external)	Triggered by the falling edge of the address decode qualified with commands		Programmable		
UART access	Accesses to COM1 (03F8–03FFh) or COM2 (02F8–02FFh) can cause an SMI or NMI through an I/O trap			Yes	Yes

CHAPTER

19 PC CARD CONTROLLER (ÉlanSC400 MICROCONTROLLER ONLY)

19.1 OVERVIEW

The integrated dual PC Card controller is compliant with *PCMCIA Standard Release 2.1* and supports up to two fully 82365-resource-compatible PC Card sockets. The PC Card Socket B interface is shared with both the parallel port interface and the GPIO31-GPIO21 signals. Only one of these interfaces can be enabled at one time.The PC Card controller is not supported on the ÉlanSC410 microcontroller.

Each card socket is capable of DMA transfers between I/O PC Cards and system DRAM. DRQ and $\overline{\text{DACK}}$ pin configurability for DMA is a subset of the *PC Card Standard* (also known as *PC Card '95* or *PC Card Standard Release 3.0—Berlin Drafts*). The PC Card controller also provides some register-level extensions to a standard 82365 to support larger memory-window addresses and faster PC Card timings.

Each socket is provided with five memory windows. Each window can be opened anywhere above 64 Kbytes in the ÉlanSC400 microcontroller's 64-Mbyte memory map with 4-Kbyte granularity on 4-Kbyte boundaries. Each window may be individually configured to access common or attribute memory. Each socket is also provided with two I/O windows that can be opened in the range of 0–64 Kbytes.

In order to save pins on the ÉlanSC400 microcontroller, some socket interface pins defined in the *PCMCIA Standard Release 2.1* electrical specification are optional or not available:

- The $\overline{\text{INPACK}}$ pin is not supported.
- The second card detect input signal for Socket A is optional (shared with another feature) and must be enabled by software if required.
- The second card detect input signal for Socket B is not supported.
- There is only one $\overline{\text{WAIT}}$ signal to support both sockets.

The PC Card controller supports all standard 82365-compatible status change interrupt and PC Card interrupt enable and routing features. The standard interrupt capability is extended by coupling the PC Card controller to the ÉlanSC400 microcontroller's Power Management Unit (PMU) to support SMI and NMI.

In addition, PC Card controller interrupts, memory accesses, and I/O accesses can be configured to cause PMU wake ups and activities. 82365-compatible socket power controls are available for Socket A and B VPP1 and VCC controls, and the 82365 auto-power feature that turns off socket power until a card is inserted is supported. The PC Card controller also supports software-generated card detect change interrupts.

For information on redirecting $\overline{\text{ROMCS0}}$ to PC Card Socket A, see Section 7.6.4.2.

19.2 REGISTERS

Two different sets of indexed registers are used to configure the PC Card controller.

- The chip setup and control (CSC) index registers are accessed via the 22h/23h index/data I/O scheme.
- The standard 82365SL (Rev.B) registers are accessed via the PC/AT I/O space at Ports 03E0h and 03E1h.

All PC Card controller registers that pertain to Socket A have indexes from 00–3Fh. All PC Card controller registers that pertain to Socket B have indexes ranging from 40–7Fh. Thus, to get the Socket B counterpart index for a given Socket A register, add 40h to the Socket A index value. If an external 82365-compatible PC Card controller were added, Socket C would be controlled by indexes 80–BFh, and Socket D would be controlled by indexes C0–FFh. See Section 19.6 for details on how an external 82365-compatible PC Card controller works with ports 03E0h0/3E1h.

Note that the PC Card controller index register 03E0h (like the ÉlanSC400 microcontroller CSC index register at Port 0022h and the other ÉlanSC400 microcontroller index registers) is a system-level resource that can be accessed by more than one driver or software thread in a system. Any interrupt-driven routine must restore the index register to its original value prior to returning from the interrupt. This ensures proper system operation.

A summary listing of the chip setup and control (CSC) and PC Card index registers used to control the PC Card controller is shown in Table 19-1. Complete register descriptions can be found in the *Élan*™SC400 Microcontroller *Register Set Reference Manual* (order #21032).

Table 19-1 PC Card Controller Register Summary

Register	I/O Address	PC Card Controller Function	Description in Register Set Manual
Chip Setup and Control (CSC) Index Registers			
MMS Window C–F Attributes Register	22h/23h Index 30h	Caching and write protection for MMS Windows C–F	page 3-38
MMS Window C–F Device Select Register	22h/23h Index 31h	Physical device selection for MMS Windows C–F	page 3-39
Pin Mux Register B	22h/23h Index 39h	PC Card Socket B signals, V_{CC} and V_{PP} control signals for Socket A and B enable	page 3-45
Pin Mux Register C	22h/23h Index 3Ah	Socket A second card detect enable	page 3-46
Wake-Up Source Enable Register D	22h/23h Index 55h	Wake-up source enable: ring indicate, Sockets A and B interrupt requests, card detects, and status change	page 3-62
Wake-Up Source Status Register D	22h/23h Index 59h	Wake-up source status: ring indicate, Sockets A and B interrupt requests, card detects, and status change	page 3-66
Activity Source Enable Register D	22h/23h Index 65h	Activity source enable: CPU memory and I/O access to PC Card Sockets A and B; ring indicate; and PC Card interrupt	page 3-74

Table 19-1 PC Card Controller Register Summary (continued)

Register	I/O Address	PC Card Controller Function	Description in Register Set Manual
Activity Source Status Register D	22h/23h Index 69h	Activity source status: CPU memory and I/O access to PC Card Sockets A and B; ring indicate; and PC Card interrupt	page 3-78
Activity Classification Register D	22h/23h Index 6Dh	Primary or secondary activity classification: CPU Memory and I/O access to PC Card Sockets A and B; ring indicate; and PC Card interrupt	page 3-82
PC Card and Keyboard SMI/NMI Enable Register	22h/23h Index 91h	SMI/NMI enable: PC Card interrupt, ring indicate, and card detects for Sockets A and B	page 3-95
PC Card and Keyboard SMI/NMI Status Register	22h/23h Index 95h	SMI/NMI status: PC Card interrupt, ring indicate, and card detects for Sockets A and B	page 3-100
SMI/NMI Select Register	22h/23h Index 98h	SMI or NMI select: PC Card interrupts	page 3-104
I/O Access SMI Enable Register B	22h/23h Index 9Ah	SMI enable: I/O access to Sockets A and B	page 3-106
I/O Access SMI Status Register B	22h/23h Index 9Ch	SMI status: I/O access to Sockets A and B	page 3-108
Internal I/O Device Disable/Echo Z-Bus Configuration Register	22h/23h Index D0h	PC Card controller enable, MMS Windows C–F setup	page 3-164
DMA Resource Channel Map Register B	22h/23h Index DCh	Sockets A and B mapping to an internal DMA controller channel	page 3-178
Suspend Pin State Register A	22h/23h Index E3h	Suspend state of Socket A and Socket interfaces	page 3-184
PC Card Extended Features Register	22h/23h Index F0h	PC Card Memory Window selection and socket mapping, force card detect event	page 3-196
PC Card Mode and DMA Control Register	22h/23h Index F1h	Operating mode, Standard mode, Enhanced mode, clock speed, and DMA enables for both sockets	page 3-198
PC Card Socket A/B Input Pull-Up Control Register	22h/23h Index F2h	Sockets A and B input pull-up resistor enable	page 3-200
PC Card Index Registers			
Identification and Revision Register	3E0h/3E1h Index 00h (Socket #A) and 40h (Socket #B)	Interface ID, revision level	page 6-7
Interface Status Register	3E0h/3E1h Index 01h (#A) and 41h (#B)	Battery voltage detect, card detect state, memory write protect, power status, ready/ busy	page 6-8
Power and RESETDRV Control Register	3E0h/3E1h Index 02h (#A) and 42h (#B)	Auto power enable, socket V_{CC} enable, V_{PP} control	page 6-9

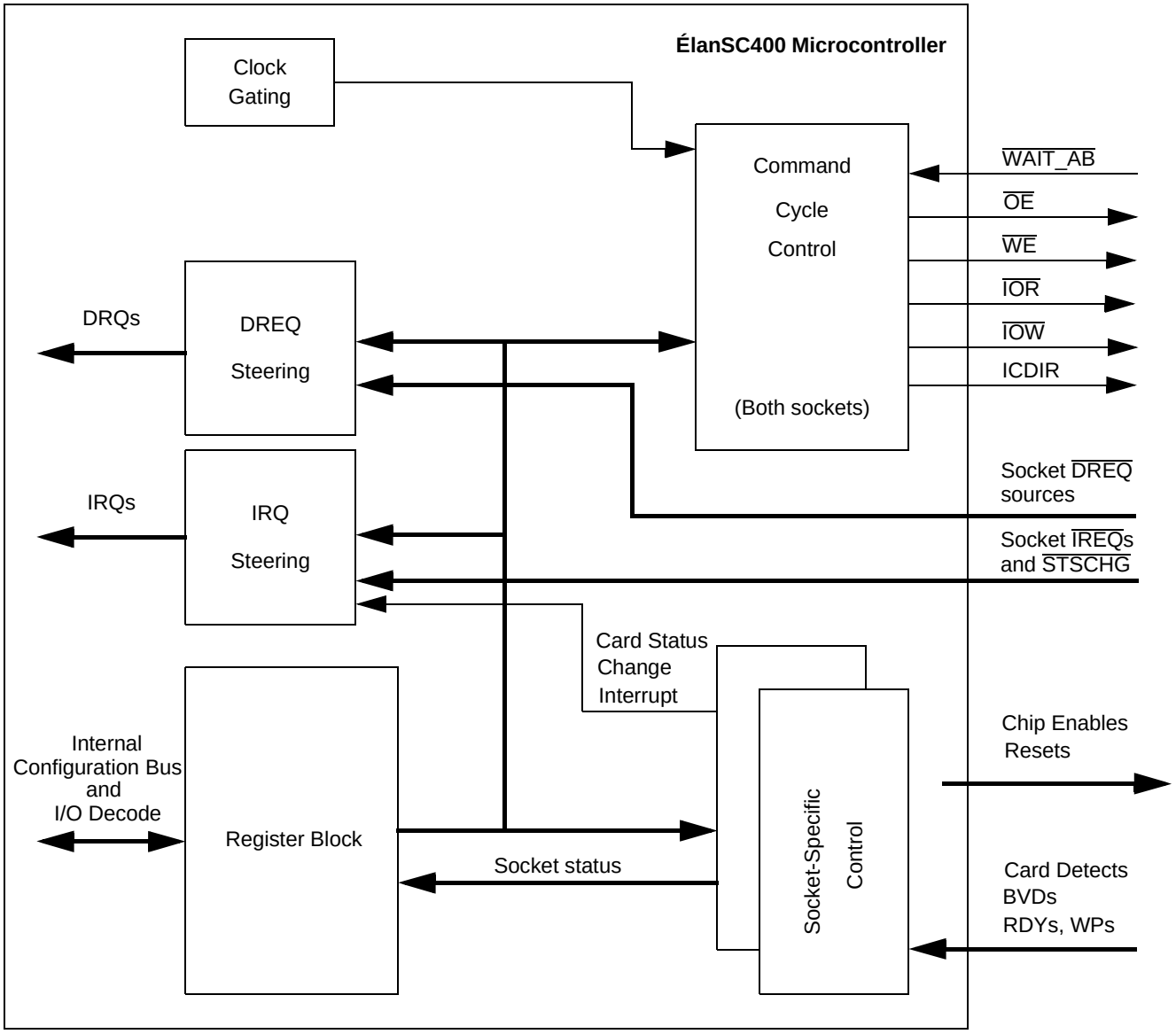
Table 19-1 PC Card Controller Register Summary (continued)

Register	I/O Address	PC Card Controller Function	Description in Register Set Manual
Interrupt and General Control Register	3E0h/3E1h Index 03h (#A) and 43h (#B)	IRQ mapping for $\overline{\text{RDY_x}}$, card status change interrupt destination, I/O and memory configuration, PC Card Reset, RST_x, ring indicate enable	page 6-11
Card Status Change Register	3E0h/3E1h Index 04h (#A) and 44h (#B)	$\overline{\text{CD_x}}$, $\overline{\text{RDY_x}}$, BVD1_x, BVD2_x states, battery warning, battery dead	page 6-12
Card Status Change Interrupt Configuration Register	3E0h/3E1h Index 05h (#A) and 45h (#B)	IRQ mapping for card status change interrupt; card status change interrupt on $\overline{\text{CD_x}}$; $\overline{\text{RDY_x}}$, BVD1_x, or BVD2_x state	page 6-13
Address Window Enable Register	3E0h/3E1h Index 06h (#A) and 46h (#B)	I/O windows 1 and 0 enable, memory windows 1–4 enable	page 6-15
I/O Window Control Register	3E0h/3E1h Index 07h (#A) and 47h (#B)	I/O window size and timing set	page 6-16
I/O Window Address Registers	3E0h/3E1h Various	I/O Window address bits for mapping into PC Card I/O address space	page 6-17–page 6-24
Memory Window Address Registers	3E0h/3E1h Various	Memory Window address bits for mapping into the PC Card memory address space	page 6-25–page 6-52
Memory Window Address Offset Registers	3E0h/3E1h Various	Memory Window 0 offset address, window write protect, $\overline{\text{REG_x}}$ active, common or attribute memory mapping	page 6-29–page 6-54
Setup Timing Registers	3E0h/3E1h Various	Setup multiplier value and prescalar select before PC Card command goes active	page 6-55–page 6-64
Command Timing Registers	3E0h/3E1h Various	Command multiplier value and prescalar select	page 6-56–page 6-65
Recovery Timing Registers	3E0h/3E1h Various	Recovery multiplier value and prescalar select for address hold time after the PC Card command goes inactive until the address changes state	page 6-57–page 6-66

19.3 BLOCK DIAGRAM

A block diagram of the PC Card controller is shown in Figure 19-1. The PC Card Socket B interface is shared with both the parallel port interface and the GPIO31-GPIO21 signals. Only one of these interfaces can be enabled at one time. The PC Card power control signals are shared with some of the GPIO signals.

Figure 19-1 PC Card Controller Block Diagram



19.4 PIN DEFINITIONS BY MODE

Several of the ÉlanSC400 microcontroller pins used for PC Card control have different functions, depending on whether or not a socket is configured for the Memory-only mode or the Memory and I/O mode. Table 19-2 compares the functions for these pins (each row of the table is one ÉlanSC400 microcontroller pin). Only the name in the "Memory-Only Mode" column is used on the ÉlanSC400 microcontroller pin list.

In many instances in this chapter, the names of the dual-function signals have been merged into the format "Memory-only name (Memory and I/O name)".

For example, WP_x ($\overline{\text{IOIS16_x}}$) represents the signal whose Memory-only mode function is "Write protect" and whose Memory and I/O function is "Dynamic data bus sizing." As a programmable option, a DMA request signal can also appear on this pin in Memory and I/O mode. The context of the description in which the signal is used determines which function is being used.

Table 19-2 Dual-Mode Signal Functions

Memory-Only Mode		Memory and I/O Mode			
Name	**Function**	**Name**	**Function**	**Name**	**Alternate Function**
$\overline{\text{RDY_x}}$	Ready indication	$\overline{\text{IREQ_x}}$	Interrupt request	Ī	
WP_x	Write protect	$\overline{\text{IOIS16_x}}$	Dynamic data bus sizing	DRQ_x	DMA request
BVD1_x	Battery voltage detect 1	$\overline{\text{STSCHG_x}}$	Status change indication		
BVD2_x	Battery voltage detect 2	$\overline{\text{SPKR_x}}$	Speaker driver	DRQ_x	DMA request

19.5 OPERATION

The ÉlanSC400 microcontroller's PC Card controller provides signals and timings to support memory, I/O, and DMA cycles to the two supported socket interfaces A and B. The PC Card controller design is optimized for a low-cost, non-buffered PC Card socket implementation.

The PCMCIA Standard Release 2.1 has specifically designed the PC Card socket interface's pin lengths to support hot PC Card insertion and removal in a non-buffered implementation. As a card is inserted, first ground is applied to the card, then power, then bus signals. The PC Card is thus able to three-state its bus interface signals by the time they come in contact with the system bus.

Each socket shares the same address and data bus, but each socket has dedicated chip selects for the low and high byte of the data bus as required by the PCMCIA Standard Release 2.1. Both sockets share a single $\overline{\text{WAIT}}$ signal. Each socket supports a reset signal that is software controllable via a PC Card controller indexed register bit.

Memory and I/O accesses to PC Cards are done via memory or I/O *windows* that software must enable before any access is possible. Interrupts can be generated by either an installed PC Card or by the PC Card controller itself, based on several events. Either of these interrupt types can be routed to several target destinations on the ÉlanSC400 microcontroller by the PC Card controller.

Each socket can be configured to operate in one of two modes as defined by the PCMCIA Standard Release 2.1: Memory-only mode, or Memory and I/O mode.

- **Memory-only mode** is the only mode originally defined in the PCMCIA Standard Release 1.0. This specification had no support for I/O cards, but defined the basic connector and card electrical and physical formats.
- **Memory and I/O mode** was added when support for I/O cards was included in the *PCMCIA Standard Release 2.1*. Memory and I/O mode redefines a few signals on the PC Card interface that were not often used or are memory-card-specific.

Although a memory card can be read when the PC Card controller is configured to be in Memory and I/O mode, the intent is that the interface be set up in Memory-only mode if a memory card (Flash, SRAM, ROM, etc.) is inserted, and in Memory and I/O mode if an I/O card is inserted (ATA, serial port/modem, network adapter, etc.). The type of card inserted and the system resources it requires can be read from the card CIS (Card Information Structure), which is defined by the *PCMCIA Standard Release 2.1*. This is typically the job of the PC Card and socket services drivers, further discussion of which is beyond the scope of this document.

In addition to the window configuration registers, the PC Card controller supports other control registers used for interrupt routing and enabling, selection of common/attribute memory, and socket power control. The status of the PC Card interface as well as the status of pending PC Card and PC Card controller interrupt events can be read. Interrupts can be routed to the power management unit to cause NMIs (Non-Maskable Interrupts) and SMIs (System Management Interrupts), or to serve as wake up or activity events.

The PC Card Controller can run at various speeds. There are two main speed categories: running at the current ISA bus clock rate (which is variable on the ÉlanSC400 microcontroller from 8 MHz down to 1 MHz) or running at the current CPU clock speed (which is variable on the ÉlanSC400 microcontroller from 33 MHz down to 1 MHz).

As described in Section 19.5.2, the PC Card controller operates in one of two modes: Standard or Enhanced.

- **Standard mode**—This mode is “standard” for the ÉlanSC400 microcontroller and does not include compatibility with the standard 82365.
- **Enhanced mode**—This mode provides full 82365-compatibility with additional enhancements, including DMA and timing controls.

When the PC Card controller is configured for Enhanced mode, the bus timings of memory cycles can be fine-tuned in terms of setup, command, and recovery (hold) times. Four individually configurable sets (three registers per set) of timing registers are used for this, and every window can be assigned to use one of the four timing register sets. Thus, if multiple resources exist on a PC Card, and each of the resources have different timings, a different window can be set up and used to access each of the resources. This provides the maximum performance possible from the PC Card. These timing registers are intended to be used only when the PC Card controller is configured for Enhanced mode. Any driver that optimizes card performance for a particular card must restore the default timings when the card is removed. This ensures proper timings for the next card that is inserted.

19.5.1 Signal Multiplexing

The PC Card address bus (A25-A0) is time-multiplexed with the ISA and ROM address bus (SA25-SA0) on the ÉlanSC400 microcontroller’s pins on a cycle-by-cycle basis. During PC Card accesses, the PC Card address appears on these pins; during ISA accesses, the ISA address appears on these pins. The ISA control signals $\overline{\text{IOR}}$ and $\overline{\text{IOW}}$ are time-multiplexed with the PC Card $\overline{\text{IORD}}$ and $\overline{\text{IOWR}}$ signals in the same way.

Note that because the $\overline{IOR}$ and $\overline{IOW}$ signals are shared with the ISA bus, DMA initiated from an ISA bus device and targeted at a PC Card is limited to common memory (i.e., the PC Card signal $\overline{REG_A}$ or $\overline{REG_B}$ is inactive).

The ÉlanSC400 microcontroller's ISA data bus (SD15-SD0) is used to directly access data on the PC Card data bus. If buffering of the PC Card address and data buses is desired, the ICDIR signal can be used along with some combinational logic external to the ÉlanSC400 microcontroller to control the direction and enabling of these buffers during PC Card accesses.

19.5.2 Memory Interface

The ÉlanSC400 microcontroller's PC Card Controller can be configured to operate in either of two modes: Standard mode or Enhanced mode. The mode applies to both sockets simultaneously (i.e., the sockets cannot be configured independently for different modes).

Standard and Enhanced modes differ in three areas: number of memory windows supported, PC Card cycle speeds supported, and PC Card DMA configuration support.

19.5.2.1 Standard Mode

Standard mode is the default power-up mode. Standard mode is further described in Section 19.5.5. It includes the following features:

- Memory Windows—Six total memory windows. Two are fixed (one for each socket) and the remaining four can "float" (i.e., can be configured for Socket A or B on a window-by-window basis.)
- Cycle Speeds—Nominal 8 MHz (PC/AT-bus clock) speed only.
- DMA Features—PC Cards cannot be configured as DMA initiators in this mode.

19.5.2.2 Enhanced Mode

Enhanced mode is entered by programming the MODE bit in the PC Card Mode and DMA Control Register (CSC index F1h). Enhanced mode is further described in Section 19.5.6. It includes the following features:

- Memory Windows: Ten total memory windows. Five are fixed for each socket.
- Cycle Speeds—Nominal 8 MHz (PC/AT-bus clock) speed or nominal 33 MHz (Local Bus clock) to support higher-performance PC Cards.
- DMA Features—PC Cards can be configured as DMA initiators in this mode. Two different PC Card signals are supported as DMA requests.

19.5.2.3 PC Card Controller Memory Windows

Memory windows are regions of variable length which are "opened" by setting aside a block of addresses in the CPU memory map at user-defined start/stop locations. Each of these memory windows can be as small as 4 Kbytes, and as large as 64 Mbytes (although no window base address can be positioned below 64 Kbytes). It is through this 4-Kbyte–64-Mbyte "viewing area" that a similarly-sized block of PC Card memory can be read from or written to.

Each of the five memory windows per socket can be individually write-protected, and the data path width can be set to either 8 or 16 bits via the memory window control registers. No dynamic memory interface width control is provided such as that provided for the I/O windows.

A typical memory window size is 4 Kbytes, so that all ten memory windows may fit into a single 64-Kbyte block (segment) of CPU address space. Because the PC Card may have

up to 64 Mbytes of memory on board, the viewed location on the PC Card is software programmable, and is commonly referred to as the *card offset*. Thus, using only a small window, the entire PC Card memory-mapped resource is accessible.

Because the PC Card controller is 82365 compatible, the card offset is related to the window's base address. One simple way to determine the value to program into the offset register (which is 14 bits distributed over two PC Card controller indexed registers—14h and 15h for Window 0's offset, for example) is to use the formula:

REGISTER = (OFFSET - WINDOW_START) >> 12

where:

REGISTER is the 14 bit offset register

OFFSET is the desired base address of the PC Card memory region to access (note 4 Kbyte granularity for this)

WINDOW_START is the window's start address which would be programmed for Socket A, Window 0 via PC Card controller index 10h and 11h

">>" refers to a shift right operation (shift right 12 bits)

Note: *PC Card controller memory windows should never be opened in any region that is enabled for linear $\overline{\text{ROMCS0}}$ decode, whether or not shadowing is enabled. Failure to adhere to this may cause improper system operation because no internal address decoding priority is defined in this regard.*

As a window setup example, the following code opens PC Card Socket A's memory window 0 as a 4-Kbyte window at 00D0000h in CPU memory space and points it to card offset 0:

```
;Set up Socket A's memory window 0 to have a start address of 00D0000h
mov      DX,3E0h  ;PC Card controller index register
mov      AL,10h           ;Window start address bits 19:12
out      DX,AL
inc      DX               ;PC Card controller data register
mov      AL,D0h
out      DX,AL

dec      DX               ;Back to the index register
mov      AL,11h           ;Window start address bits 25:20
out      DX,AL
inc      DX               ;Data
mov      AL,0
out      DX,AL

;Set up Socket A's memory window 0 to have an end address of 00D0000h.
;This is a 4 Kbyte window
dec      DX               ;Index
mov      AL,12h           ;Window stop address bits 19:12
out      DX,AL
inc      DX               ;Data
mov      AL,D0h
out      DX,AL
```

```
dec     DX              ;Index
mov     AL,13h          ;Window stop address bits 25:20
out     DX,AL
inc     DX              ;Data
mov     AL,0
out     DX,AL

;Set up Socket A's memory window 0 card offset to be (OFFSET - WINDOW_START)
;>> 12 where the desired offset is 0, and the window start address is
;D0000h. Note that 0-00D0000h=FFF30000h, so the 14 bit offset value=3F30
;(The top 2 bits of this register control other features, so be sure to
;mask them off)

dec     DX              ;Index
mov     AL,14h          ;Encoded window offset address bits 19:12 to
                        ;index 14h
out     DX,AL
inc     DX              ;Data
mov     AL,30h
out     DX,AL

dec     DX              ;Index
mov     AL,15h          ;Encoded window offset address bits 25:20 to
                        ;index 15h
out     DX,AL
inc     DX              ;Data
in      AL,DX           ;Top 2 bit of this register must be preserved
and     AL,0C0h
or      AL,3Fh
out     DX,AL
```

Note: *This example is meant to show basic window setup only. For this window from Socket A to function properly, it must be enabled via PC Card index 06h, and socket power must be applied via PC Card index 02h as a minimum.*

19.5.3 I/O Interface

Both sockets have two I/O windows available. I/O PC Cards of both 8- and 16-bit widths are supported on both sockets.

Each I/O window has the following features:

- Full 16-bit decode is performed for single-byte addressability of the entire 64-Kbyte system I/O address space.
- 64-Kbyte I/O range is accessible via 16-bit wide start and stop registers.

The following PC Card optional signals are supported:

- $\overline{\text{SPKR_A}}$ and $\overline{\text{SPKR_B}}$ for digital audio.
- $\overline{\text{STSCHG_A}}$ and $\overline{\text{STSCHG_B}}$ can be mapped to system interrupts.
- $\overline{\text{STSCHG_A}}$ and $\overline{\text{STSCHG_B}}$ ($\overline{\text{RI}}$) can be configured as a PMU activity or a wake-up source.

19.5.3.1 I/O Windows

PC Card controller I/O windows differ slightly from memory windows in that no address translation is performed. This is because a PC Card controller I/O window is capable of being made to be 64 Kbytes wide, which is the same as the maximum I/O range of an x86 CPU like the ÉlanSC400 microcontroller.

There are two I/O windows per socket, and they are available regardless of whether the PC Card controller is in Standard or Enhanced mode. In order for I/O windows to be used however, the PC Card controller must be configured to be in Memory and I/O mode by setting bit 5 of the Interrupt and General Control Register for the socket on which an I/O window is to be opened.

Each I/O window is defined in terms of a 16-bit start and finish address, thus providing I/O windows as small as 1 byte and as large as 65536 bytes with 1-byte granularity. If the start address is made equal to the finish address, the window will be 1 byte wide.

The PC Card controller makes no attempt to limit where the I/O windows are opened in the 0–64 Kbyte range, so care should be taken not to conflict with other I/O mapped resources (especially the PC Card controller index and data registers). I/O windows have individual enable bits that are located together with the memory window enable bits in the Address Window Enable Register on a per-socket basis.

I/O windows may be forced to 8 or 16 bits in width via a register bit, or dynamically sized based on the $\overline{\text{IOIS16}}$ signal which may be driven by a PC Card. The selection of whether this is forced or dynamic is done via a register control bit, and would typically be configured by a PC Card device driver when the card is inserted.

19.5.4 PC Card Bus Cycles

The possible PC Card bus cycle types and the associated PC Card command signal are summarized in Table 19-3. Decode tables for each function follow.

Table 19-3 PC Card Supported Cycle Types

Cycle Type	PC Card Command Signal
Memory read (attribute or common)	$\overline{\text{OE}}$
Memory write (attribute or common)	$\overline{\text{WE}}$
I/O read	$\overline{\text{IOR}}$
I/O write	$\overline{\text{IOW}}$
DMA read (target)	$\overline{\text{OE}}$
DMA write (target)	$\overline{\text{WE}}$
DMA read (initiator)	$\overline{\text{IOW}}$ (TC on $\overline{\text{WE}}$)
DMA write (initiator)	$\overline{\text{IOR}}$ (TC on $\overline{\text{OE}}$)

Table 19-4 PC Card Attribute Memory Read Function

Mode	$\overline{\text{REG_x}}$	$\overline{\text{MCEH_x}}$	$\overline{\text{MCEL_x}}$	SA0	$\overline{\text{OE}}$	$\overline{\text{WE}}$	SD15–SD8	SD7–SD0
Byte Access	L	H	L	L	L	H	Three-state	Even byte
	L	H	L	H	L	H	Three-state	not valid
Word Access	L	L	L	x	L	H	Not valid	Even byte
Odd-Byte-Only Access	L	L	H	x	L	H	Not valid	Three-state

Table 19-5 PC Card Attribute Memory Write Function

Mode	REG_x	MCEH_x	MCEL_x	SA0	OE	WE	SD15–SD8	SD7–SD0
Byte Access	L	H	L	L	H	L	xx	Even byte
	L	H	L	H	H	L	xx	xx
Word Access	L	L	L	x	H	L	xx	Even byte
Odd-Byte-Only Access	L	L	H	x	H	L	xx	xx

Table 19-6 PC Card Common Memory Read Function

Mode	REG_x	MCEH_x	MCEL_x	SA0	OE	WE	SD15–SD8	SD7–SD0
Byte Access	H	H	L	L	L	H	Three-state	Even byte
	H	H	L	H	L	H	Three-state	Odd byte
Word Access	H	L	L	x	L	H	Odd byte	Even byte
Odd-Byte-Only Access	H	L	H	x	L	H	Odd byte	Three-state

Table 19-7 PC Card Common Memory Write Function

Mode	REG_x	MCEH_x	MCEL_x	SA0	OE	WE	SD15–SD8	SD7–SD0
Byte Access	H	H	L	L	H	L	XX	Even byte
	H	H	L	H	H	L	XX	Odd byte
Word Access	H	L	L	x	H	L	Odd byte	Even byte
Odd-Byte-Only Access	H	L	H	x	H	L	Odd byte	xx

Table 19-8 PC Card I/O Read Function

Mode	REG_x	MCEH_x	MCEL_x	SA0	IOR	IOW	SD15–SD8	SD7–SD0
Byte Access	L	H	L	L	L	H	Three-state	Even byte
	L	H	L	H	L	H	Three-state	Odd byte
Word Access	L	L	L	x	L	H	Odd byte	Even byte
High Byte Only	L	L	H	x	L	H	Odd byte	Three-state

Table 19-9 PC Card I/O Write Function

Mode	REG_x	MCEH_x	MCEL_x	SA0	IOR	IOW	SD15–SD8	SD7–SD0
Byte Access	L	H	L	L	H	L	xx	Even byte
	L	H	L	H	H	L	xx	Odd byte
Word Access	L	L	L	x	H	L	Odd byte	Even byte
Odd-Byte-Only Access	L	L	H	x	H	L	Odd byte	xx

Table 19-10 PC Card DMA Read Function

Mode	DACK	DREQ	MCEH_x	MCEL_x	OE	WE	IOR	IOW	SD15–SD8	SD7–SD0
Byte Access	H	L	H	L	H	TC	H	L	xx	Even byte
Word Access	H	L	L	L	H	TC	H	L	Odd byte	Even byte

Table 19-11 PC Card DMA Write Function

Mode	$\overline{\text{DACK}}$	DREQ	$\overline{\text{MCEH_x}}$	$\overline{\text{MCEL_x}}$	$\overline{\text{OE}}$	$\overline{\text{WE}}$	$\overline{\text{IOR}}$	$\overline{\text{IOW}}$	SD15–SD8	SD7–SD0
Byte Access	H	L	H	L	$\overline{\text{TC}}$	H	L	H	xx	Even byte
Word Access	H	L	L	L	$\overline{\text{TC}}$	H	L	H	Odd byte	Even byte

19.5.4.1 Memory Write Protection

One exception to the cycle command decode is when a memory write is attempted to a write-protected region. Write protection to a memory region can be indicated by one of two sources:

- The WR_PROT bit from the Memory Window Address Offset High Register is set for the window being accessed during the current cycle
- During a write-protected ROM cycle redirected to Socket A

If one of these two conditions is true, then the $\overline{\text{WE}}$ signal is held in its inactive state for the duration of the cycle, so that the PC Card in the socket does not see the memory write command.

19.5.4.2 Non-DMA Cycle Timing

The timing control registers are responsible for directing the PC Card cycle command control block during non-DMA cycles issued to a PC Card. The timing control registers are divided into four independent timing sets. Each set has three registers responsible for:

- Setup timing
- Command timing
- Recovery timing

Each memory window can be configured for one of the four timing sets. This selection is done using the Memory Window (0–4) Stop Address High Registers.

The contents of the timing control registers are basically counter values. They tell the command cycle timer how many clocks to count for each phase (setup, command, and recovery) of a PC Card cycle. Thus, their meaning in terms of how much time is spent in each phase is dependent on the clock speed used for the command cycle timer. The clock speed is determined by three factors: The value of both the MODE and CLK_SEL bits in the PC Card mode and DMA Control Register and the PMU state.

The MODE bit in the PC Card Mode and DMA Control Register selects between Standard and Enhanced mode for the PC Card controller block.

- In Standard mode, only the PC/AT bus (8 MHz) clock can be used for cycle control. Thus, the granularity for cycle phase timing is 125 ns.
- In Enhanced mode, the CLK_SEL bit in the PC Card Mode and DMA Control Register selects between the PC/AT bus (nominal 8 MHz) clock and the VL-bus (nominal 33 MHz) clock. Thus, when the VL-bus clock is selected, the granularity for cycle phase timing is 30 ns.

The last factor in clock speed used for the command cycle timer is the PMU state. The PMU has control of the PC/AT bus and VL-bus clocks for power savings reasons and can enter states that stretch out clock cycles. This has the effect of also stretching out PC Card accesses.

The actual timings of each phase of all non-DMA memory or I/O cycles are based on the following:

- Clock speed as described above
- Value programmed into the command, setup, and recovery timing control set selected by a particular memory or I/O window
- Operating mode (Standard or Enhanced)

For both modes:

t-setup = 4 clocks + value programmed into setup timing control

t-command = 1 clock + value programmed into command timing control

t-recovery = 2 clocks + value programmed into recovery timing control

Because this PC Card controller is compatible with the 82365SL (Rev. B) and the controller resets to Standard mode (PC/AT Bus clock timing), the four timing sets reset to values consistent with the four possible wait state settings (0, 1, 2, or 3 PC/AT bus wait states) of 82365SL (Rev. B) memory windows. This means that default PC Card cycles are of the same length as 82365SL (Rev. B) cycles.

The values of the timing control registers should not be changed when the controller is in Standard mode in order to maintain 82365SL (Rev. B) timing compatibility. The timing sets are intended to be changed when the controller is in Enhanced mode to take advantage of the higher access speeds attainable with the VL-bus clock.

Each of the timing control registers has a two-bit Prescalar Select field and a five-bit Multiplier Value field. The Prescalar Select field selects a weighting described in Table 19-12.

Table 19-12 Prescalar Select Field Weighting

Field Value	Prescalar Weighting
00	N_{pres}=1
01	N_{pres}=16
10	N_{pres}=256
11	N_{pres}=4096

Note: *The Multiplier Value, N_{val}, is combined with the Prescalar Weighting, N_{pres}, to determine the number of clocks to count for the current state (Setup, Command active, or Recovery). The Current State (S,C, or R) = (N_{pres} x N_{val}) + 1.*

19.5.5 Using Standard PC Card Mode

Standard mode is the default mode. In Standard PC Card mode, a total of six PC Card memory windows is available. Each socket has one memory window dedicated to it. The remaining four windows are mapped to PC Card Socket A by default, but are individually mappable to either Socket A or Socket B. In this Standard PC Card mode, four of the memory windows that are normally used for Socket B (in Enhanced PC Card mode) are used for MMS windows C–F instead.

When only one socket is implemented in the system design (i.e., Socket A), the ÉlanSC400 microcontroller provides one fully 82365-compatible PC Card socket. If two PC Card sockets are implemented in a system design and the Standard PC Card mode is selected, the six available PC Card memory windows can be mapped in various combinations between Socket A and Socket B. In any situation in which a socket has less than five memory windows available to it, compatible PC Card drivers are not guaranteed to work with the sockets. Although a memory window from Socket A may be mapped to Socket B, the controls still remain in their original Socket A index locations.

19.5.5.1 Memory Window Redirection

In Standard mode, four of the memory windows nominally assigned to Socket A can be reassigned to Socket B. This feature is controlled by the PC Card Extended Features Register (CSC index F0h). The bits MEM_WIN_SEL[3:0] in this register control the destination socket for PC Card memory cycles, as shown in Table 19-13. Note that in Enhanced Mode, the bits MEM_WIN_SEL[3:0] have no effect on PC Card cycles; all five memory windows for each socket are available to that socket only.

Table 19-13 Memory Window Socket Mapping

CSC Index F0h MEM_WIN_SEL [3–0]	Socket A Memory Windows 1–4 Socket Mapping	
	Socket A	Socket B
0000 (0h)	1,2,3,4	None
0001 (1h)	2,3,4	1
0010 (2h)	1,3,4	2
0011 (3h)	3,4	1,2
0100 (4h)	1,2,4	3
0101 (5h)	2,4	1,3
0110 (6h)	1,4	2,3
0111 (7h)	4	1,2,3

CSC Index F0h MEM_WIN_SEL [3–0]	Socket A Memory Windows 1–4 Socket Mapping	
	Socket A	Socket B
1000 (8h)	1,2,3	4
1001 (9h)	2,3	1,4
1010 (Ah)	1,3	2,4
1011 (Bh)	3	1,2,4
1100 (Ch)	1,2	3,4
1101 (Dh)	2	1,3,4
1110 (Eh)	1	2,3,4
1111 (Fh)	None	1,2,3,4

When a hit to one of the Socket A memory windows 1 through 4 is decoded, the bits MEM_WIN_SEL[3:0] determine which socket's $\overline{\text{MCEL_x}}$, $\overline{\text{MCEH_x}}$, and $\overline{\text{REG_x}}$ pins are actually activated. Table 19-14 outlines the effects the redirection has on the socket-specific PC Card cycle control signals. In the table, the status of the $\overline{\text{REG_x}}$ pin is described in terms of how the REG_ACT bit in the Memory Window Address Offset High Register for the hit window is used.

Table 19-14 Memory Window Redirection Effects

MEM_WIN_SEL [3:0]	Memory Window Hit	Socket A		Socket B	
		$\overline{\text{MCEx_A}}$	$\overline{\text{REG_A}}$	$\overline{\text{MCEx_B}}$	$\overline{\text{REG_B}}$
XXX0	1, Socket A	Active	win 1 REG_ACT	Inactive	Inactive
XXX1	1, Socket B	Inactive	Inactive	Active	win 1 REG_ACT
XX0X	2, Socket A	Active	win 2 REG_ACT	Inactive	Inactive
XX1X	2, Socket B	Inactive	Inactive	Active	win 2 REG_ACT
X0XX	3, Socket A	Active	win 3 REG_ACT	Inactive	Inactive
X1XX	3, Socket B	Inactive	Inactive	Active	win 3 REG_ACT
0XXX	4, Socket A	Active	win 4 REG_ACT	Inactive	Inactive
1XXX	4, Socket B	Inactive	Inactive	Active	win 4 REG_ACT

19.5.5.2 Configuring MMS Windows C–F

MMS windows C–F are configured using a combination of PC Card index registers and CSC index registers. PC Card Socket B Memory Window 1–4 configuration registers are the PC Card index registers that are used to define the start address and the stop address of the window in the CPU address space, the offset address, and the window enable/disable configuration. Table 19-15 below shows the PC Card Socket B memory window resources that are used to configure MMS windows C–F in Standard PC Card mode.

Note that if the integrated PC Card controller is disabled, the CPU will not be able to access the PC Card index registers. If the MMS C–F windows are setup when the integrated PC Card controller is enabled and then the integrated PC Card controller is disabled, the MMS C–F windows would still be functional.

Table 19-15 PC Card Socket B Memory Window Resources Used for MMS

PC Card Socket B Memory Window Control	MMS Window	PC Card Index Registers Used
Window 0	None	None
Window 1	MMS C	46h[1], 58–5Dh
Window 2	MMS D	46h[2], 60–65h
Window 3	MMS E	46h[3], 68–6Dh
Window 4	MMS F	46h[4], 70–75h

19.5.6 Using Enhanced PC Card Mode

Enhanced mode is enabled by programming the MODE bit in the PC Card Mode and DMA Control Register.

In the Enhanced PC Card mode, the PC Card control registers are used to control PC Card Socket B memory windows 1–4. MMS windows C–F are not available. In this mode, any CSC index register bits that pertain to MMS window C–F control have no effect.

19.5.7 DMA Interface

The ÉlanSC400 microcontroller supports DMA between PC Cards and system memory/ ISA memory, as defined in the *PC Card Standard* (also known as *PC Card '95* or *PC Card Standard Release 3.0—Berlin Drafts*). DMA is supported between an I/O PC Card and system memory. DMA between two PC Cards is not supported. PC Card DMA is only supported in Enhanced mode. (See Table 4-15 for a complete listing of ISA DMA cycle types and command strobes generated.)

One of two PC Card interface signals from each socket can be configured as the DREQ (DMA Request) signal to be routed to the ÉlanSC400 microcontroller's DMA controller: BVD2_x ($\overline{\text{SPKR_x}}$), or WP_x ($\overline{\text{IOIS16_x}}$). Regardless of which signal is configured to serve as DREQ on the PC Card interface, the $\overline{\text{REG_x}}$ signal always acts as the DMA Acknowledge ($\overline{\text{DACK_x}}$) signal. The socket must be configured for Memory and I/O mode via the CARD_IS_IO bit in the Interrupt and General Control Register before a card can issue DMA requests. Note that the *PC Card Standard* requires that a third PC Card signal ($\overline{\text{INPACK}}$) be available to be used as the DREQ input. The ÉlanSC400 microcontroller does not support the $\overline{\text{INPACK}}$ interface signal.

DMA write verify cycles to the PC Card are also supported specifically to support PC Card floppy disk drive controllers.

19.5.7.1 DMA Cycle Timing

The ÉlanSC400 microcontroller has several enhancements to support DMA to and from PC Cards. A PC Card can be either a DMA target or a DMA initiator.

When a PC Card is a DMA target, the PC Card cycles have the same format as normal memory cycles (i.e., the decode for the window hits is handled by the MMU in the same way as cycles originating from the CPU).

When a PC Card is a DMA initiator, the PC Card I/O cycles have the same timing as the $\overline{\text{DIOR}}$ and $\overline{\text{DIOW}}$ signals from the DMA controllers. These signals are simply gated onto the PC Card $\overline{\text{IOR}}$ and $\overline{\text{IOW}}$ signals, respectively. DMA Terminal Count cycles and DMA verify cycles are exceptions; these cycles have their own state machines that track when to pulse the PC Card I/O command signals.

For DMA Terminal Count cycles, a state machine clocked by the DMA clock tracks the type of cycle being requested. It waits for the cycle state machine to enter the Command state, and if it determines that a PC Card-initiated DMA is being serviced and the Command cycle is more than two clocks long, it will enter a state that allows the TC input to be enabled onto the $\overline{\text{WE}}$ or $\overline{\text{OE}}$ signal (as appropriate). When there is one clock left in the Command state, it will inactivate the TC signal on $\overline{\text{WE}}$ or $\overline{\text{OE}}$.

For DMA verify cycles, the $\overline{\text{IOR}}$ command is pulsed one time for a period equal to three and a half DMA clock periods. This means that PC Card DMA verify cycles can only be run in single-transfer DMA mode.

For PC Card DMA cycles, the PC Card controller timing set registers are disabled. During these cycles, all PC Card cycle timing is dictated by the DMA controller. The standard setup, command, and recovery timing for these PC Card DMA cycles will be 102 ns (min), 250 ns (min), and 53 ns (min), respectively, based on a DMA controller clock frequency of 4 MHz. If the DMA controller clock frequency is modified, the PC Card setup, command, and recovery timing will be scaled accordingly. A PC Card DMA device can add wait states to memory or I/O accesses by asserting the WAIT signal if the proper setup from command is observed.

19.5.8 System Interrupt Control

System interrupt generation by the PC Card controller is very flexible.

- A PC Card can generate an interrupt request on its RDY_x (IREQ_x) pin when configured for the Memory and I/O mode.
- Also, the PC Card controller can generate a card status change interrupt when changes in state are detected on any of several PC Card interface signals when the socket is configured for either Memory-only or Memory and I/O mode.
- Finally, a Ring Indicate signal can be enabled to the PMU block to indicate a change in card status when a card's BVD1_x (STSCHG_x) signal is active and the socket is configured for the Memory and I/O mode.

The standard PC/AT edge-triggered interrupts are supported.

- A card status change interrupt can be generated from changes in the following signals: CD_A, CD_B, BVD1_A, BVD1_B, BVD2_A, BVD2_B, RDY_A, and RDY_B (for memory cards only.) The status change interrupts can be steered to any of the following system interrupts: SMI, NMI, IRQ3–5, IRQ7, IRQ9–12, and IRQ14–15.
- The PC Card I/O interface signals RDY_A (IREQ_A) and RDY_B (IREQ_B) (the PC Card I/O function is indicated in parenthesis) can be steered to any of the following system interrupts: IRQ3–5, IRQ7, IRQ9–12, and IRQ14–15.
- The PC Card I/O interface signals BVD1_A (STSCHG_A) and BVD1_B (STSCHG_B) (the PC Card I/O function is indicated in parenthesis) can be steered to any of the following system interrupts: NMI, SMI, IRQ3–IRQ5, IRQ7, IRQ9–IRQ12, and IRQ14–IRQ15.

19.5.8.1 Socket Status Inputs

A card status change interrupt for each socket can be generated by any of four different sources depending on the configuration of the Card Status Change and the Card Status Change Interrupt Configuration registers. Refer to these register descriptions for details on how these four sources control the generation of the card status change interrupt for a socket.

The socket status inputs, BVD1_x, BVD2_x, CD_x, and RDY_x, are used to generate the card status change interrupt, indicating a socket status change. Changes in the state of these signals need to be latched to generate the interrupt and be read by system software to determine the cause of the interrupt. The Card Status Change Register description explains how each of these register bits is to be controlled by hardware. The PC Card controller is compliant with revision B of the 82365. Unlike revision C compatibility, the status bits will latch when a status change is detected even when the event is not first unmasked. To avoid spurious interrupts when enabling status change event sources, the latch should be cleared prior to unmasking the status change interrupt source.

The CD_CHNG bit in the Card Status Change Register can also be set (but not cleared) by writing to the FORCE_CD_x bit in the PC Card Extended Features Register. This feature allows software to generate a card detect change event that can be read back from the Card Status Change Register.

19.5.9 Sound Generation

When a socket is configured for the Memory and I/O mode, its BVD2_x (SPKR_x) pin can be used to generate sounds on the system speaker via the ÉlanSC400 microcontroller's SPKR pin.

The first step of this feature is the masking of the BVD2_x ($\overline{SPKR_x}$) signals with the CARD_IS_IO bit in the Interrupt and General Control Register (no sounds can be generated on BVD2_x when the socket is configured for the Memory-only mode and the masked signal is held in the inactive high state). The resulting masked $\overline{SPKR_x}$ signals are exclusive-ORed together and sent to the PC/AT port to be merged with the other sources of the ÉlanSC400 microcontroller's SPKR signal.

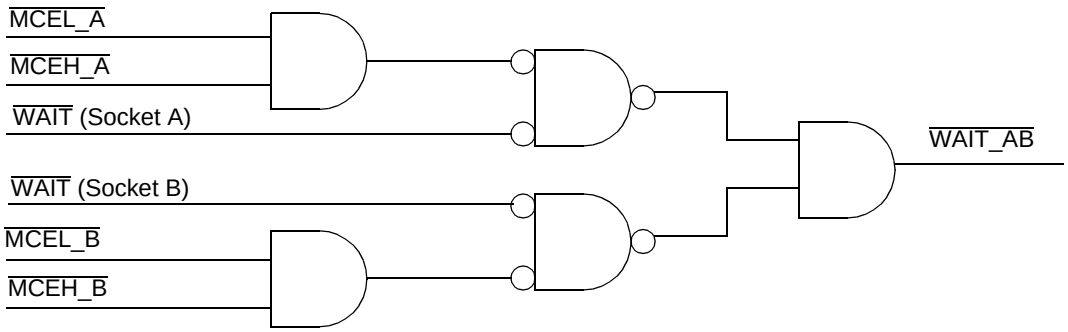
19.5.10 Using the $\overline{WAIT_AB}$, $\overline{CD_A}$, and $\overline{CD_B}$ Pins

To achieve the maximum benefit from the pins available on the ÉlanSC400 microcontroller, some of the PC Card signals specified in the *PCMCIA Standard Release 2.1* must be gated together before driving the ÉlanSC400 microcontroller pin. This merging function is described in the following sections.

19.5.10.1 $\overline{WAIT_AB}$ Signal Merging

The ÉlanSC400 microcontroller has only one pin, $\overline{WAIT_AB}$, to support the PC Card $\overline{WAIT}$ signal from Socket A and Socket B. To support $\overline{WAIT}$ from both sockets, the $\overline{WAIT}$ signal from each socket should be logical ORed together after being masked off by their respective Card Enable pins as shown in Figure 19-2. In other words, $\overline{WAIT}$ from Socket A should be logical ANDed with $\overline{MCEL_A}$ and $\overline{MCEH_A}$ before being ORed with the same masking function on Socket B's $\overline{WAIT}$.

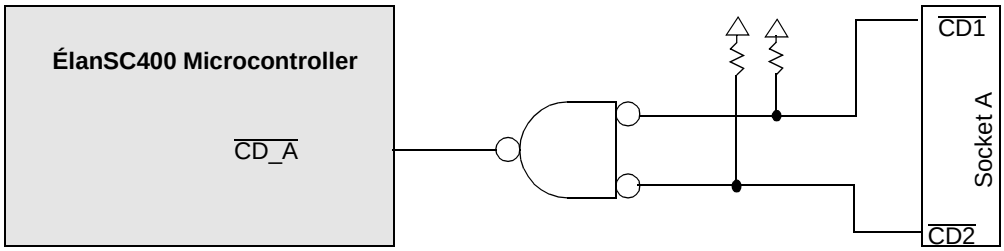
Figure 19-2 Merging $\overline{WAIT}$ signals from Sockets A and B



19.5.10.2 $\overline{CD_A}$ and $\overline{CD_B}$ Signal Merging

The ÉlanSC400 microcontroller has only one dedicated card detect pin to support the PC Card $\overline{CD1}$ (Card Detect 1) and $\overline{CD2}$ (Card Detect 2) pins from Socket A. The $\overline{CD_A}$ pin is the dedicated card detect input for Socket A. The Card Detect function that this signal is intended to perform can be achieved by applying the logical OR function to the $\overline{CD1}$ and $\overline{CD2}$ pins from Socket A, and then sending the resulting signal to the $\overline{CD_A}$ ÉlanSC400 microcontroller pin as shown in Figure 19-3.

Figure 19-3 Card Detect Function for Socket A



The same can be done for CD_B using CD1 and CD2 from Socket B. This ensures that a card is not detected until it is fully inserted because the CD1 and CD2 pins are located at opposite edges of the card.

To avoid having to use the external gate, a second Card Detect input pin can be configured for Socket A. The input function CD_A2 is multiplexed on one of the ÉlanSC400 microcontroller GPIO pins. If the CD_A2 function is selected via firmware, the external gate can be eliminated.

19.5.11 Power Considerations

19.5.11.1 Card V_{CC} and V_{PP} Control

An 82365SL-compatible V_{CC} and V_{PP} control interface is provided for both Socket A and Socket B. The following interface signals provide control for the sockets that V_{CC} and V_{PP} supply:

- Socket A—PCMA_VCC, PCMA_VPP1, PCMA_VPP2
- Socket B—PCMB_VCC, PCMB_VPP1, PCMB_VPP2

These signals are multiplexed with other ÉlanSC400 microcontroller interface signals. The PC Card functionality for these pins can be enabled on a socket-by-socket basis. Bits in the Power and RESETDRV Control Register (PC Card index 02h (Socket A) and Index 42h (Socket B)) are used to control these features, as shown in Table 19-16 and Table 19-17.

Table 19-16 VPP Control Signal Definition

Bit 4 V_{CC} Power	Bit 1 V_{PP} Control Bit 1	Bit 2 V_{PP} Control Bit 0	PCMx_VPP2	PCMx_VPP1	PCMx_VCC	Comments
1	0	0	0	0	0	V_{PP} is N/C V_{CC} enabled
1	0	1	0	1	0	V_{PP} = VCC V_{CC} enabled
1	1	0	1	0	0	V_{PP} = +12V V_{CC} enabled
1	1	1	0	0	0	V_{PP} is N/C V_{CC} enabled
0	X	X	0	0	1	V_{PP} is N/C V_{CC} disabled

Table 19-17 VCC Control Signal Definition

Socket $\overline{CD_x}$ Low	Bit 5 Auto Power Control	Bit 4 V_{CC} Power	PCMx_VCC	PC Card Power Active (Bit 6 of Interface Status Register)	Comments
X	X	0	1	0	Socket forced off
X	0	1	0	1	Socket forced on
No	1	1	1	0	Auto power enabled and no card inserted
Yes	1	1	0	1	Auto power enabled and card inserted/powered

The ÉlanSC400 microcontroller does not directly support the external data buffer control pin as is found on the 82365SL controller. The ÉlanSC400 microcontroller's PC Card implementation is essentially a non-buffered 82365SL design. An external buffer may be included in the system design and would require a small amount of external logic to provide the appropriate control.

19.5.11.2 Power Considerations for System Design

Powering down sections of a system during operation is difficult to handle correctly, and the PC Card power planes are no different. Fully buffering each PC Card socket allows the system to power the cards up and down at any time. However, the major drawback is that there are many signals to buffer, and total system cost, board space, and power consumption will all be increased. This is acceptable for some but not for all systems. If the system design does not fully buffer each PC Card socket, then each of the shared signals on the ÉlanSC400 microcontroller requires some amount of special consideration. Table 19-18 lists the PC Card signals and the other parts of the system with which they are shared.

Table 19-18 Shared PC Card Signals

PC Card Signals	Shared with
Address	Other PC Card socket, ISA bus, ROM, VL-bus
Data	Other PC Card socket, ISA bus, ROM, VL-bus, DRAM (if 32-bit; buffer controls available)
$\overline{IOR}/\overline{IOW}$	Other PC Card socket, ISA bus
$\overline{WAIT}$	Other PC Card socket
$\overline{OE}/\overline{WE}$	Other PC Card socket

- **Address Signals**—Shared with the other PC Card socket, ISA bus, ROM, VL-bus. Because the address is shared with other interfaces, the card will have to be powered up when it is connected and the system is operating (i.e., not in Suspend mode). Because the address is not bidirectional (driven by the ÉlanSC400 microcontroller only), the cards can be 3.3 V or 5 V (the designer should ensure that nothing in the system pulls an address line up to 5 V). During Suspend mode, the address signals all go Low so the cards can be powered off in Suspend.
- **Data Signals**—Shared with the other PC Card socket, ISA bus, ROM, VL-bus, DRAM. There are many considerations here depending on which of the above interfaces are used in the system, and the voltage at which they are run. Because the data is shared

with other interfaces, the card will have to be powered up when it is connected and the system is operating (i.e., not in Suspend mode). Because the data bus is bidirectional, the voltages become more of an issue. DRAM and VL bus in this system are 3.3 V only. If the PC Card power plane is to be at 5 V (or the ISA bus, parallel port, or ROM are 5 V), then the SD level-translating buffer must be added to the system (controlled by the ÉlanSC400 microcontroller's $\overline{\text{DBUFOE}}$, $\overline{\text{DBUFRDL}}$, and $\overline{\text{DBUFRDH}}$ signals). This will isolate the 5-V devices (ISA, ROM, parallel port, PC Card) from the 3.3-V devices (DRAM and VL-bus). If the card is to be powered at 3.3 V, and the ISA/ROM are 5 V, then additional buffering is needed to isolate the PC Cards sockets from the ISA/ROM devices. The ÉlanSC400 microcontroller signal ICDIR is provided for steering this buffer (the socket card enables ($\overline{\text{MCEL_x}}$ and $\overline{\text{MCEH_x}}$) can be used to enable the buffers).

- **$\overline{\text{IOR}}$/$\overline{\text{IOW}}$ Signals**—Shared with other PC Card socket, ISA bus. Because the data is shared with other interfaces, the card will have to be powered up when it is connected and the system is operating (i.e., not in Suspend mode). If the card is to be powered off in Suspend mode, then these signals should be buffered for each card. In Suspend mode, $\overline{\text{IOR}}$ and $\overline{\text{IOW}}$ are left High; this would back-power the card if it is not buffered off.
- **$\overline{\text{WAIT}}$ Signals**—Shared with the other PC Card socket. Because the $\overline{\text{WAIT}}$ signals for the two sockets need to be ORed together (logical OR; since they are active Low, this is actually an AND gate), their pull-ups must be handled carefully. On the system board, each card's $\overline{\text{WAIT}}$ pull-up would normally be tied to that card's V_{CC}, but this can cause problems in a non-buffered system. With each socket $\overline{\text{WAIT}}$ pulled up to that card's V_{CC}, and the two $\overline{\text{WAIT}}$ signals ORed together, neither socket can be powered down at any time, even if it does not have a card installed. (If one socket is powered down when the other socket is in use, the powered down socket's V_{CC} goes away, the pull-up no longer pulls up, the AND gate gets a low input, the $\overline{\text{WAIT}}$ signal is seen as Low at the ÉlanSC400 microcontroller, and the system locks up when it attempts to access the socket with a card. The ÉlanSC400 microcontroller cannot distinguish which card is actually pulling the $\overline{\text{WAIT}}$). The best approach for this is to tie the socket $\overline{\text{WAIT}}$ pull-ups to a V_{CC} that is always on when the system is operating. This pull-up should be gated so the cards can be powered off in Suspend mode (and will not be back-powered by the $\overline{\text{WAIT}}$ pull-up).
- **$\overline{\text{OE}}$/$\overline{\text{WE}}$ Signals**—Shared with the other PC Card socket. If the card is to be powered off in Suspend mode, then these signals should be buffered for each card. In Suspend mode, $\overline{\text{OE}}$ and $\overline{\text{WE}}$ are left High; this would back-power the card if it is not buffered off.

The PC Card power control signals allow the system to turn each power plane of the card on and off. $\overline{\text{PCMx_VCC}}$ (x being A or B) controls the 5-V (or 3-V) power plane; and PCMx_VPP1 and PCMx_VPP2 work together to choose 12 V, V_{CC}, or GND for the PC Card VPP power pins. To design a system that provides either 5 V or 3.3 V to the PC Card power planes, use an ÉlanSC400 microcontroller GPIO signal for the 3.3-V enable (or use a GPIO to steer the $\overline{\text{PCMx_VCC}}$ signal to either the 5-V or 3-V enable).

The PC Card sockets are usable individually, but they are not able to be powered individually if they are not buffered.

19.6 INITIALIZATION

The PC Card controller is disabled at power-on reset and must be configured and enabled by software. There are really two levels at which the PC Card controller can be disabled:

- Individual features can be turned off (i.e., PC Card windows can be disabled, IRQs unrouted, etc.).
- Access to the PC Card controller index and data registers can be disabled (ports 3E0h and 3E1h respectively).

The PC Card controller starts off with both the individual features and the access to the index and data registers being disabled. To gain access to the registers used to turn on individual features, the PC Card controller index and data ports must be made accessible by enabling their corresponding internal address decode by setting CSC index D0h[1].

Note: *Subsequently turning off the index/data port address decode by clearing CSC index D0h[1] does not disable any PC Card controller features (windows, etc.) that have already been turned on. To completely disable the PC Card controller, all features must be turned off individually, and then CSC index D0h[1] must be cleared.*

When the PC Card controller is disabled, all of the CPU I/O accesses to the PC Card controller indexed registers (i.e., ports 03E0h and 03E1h) are driven to the ÉlanSC400 microcontroller's ISA or VL-bus. When the PC Card controller is enabled, all writes to Port 03E0h go to both the internal PC Card controller's index register *and* to the ISA or VL-bus. This is done to support the possibility of having a second 82365-compatible PC Card controller external to the ÉlanSC400 microcontroller to support two additional PC Card sockets C and D. Reads from Port 03E0h come from the internal PC Card index register only and are not seen on external buses. The destination for I/O reads or writes to the PC Card controller data port (03E1h) depends upon the data that was last written to Port 03E0h. If the last data written to Port 03E0h was 80–FFh, then subsequent Port 03E1h accesses will go to the external ISA or VL-bus only. This will remain the case until new data that is between 00–7Fh is written to Port 03E0h, at which time all subsequent accesses to Port 03E1h will go to the internal PC Card controller only.

Immediately following power-on reset, the PC Card controller defaults to Standard mode, which supports only one fully 82365-compatible PC Card socket (or two sub-82365 sockets that must share six memory windows instead of the normal ten windows), no PC Card controller DMA capability, and standard ISA timings only. In Standard mode, four of the memory windows (windows 1–4) that normally belong to Socket B are unavailable because they are redefined to be general-purpose MMS. See Section 19.5.5.1 for more information on these MMS windows. See Section 19.5.5 for more information on Standard mode. The PC Card controller can be configured for Enhanced mode by setting CSC index F1h[0]. Enhanced mode supports all ten 82365-compliant memory windows and PC Card controller DMA, and is discussed in Section 19.5.6 and Section 19.5.7. Other than the memory window, DMA, and timing features just described, there are no other differences between the Standard and Enhanced modes.

19.6.1 Identification and Revision Register

The Identification and Revision Register for each socket has two different modes for read-back: In one, the 82365SL-(Rev.B)-compatible value of 82h is read back. In the other, the ÉlanSC400 microcontroller-specific value of 0Fxh is read back. (The actual value depends on the specific version of the ÉlanSC400 microcontroller.) This allows the PC Card controller to both identify itself as 82365SL (Rev.B)-compatible and identify the ÉlanSC400 microcontroller-specific features that are available.

The default read value is 82h. In order to read the ÉlanSC400 microcontroller-specific value, these steps must be followed:

1. The Identification and Revision Register index value (00h for Socket A, 40h for Socket B) must be written to the PC Card controller index register at 03E0h.
2. The PC Card controller data register at 03E1h must be written. This write goes to the Identification and Revision Register, which is read-only in the 82365SL (Rev.B). For this reason, the ÉlanSC400 microcontroller's PC Card controller ignores the data written and records only the fact that the write occurred.

3. The PC Card controller data register at 03E1h must be read immediately after step 2.
4. If any other reads or writes occur between steps 2 and 3, the mechanism is broken and the 82365SL (Rev.B)-compatible value of 82h is read back. Thus, these steps must be surrounded with STI/CLI CPU instructions to avoid an interrupt-handling routine from disarming the PC Card controller stepping-level read-back circuit.

19.7 POWER MANAGEMENT

The PC Card controller core manages its own power by gating its clock.The clock is enabled only when the following conditions are true:

- A PC Card cycle has been started.
- Any CPU cache line write-back (due to PC Card-initiated DMA) has completed.

The PC Card controller can operate at up to 33 MHz. During power-saving modes, the clock to the controller can be dropped down as low as DC. Because PC Card cycles are measured in terms of the number of clock cycles, slowing down the clock to the controller slows down PC Card cycles, because the number of clocks counted per cycle remains constant.

Operation of the PC Card controller is affected by the power-management functions shown in Table 19-19.

Table 19-19 Power Management in the PC Card Controller

PC Card Controller Event	Description	Power Management Effect			
		Wake-Up	Activity	SMI	NMI
PC Card Ring Indicate signal	Triggered by a falling edge on the signal when the PC Card controller is programmed (PC Card index 03h or 43h) for a ring indicate signal. The PC Card controller uses the BVD1_x pins for ring indicate signals.	Yes	Programmable	Yes	Yes
PC Card Detect signals	Triggered by either PC Card Detect signal rising or falling edge	Yes		Yes	Yes
PC Card IRQ signals	Triggered by either PC Card Interrupt Request signal rising edge (only active if the IRQ is enabled in the interrupt controller)	Yes			
PC Card Status Change IRQs	Triggered by either PC Card Status Change Interrupt Request signal rising edge (only active if the IRQ is enabled in the interrupt controller)	Yes			
CPU access to PC Card Socket A and B memory	Triggered by falling edge of address decode qualified with command		Programmable		
CPU access to PC Card Socket A and B I/O	Triggered by falling edge of address decode qualified with command		Programmable		
PC Card INTR signal	Triggered by falling edge		Programmable	Yes	Yes
PC Card Socket A and B I/O access	Can cause an SMI/NMI through an I/O trap; the actual address range is programmed in the PC Card controller			Yes	Yes

CHAPTER

20 GRAPHICS CONTROLLER (ÉlanSC400 MICROCONTROLLER ONLY)

20.1 OVERVIEW

The graphics controller included on the ÉlanSC400 microcontroller offers a low-cost integrated graphics solution for the mobile terminal market. Integration with the main processor and system logic affords the advantages of an integrated local-bus interface and frame and font buffers which are shared with main memory. The graphics controller is not supported on the ÉlanSC410 microcontroller.

The graphics controller includes the following features:

- Supports multiple panel resolutions
- Provides internal unified memory architecture (UMA) with optional write-through caching of graphics buffers
- Stores frame and font buffer data in system DRAM, eliminates extra memory chip
- Provides software compatibility with Color Graphics Adapter (CGA), Monochrome Display Adapter (MDA), and Hercules Graphics Adapter (HGA) text and graphics
- Supports single-scan or dual-scan monochrome LCD panels with 4- or 8-bit data interface
- Typical panels supported include:
  - — 640x200, 640x240, 640x480, 480x320, 480x240, 480x128, 320x200, 320x240
  - — Other resolutions may be supported
- Supports single-scan color SuperTwisted Nematic (STN) panels with 8-bit interface, same resolutions as monochrome mode
- Internal local-bus interface provides high performance
- Logical screen may be larger than physical window.
- Supports panning and scrolling
- Supports horizontal dot doubling and vertical line doubling

The following MDA/CGA-compatible text mode features are supported:

- 40, 64, or 80 columns with characters 16, 10, or 8 pixels wide
- Variable height characters up to 32 lines
- Variable width characters—8, 10, or 16 pixels
- MDA Monochrome, or CGA 4 gray shades, 16 gray shades, or 16 colors
- 16-Kbyte downloadable font area, relocatable on 16-Kbyte boundaries within lower 16 Mbytes of system DRAM (may be write protected)
- 16-Kbyte graphics frame buffer (MMS Window), relocatable on either 16-Kbyte boundaries within lower 16 Mbytes of system DRAM (CGA-compatible mode) or 32-Kbyte boundaries when the frame buffer is larger than 16 Kbytes (flat-mapped mode)

The following graphics mode features are supported:

- 640x200 1 bit-per-pixel, CGA-compatible graphics buffer memory map
- 320x200 2 bits-per-pixel, CGA-compatible graphics buffer memory map
- 640x480 2 bits-per-pixel, flat memory map (lower resolutions supported)
- 640x480 1 bit-per-pixel, flat memory map
- 1, 2, or 4 bits-per-pixel packed-pixel flat-mapped graphics up to 640x240/480x320 with two mapping modes:
  - — 16-Kbyte window with bank swapping to address up to 64 Kbytes of graphics frame buffer while consuming only 16 Kbytes of DOS/Real-mode CPU address space
  - — Direct-mapped (no bank swapping) with locatable base address, up to 128-Kbyte direct addressability
- Hercules Graphics mode emulation (HGA)

20.2 REGISTERS

Graphics controller registers are indexed using I/O ports 03D4h (index) and 03D5h (data) for Color Graphics Adapter (CGA) mode and I/O ports 03B4h (index) and 03B5h (data) for Monochrome Display Adapter (MDA) mode. Different ports are used, depending on the graphics mode selected. The mode is selected using bit 0 of the Internal Graphics Control Register A (CSC index DDh).

- When MDA mode is selected, the MDA index and data registers are located at ports 03B4h and 03B5h, respectively, in the I/O address space.
- When CGA mode is selected, the CGA index and data registers are located at ports 03D4h and 03D5h, respectively, in the I/O address space.

The graphics controller indexed registers are accessed using a two-step process:

- An I/O write to the I/O address port for the chosen mode is performed. The data written is the index of the requested graphics controller register.
- This I/O write is followed by an I/O read or write to the data port for the chosen mode. This access causes the graphics controller to allow access to the addressed configuration register.

A summary listing of the direct-mapped, chip setup and control (CSC) index, and graphics index registers used to control the LCD graphics controller is shown in Table 20-1. Complete register descriptions can be found in the *Élan™ SC400 Microcontroller Register Set Reference Manual* (order #21032).

Table 20-1 Graphics Controller Register Summary

Register	I/O Address	Graphics Controller Function Keyword	Description in Register Set Manual
Direct-Mapped Registers			
CGA/MDA Index Registers	03B4h, 03D4h	Graphics controller indexed register to read or write for MDA/HGA or CGA modes	page 2-130, page 2-135
CGA/MDA Data Ports	03B5h, 03D5h	Data to be written to register selected in 3x4h for MDA/HGA or CGA modes	page 2-131, page 2-136

Table 20-1 Graphics Controller Register Summary (continued)

Register	I/O Address	Graphics Controller Function Keyword	Description in Register Set Manual
MDA/HGA Mode Control Register	03B8h	Text blink control, video blanking, HGA graphics enable, MDA/HGA select, HGA page select	page 2-132
MDA/HGA Status Register	03BAh	Vertical retrace status (simulated vertical sync), display-memory access status (simulated horizontal sync)	page 2-133
HGA Configuration Register	03BFh	Allow HGA page select, HGA text or graphics enable	page 2-134
CGA Mode Control Register	03D8h	Text attribute, CGA graphics control, video blanking, color burst select, text or graphics, CGA column select	page 2-137
CGA Status Register	03DAh	Vertical retrace status (simulated vertical sync), display-memory access status (simulated horizontal sync), light pen switch, light pen status	page 2-139
CGA Color Select Register	03D9h	Alternate palette, alternate background; intense, red, green, or blue border/background	page 2-138
Chip Setup and Control (CSC) Index Registers			
DRAM Control Register	22h/23h Index 04h	$\overline{\text{CAS}}$ pulse width for graphics controller reads	page 3-14
Cache and VL Miscellaneous Register	22h/23h Index 14h	Write-through caching of graphics memory	page 3-23
PMU Force Mode Register	22h/23h Index 40h	Standby mode graphics enable	page 3-51
Activity Source Enable Register A	22h/23h Index 62h	Activity source enable: CPU access to internal graphics I/O and internal graphics memory	page 3-71
Activity Source Status Register A	22h/23h Index 66h	Activity source status: CPU access to internal graphics I/O and internal graphics memory	page 3-75
Activity Classification Register A	22h/23h Index 6Ah	Primary or secondary activity classification: CPU access to internal graphics I/O and internal graphics memory	page 3-79
CLK_IO Pin Output Clock Select Register	22h/23h Index 83h	Route internal graphics dot clock to external CLK_IO pin	page 3-91
I/O Access SMI Enable Register A	22h/23h Index 99h	SMI on I/O access to internal graphics controller	page 3-105
I/O Access SMI Enable Register B	22h/23h Index 9Ah	SMI on I/O access to external VGA graphics controller	page 3-106
I/O Access SMI Status Register A	22h/23h Index 9Bh	SMI status of I/O access to internal graphics controller	page 3-107
I/O Access SMI Status Register B	22h/23h Index 9Ch	SMI status of I/O access to external VGA graphics controller	page 3-108

Table 20-1 Graphics Controller Register Summary (continued)

Register	I/O Address	Graphics Controller Function Keyword	Description in Register Set Manual
Internal Graphics Control Register A	22h/23h Index DDh	Graphics controller enable, CGA/MDA mode, compatibility mode, linear flat-mapped graphics mode, panel type, drive width, horizontal dot doubling, and vertical line doubling	page 3-179
Internal Graphics Control Register B	22h/23h Index DEh	Non-display data value, blanked data value, text mode data polarity, graphic modes data polarity, pixel depth for linear flat-mapped modes, lockout for CSC registers at 3x4h/ 3x5h, underline attribute	page 3-180
Graphics Index Registers: Legacy (CGA/MDA) Registers			
Cursor Start Register	3x4h/3x5h Index 0Ah	Alphanumeric cursor start line, blinking control	page 5-6
Cursor End Register	3x4h/3x5h Index 0Bh	Last line of alphanumeric cursor	page 5-7
Start Address High Register	3x4h/3x5h Index 0Ch	High-order start address bits: first data to be displayed at top of screen	page 5-8
Start Address Low Register	3x4h/3x5h Index 0Dh	Low-order start address bits: first data to be displayed at top of screen	page 5-9
Cursor Address High Register	3x4h/3x5h Index 0Eh	High-order cursor address bits: alphanumeric cursor location	page 5-10
Cursor Address Low Register	3x4h/3x5h Index 0Fh	Low-order cursor address bits: alphanumeric cursor location	page 5-11
Light Pen High Register (Read Only)	3x4h/3x5h Index 10h	Value of Cursor Address High Register for CGA compatibility	page 5-12
Light Pen Low Register (Read Only)	3x4h/3x5h Index 11h	Value of Cursor Address Low Register for CGA compatibility	page 5-13
Graphics Index Registers: Extended Features			
Horizontal Total Register	3x4h/3x5h Index 30h	Total number of characters in a horizontal line, slowing the frame rate	page 5-14
Horizontal Display End Register	3x4h/3x5h Index 31h	Number of the last character position in a line output from the frame buffer	page 5-15
Horizontal Line Pulse Start Register	3X4/3X5 Index 32h	Horizontal line pulse start, horizontal line pulse width, timing requirements	page 5-16
Horizontal Border End Register	3x4h/3x5h Index 33h	Last character position to be displayed at the end of a line	page 5-17
Non-display Lines Register	3x4h/3x5h Index 34h	Non-display lines to be added to the bottom of the vertical display sequence after vertical adjust rolls over	page 5-18
Vertical Adjust Register	3x4h/3x5h Index 35h	Vertical adjust, excess lines	page 5-19

Table 20-1 Graphics Controller Register Summary (continued)

Register	I/O Address	Graphics Controller Function Keyword	Description in Register Set Manual
Overflow Register	3x4h/3x5h Index 36h	Vertical synch mode, eighth bits of the Vertical Display Enable End Register and Vertical Border End Register	page 5-20
Vertical Display End Register	3x4h/3x5h Index 37h	Number of the last character line to be output from the frame buffer at the bottom of the screen	page 5-21
Vertical Border End Register	3x4h/3x5h Index 38h	Last character line to be output to the panel at the bottom of the display	page 5-22
Frame Sync Delay Register	3x4h/3x5h Index 39h	Number of character clocks to delay frame sync from beginning of horizontal line pulse	page 5-23
Dual Scan Row Adjust Register	3x4h/3x5h Index 3Bh	Dual scan mode, character row overlap	page 5-24
Dual Scan Offset Address High Register	3x4h/3x5h Index 3Ch	Dual scan mode, high byte of offset address between lower and upper screens	page 5-25
Dual Scan Offset Address Low Register	3x4h/3x5h Index 3Dh	Dual scan mode, low byte of offset address between lower and upper screens	page 5-26
Offset Register	3x4h/3x5h Index 3Eh	Frame buffer width	page 5-27
Underline Location Register	3x4h/3x5h Index 3Fh	Scan line number of the underline attribute used in MDA modes	page 5-28
Maximum Scan Line Register	3x4h/3x5h Index 40h	Number of lines in a character row of identically addressed horizontal lines minus one	page 5-29
LCD Panel AC Modulation Clock Control Register	3x4h/3x5h Index 41h	Horizontal line divide ratio, modulation mode	page 5-30
Font Table Register	3x4h/3x5h Index 42h	Offset font plane, character width, and font table write-protection	page 5-31
Graphics Controller Grayscale Mode Register	3x4h/3x5h Index 43h	Grayscale functions: remapping, mapping mode, shade mode, contrast enhancement, color STN, and color border	page 5-32
Graphics Controller Grayscale Remapping Registers	3x4h/3x5h Index 44–4Bh	Grayscale remapping registers for corresponding input grayscale code	page 5-34
Pixel Clock Control Register	3x4h/3x5h Index 4Ch	Graphics dot clock base frequency and divide select	page 5-36
Frame Buffer Base Address Register	3x4h/3x5h Index 4Dh	Frame buffer window base address high byte	page 5-37
Font Buffer Base Address High Byte	3x4h/3x5h Index 4Eh	Font buffer window base address high byte	page 5-38
Frame/Font Buffer Base Address Register Low	3x4h/3x5h Index 4Fh	Frame and font buffers window base address low bytes, Graphics Frame Buffer MMS window enable, MMS page select, allocate DRAM	page 5-39

Table 20-1 Graphics Controller Register Summary (continued)

Register	I/O Address	Graphics Controller Function Keyword	Description in Register Set Manual
PMU Control Register 1	3x4h/3x5h Index 50h	Power-up power sequencing delays, PMU power control enable, and software power-up and power-down	page 5-40
PMU Control Register 2	3x4h/3x5h Index 51h	Power-up power sequencing delays	page 5-41
Extended Feature Control Register	3x4h/3x5h Index 52h	Extended feature control: RGBI output, CGA legacy I/O trap SMI/NMI generation enable, inter-frame FIFO flush/refill delay, cursor blink rate, HGA register extensions, HGA read-back, page memory enable, hidden flush	page 5-42

20.3 BLOCK DIAGRAM

Figure 20-1 shows a block diagram of the LCD graphics controller. Because the VL-bus and the graphics controller share control signals, use of the internal graphics controller is traded with having an external VL-bus. If either 32-bit DRAMs, 32-bit ROMs, or the VL-bus is enabled, the internal graphics controller is unavailable.

20.4 OPERATION

The LCD graphics controller on the ÉlanSC400 microcontroller supports the following modes of operation:

- CGA graphics modes
- HGA graphics modes
- CGA/MDA text modes—80, 64, and 40 column
- Flat-mapped graphics modes—Support flat linear maps of 1, 2, or 4 bits-per-pixel (BPP) up to resolutions of 480x320 or 640x240 and 640x480 at 1 or 2 BPP

20.4.1 Using the Graphics Controller

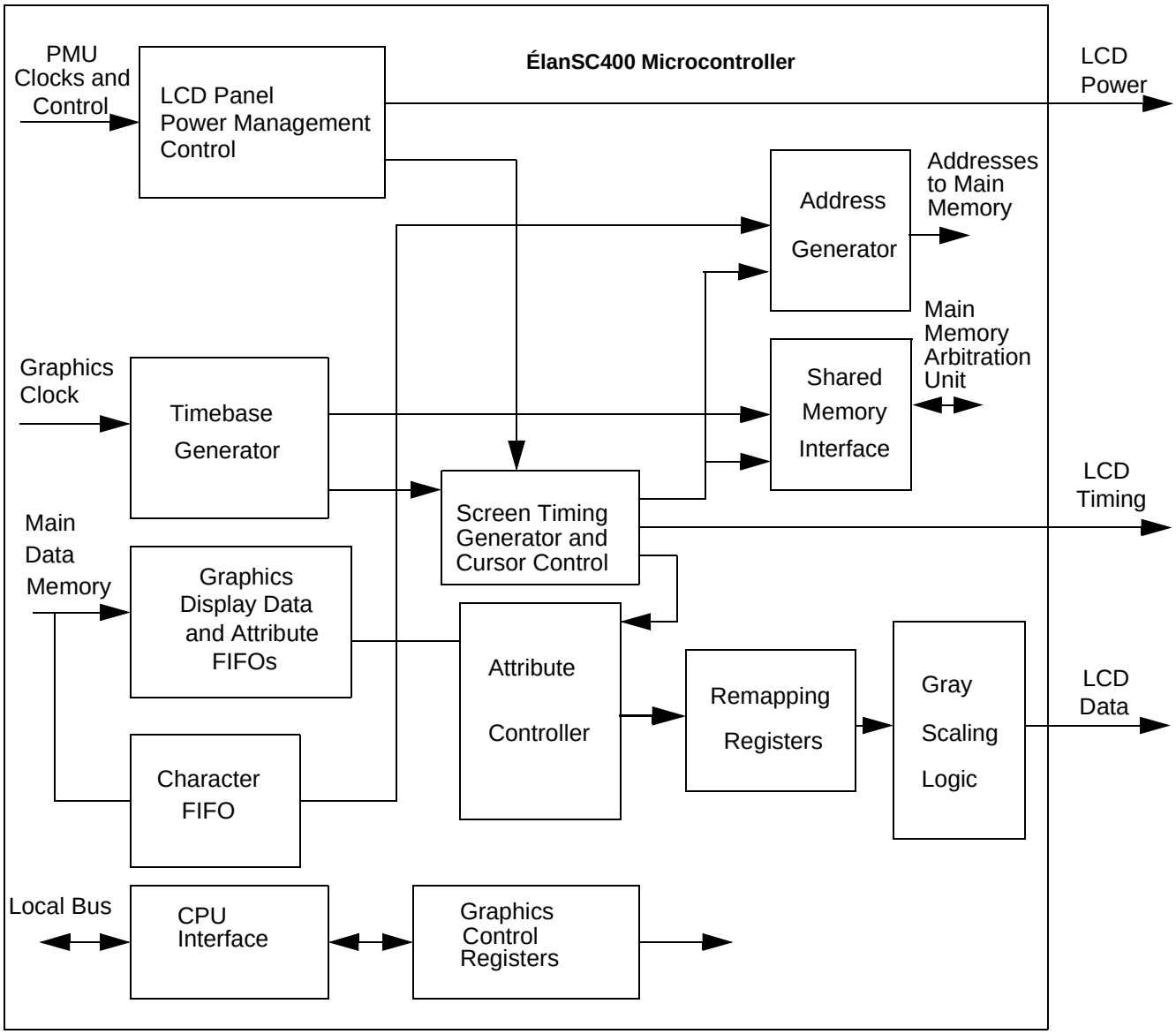
The graphics controller provides the necessary control registers, register and memory decodes, bus interface logic, data path steering, and interrupt generation to support LCD panel operation. The entire graphics I/O space can be deactivated and become invisible to the CPU.

20.4.1.1 Interrupts and I/O Trapping

An interrupt source and a PMU activity event source are provided. The interrupt source is triggered by writes to the 6845-compatible cursor address registers at graphics index 0Eh and 0Fh. The interrupt source can be used to keep track of the cursor location independent of application software when the physical display screen is smaller than the frame buffer. The PMU activity event is triggered by any read or write to the active graphics frame buffer.

I/O trapping via SMI/NMI is supported for all of the I/O registers and may be selectively disabled for certain frequently-used registers that are CGA-compatible.

Figure 20-1 Graphics Controller Block Diagram



20.4.1.2 Clock Control

The master pixel clock is generated from a dedicated PLL with user-programmable frequency (graphics index 4Ch). All other primary clocks and strobes used in the system are derived from the master pixel clock.These include the character clock, which drives the screen controller, the graphics dot (or pixel shifter) clock, and the strobes used for loading data into the shift registers and reading data from the internal FIFO.

20.4.1.3 Screen Timing Generation and Cursor Control

Screen timing generation is based on a hybrid implementation of the 6845 and VGA CRT control registers. Start address generation and text mode cursor control follows the CGA/MDA standard. An offset register similar to the standard VGA offset register is also included. The offset register supports a virtual screen (i.e., a small physical screen that windows into a larger “virtual” screen). Scrolling and character panning are available using the start address registers.

The following additional features are included:

- AC modulation control—Selectable to either one toggle (phase change) per frame or up to 128 horizontal lines per toggle
- Frame and line pulse timing control—Allows the graphics controller to have compatible timing with a large number of different LCD panels
- Vertical and horizontal border registers—Allow unused areas of the display panel to be blanked, if necessary
- Dual-scan screen setup registers—Allows for setup of dual-scan screens in text or graphics modes
- Optional SMI/NMI trapping—Allows for CGA mode-set register compatibility

20.4.1.4 Internal Unified Memory Architecture

Unlike older graphics controller architectures where a separate memory device was used to support the graphics controller frame and font buffers, the ÉlanSC400 microcontroller's graphics controller uses a portion of main system DRAM for these buffers to lower system cost. This technique is known as Unified Memory Architecture (UMA).

With UMA, the system cost is lowered, power consumption is reduced, board space is saved, and external design is simplified. On the other hand, the graphics controller must constantly access the main system DRAM to refresh the LCD. Because delays in providing data to the LCD refresh would result in visual artifacts present on the LCD screen, the graphics controller is given very high priority over other types of DRAM accesses. Because the amount of data that needs to be transferred from system DRAM to the graphics controller to support screen refresh is proportional to the display resolution as well as the *color depth* of each pixel (number of bits of data required to form each pixel), system performance can decrease as LCD panel resolution and color depth increase.

20.4.2 Graphics Buffers

The ÉlanSC400 microcontroller's graphics controller can maintain two buffers in UMA DRAM: the frame buffer (also known as the Graphics Frame Buffer MMS Window) and the font buffer. The frame buffer has meaning in either text or graphics modes, whereas the font buffer is only supported in text mode. The frame buffer is illustrated in Figure 20-2.

20.4.2.1 Using the Frame Buffer in Text Mode

In text mode, software writes two types of data to the frame buffer. These are the ASCII code of the character to be displayed and an attribute byte that modifies display characteristics of the ASCII character (color, intensity, or blinking). Thus, two bytes are written into the frame buffer for each text mode character displayed.

For example, a standard CGA 80x25 text display uses 80 x 25 x 2 = 4000 bytes for each screen that is displayed. Because the ÉlanSC400 microcontroller's text mode frame buffer is fixed at 16 Kbytes, data for up to four different text mode screens (with a few unused bytes left over per screen) can be stored in the font buffer at any time.

The Start Address High and Low registers (graphics index 0Ch and 0Dh) are used to specify where in the frame buffer the text data for the upper left corner of the display should be fetched. Using these two registers, it is possible to quickly select which portion of the text frame buffer is displayed at any time. The format of the text mode frame buffer is discussed in Section 20.4.5.1.1.

20.4.2.2 Using the Frame Buffer in Graphics Mode

In graphics mode, software writes data into the frame buffer in order to display individual pixels. The ÉlanSC400 microcontroller's graphics controller can be configured to use either 1, 2, or 4 bits of the frame buffer data to form each pixel displayed.

With 1 bit-per-pixel, a pixel can have only 2 states: on or off. In this mode, an *off* pixel can not be seen on the display, and an *on* pixel is displayed at full contrast giving a dark appearance on a monochrome LCD.

Adding to the pixel depth (configuring the graphics controller for 2 or 4 BPP) allows gray shades to be displayed.

20.4.2.3 Graphics Mode Memory Maps

There are three types of memory maps available in graphics mode on the ÉlanSC400 microcontroller: CGA compatible, linear or flat-mapped, and paged.

20.4.2.3.1 CGA-Compatible Mode

The CGA-compatible memory map is provided for software compatibility with applications that use the CGA memory map. For performance reasons on early PCs, the 16-Kbyte CGA graphics frame buffer is split into two address ranges. The first 8 Kbytes control even-numbered scan lines on the LCD display, and the second 8 Kbytes control odd numbered scan lines. Two pixel depths are available for the CGA-compatible graphics mode: 1 BPP or 2 BPP, which correspond to the legacy CGA resolutions of 640x200 or 320x200 that are supported by the ÉlanSC400 microcontroller's LCD controller. When the graphics controller is put into CGA-compatible mode, the frame buffer is fixed at 16 Kbytes in size.

20.4.2.3.2 Flat-Mapped Mode

The flat-mapped mode (often referred to as *linear packed-pixel mode* due to the lack of CGA's split addressing) takes advantage of modern graphics hardware performance capabilities to get rid of the split memory map. The flat-mapped mode can be considered the native graphics mode of the ÉlanSC400 microcontroller and should be used for all new graphics driver development. It supports 1, 2, or 4 BPP operation using a memory map for pixel data that is more intuitive for software writers, and also provides higher performance for some graphics operations.

The flat-mapped mode frame buffer size is based upon the pixel color depth: 64 Kbyte for 1 BPP mode and 128 Kbytes for 2 and 4 BPP modes. As in text mode, multiple graphics screens can be stored in the graphics frame buffer; the number is limited only by the number of screens that can fit in a 64-Kbyte (1 BPP) or 128-Kbyte (2–4 BPP) frame buffer. For example, if the LCD resolution is small, then each screen will take up less graphics frame buffer space, so more screens can be stored at once.

To determine the number of screens that can be stored for a particular resolution and pixel color depth, multiply the LCD pixels in the "X" dimension by those in the "Y" dimension, and multiply by the color depth (number of BPP). Divide the result by eight to get the number of bytes required to store a single screen's worth of data, then divide 64 Kbytes or 128 Kbytes (based on selection of 1 BPP or 2–4 BPP as explained earlier) to get the number of screens that will fit into the graphics frame buffer.

Regardless of whether graphics or text mode is being used, the frame buffer base address must be configured at system boot time. The memory maps described above are then relative to the frame buffer base address. This programming is done via the Frame Buffer Base Address Register and the Frame/Font Buffer Base Address Register Low (graphics index 4Dh and 4Fh). The frame buffer base address for any of the above modes can be set to any 16-Kbyte boundary within the lowest 16 Mbytes of system DRAM when the frame

buffer is 16 Kbytes and to any 32-Kbyte boundary within the lowest 16 Mbytes of system DRAM when the frame buffer is larger than 16 Kbytes.

20.4.2.3.3 Paged Mode

The paged mapping mode is provided for use when CPU address space is limited, such as in a Real-mode-only system. When paged mode is enabled, a 64-Kbyte frame buffer is available and can be located above 1 Mbyte using the frame buffer base address registers mentioned earlier. This mode differs from other modes in that the software that is updating the 64-Kbyte graphics-only (text mode not supported) frame buffer will not access it directly (i.e., at the address programmed into the frame buffer base address), but rather via a special 16-Kbyte LDC graphics window that becomes available at 00B8000h in the CPU address space when paged mode is enabled. Although the CPU can only access 16 Kbytes of the 64-Kbyte buffer at a time, the graphics controller can access the entire 64 Kbytes at all times, so that the frame buffer data can be used to constantly refresh the LCD screen.

20.4.2.4 Font Buffer

The font buffer is used only in text mode and does not exist in any graphics mode. The font buffer can be made to reside anywhere below 16 Mbytes in system DRAM on a 16-Kbyte boundary. The font buffer is used to hold pixel data that is used to form the ASCII characters available in text mode. A piece of graphics hardware known as the character generator uses the ASCII codes stored in even addresses of the text frame buffer to look up the associated ASCII character bitmap data in the font buffer, and then display it to the screen.

The font buffer is fixed at 16 Kbytes in size, and can hold character bitmap data for characters up to 32 pixels in height, and of 8, 10, or 16 pixel in width. There are 256 ASCII characters that must be supported by each set of text character fonts (character bitmap is referred to as a font).

It is possible to store more than one set of fonts at a time in the font buffer. The number of font sets that can be stored is based on the fixed 16-Kbyte font buffer size and the number of bytes required per font set. The number of bytes per font set is based on the size of the font (character cell). When the cell height (see the Maximum Scan Line Register at graphics index 40h) and width (see the Font Table Register at graphics index 42h) have been determined, one or more different font sets of identical size (again, based on the size of the character cell) can be stored in the font buffer. Then, any of the loaded font sets can be quickly selected for display by selecting a font offset between 0 and 31 via graphics index 42h. The font buffer format is detailed in Section 20.4.5.3.

20.4.2.5 Managing Graphics Memory

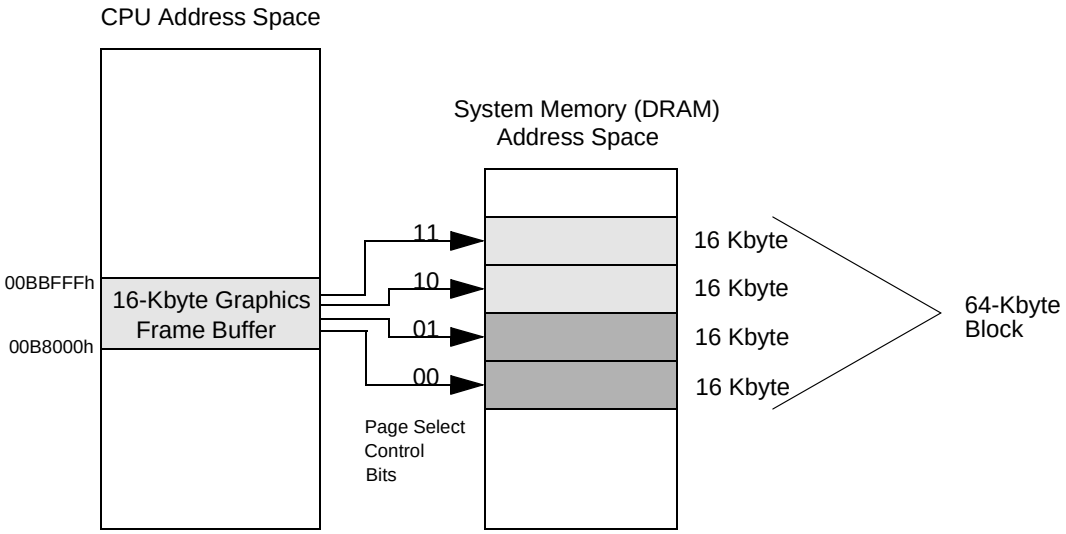
The following general guidelines apply:

- Graphics memory must be in system memory (DRAM) space. This means that the address must be lower than the top-of-DRAM value that is calculated by the DRAM controller when it is programmed.
- Graphics memory must not overlap with an MMS window, a PC Card window, or a region that has been enabled for linear ROM0 decode when shadowing has been enabled. (The possible shadow ROM areas are 00C0000–00FFFFFh.)
- Accesses in the range of 00B0000–00FFFFFh that coincide with a graphics frame or font buffer will be directed to DRAM. If the access is not in a graphics area (and not in ROM, shadow ROM, MMS, or PC Card areas), it will go to ISA. Note that there is an exception if the ISA window is put over the graphics region.
- Font memory has write-protect priority over the normal system memory write-protect window. If the programmer does not write-protect the font area and then puts a system

memory write-protect window in the same place as the font window, the font window will not be write-protected.

- Graphics hits are write-through cacheable by setting CSC index 14h[7]. An SMM save-state region cannot be put over a graphics area. Non-cached graphics hits have higher priority than linear ROM0 (shadowed, non-shadowed or boot) hits, which are higher than the non-cache window hits. When using the non-cache window, make sure the window is not in the range 00C0000–00FFFFFh, 3FF0000–3FFFFFFh, the SMM save-state region, or PC Card windows.

Figure 20-2 16-Kbyte Graphics Frame Buffer MMS Window Implementation



20.4.3 CGA Graphics Modes

In the CGA graphics modes (also called all-points-addressable or APA), graphics-memory bits directly represent display pixels. No indirect mapping to a font table is used. The use of either one or two bits-per-pixel defines the color depth of the image.

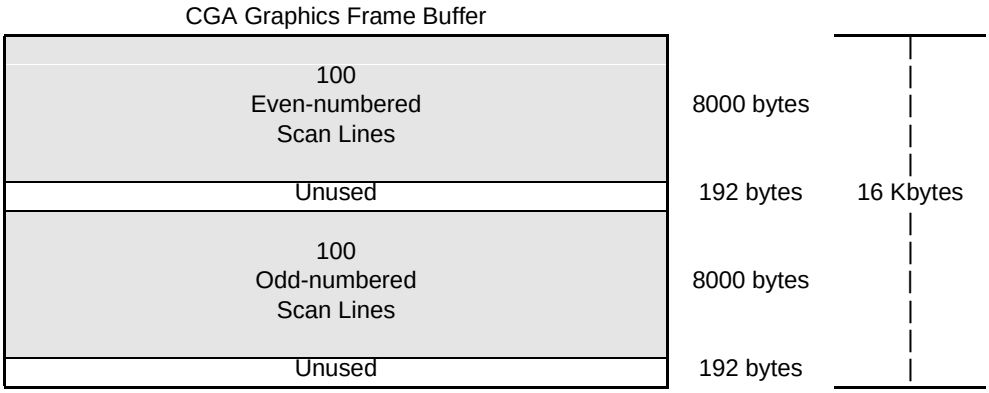
- The CGA graphics modes are enabled by setting bit 1 of the CGA Mode Control Register (Port 03D8h).
- Bit 4 of the CGA graphics mode register selects between 320x200 four-color mode or 640x200 two-color mode.
- The CGA Color Select Register (Port 03D9h) can be used to map colors in the CGA graphics modes.

20.4.3.1 CGA Graphics Pixel Formats

20.4.3.1.1 High-Resolution Mode

As discussed earlier, in the CGA high-resolution mode, each byte in memory contains information relating to eight pixels. The bytes are organized sequentially using the odd/even format described in Figure 20-3, resulting in a screen resolution of 640x200, with two colors mapped to each pixel.

Figure 20-3 CGA Graphics Mode Memory Map



The byte offset and bit offset of a given pixel in the display coordinates (origin located in the top left corner of the screen; y increases positively in the downward direction; x increases positively in the rightward direction) may be calculated from x- and y-coordinates as follows:

Byte offset = ((y%2)*8192) + ((y/2)*80) + (x/8)

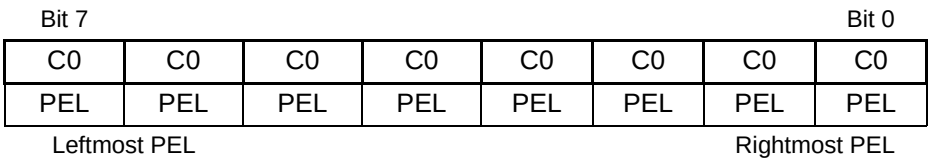
C0 Bit offset = 7 - (x%8)

where:

/ is integer division with truncation

% is the integer modulus (remainder) operator

Figure 20-4 Memory Byte Format (CGA High-Resolution Graphics)



20.4.3.1.2 Low-Resolution Mode

In the CGA low-resolution mode, each byte in memory contains information relating to four pixels. The bytes are organized sequentially using the odd/even format described in Figure 20-3, resulting in a screen resolution of 320x200, with four colors mapped to each pixel.

The byte offset and bit offset of a given pixel in the display coordinates (origin located in the top left corner of the screen; y increases positively in the downward direction; x increases positively in the rightward direction) may be calculated from x- and y-coordinates as follows:

Byte offset = ((y%2)*8192) + ((y/2)*80) + (x/4)

C1 Bit offset (msb) = 7 - (x%4)*2

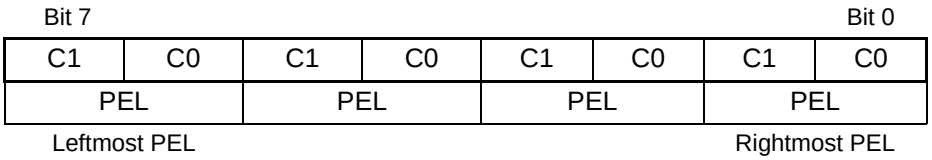
C0 Bit offset (lsb) = 6 - (x%4)*2

where:

/ is integer division with truncation

% is the integer modulus (remainder) operator

Figure 20-5 Memory Byte Format (CGA Low-Resolution Graphics)



20.4.3.2 CGA Graphics Color Processing

20.4.3.2.1 320x200 Mode

In CGA low-resolution mode, the C1 and C0 bits map to RGBI colors as shown in Table 20-2:

Table 20-2 Color Mapping in CGA Low-Resolution Mode

C1	C0	Red	Green	Blue	Intensity
0	0	Port 03D9h[2]	Port 03D9h[1]	Port 03D9h[0]	Port 03D9h[3]
0	1	0	1	Port 03D9h[5]	Port 03D9h[4]
1	0	1	0	Port 03D9h[5]	Port 03D9h[4]
1	1	1	1	Port 03D9h[5]	Port 03D9h[4]

20.4.3.2.2 640x200 Mode

In CGA high-resolution mode, the C0 bit maps to RGBI colors as shown in Table 20-3.

Table 20-3 Color Mapping in CGA High-Resolution Mode

C0	Red	Green	Blue	Intensity
0	0	0	0	0
1	Port 03D9h[2]	Port 03D9h[1]	Port 03D9h[0]	Port 03D9h[3]

20.4.4 HGA Graphics Modes

In the HGA graphics modes, memory is divided into four interleaved sections, a simple extension of the method used in CGA graphics mode. Only 1 bit-per-pixel is supported.

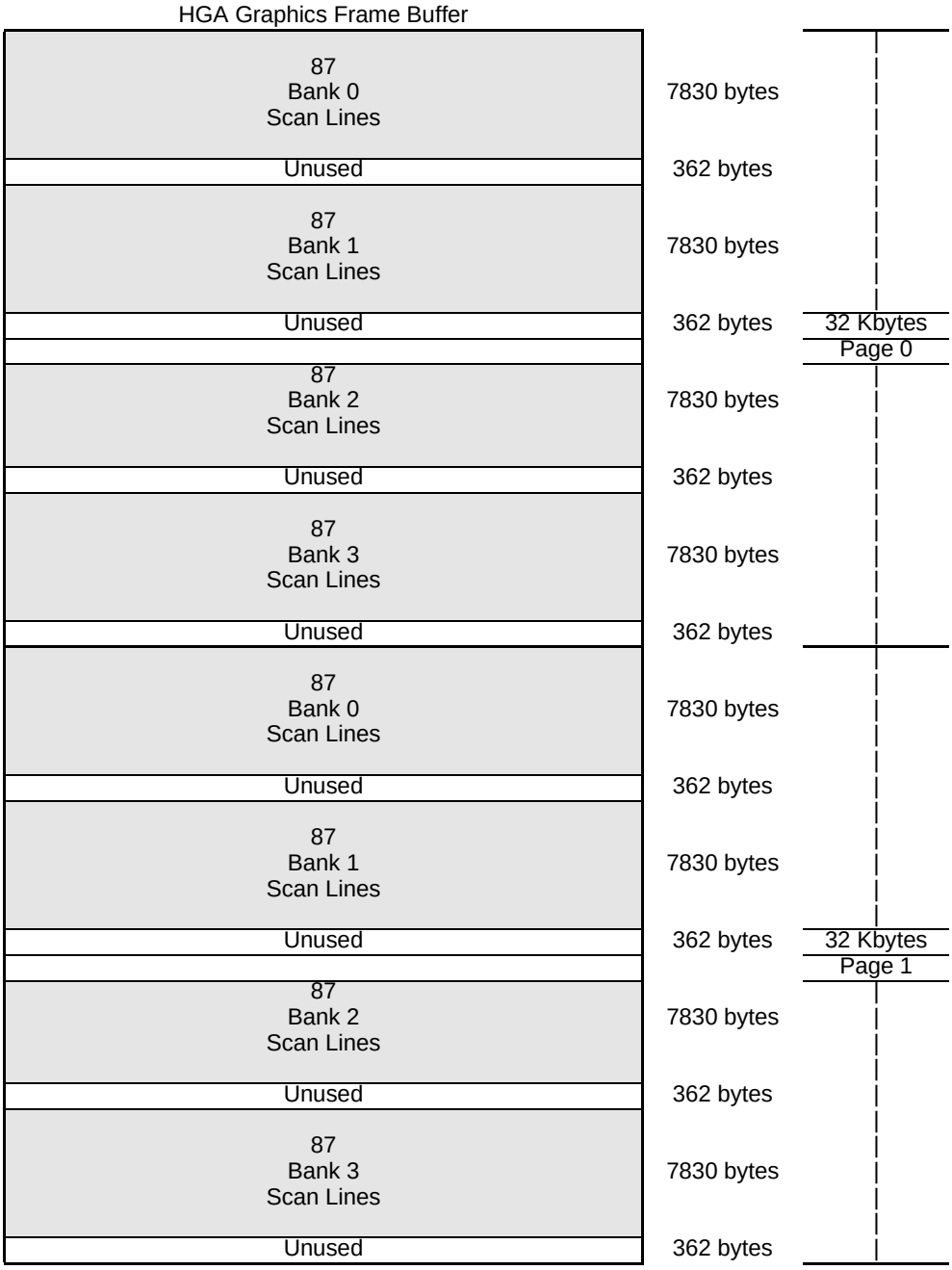
- The HGA graphics mode is enabled by setting bit 4 of the Extended Feature Control Register (graphics index 52h) to logic 1.
- Doing this makes the HGA mode register at Port 03B8h and the HGA Configuration register at Port 03BFh visible.

20.4.4.1 HGA Graphics Mode Memory Model

In the HGA graphics modes, display memory is divided into rows of four memory-interleaved scan lines. Figure 20-6 illustrates the HGA memory model. The standard HGA screen dimensions are 720 by 348.

- The top quarter of each page is allocated to the first scan line of each four-line set (lines 0,4,8...), the second quarter to the second scan line of each four-line set (lines 1,5,9...), etc.
- The character height is set to 4, with the lowest two row-scan line counter bits used to select the memory planes.
- In addition, HGA graphics mode optionally supports two 32-Kbyte pages with Port 03B8h, bit 7 being the page select bit.

Figure 20-6 HGA Graphics Mode Memory Map



20.4.4.2 HGA Graphics Pixel Formats

In the HGA graphics mode, each byte in memory contains information relating to eight pixels. The bytes are organized sequentially using the interleaved format described above, resulting in a screen resolution of 720x348, with two colors mapped to each pixel.

The byte offset and bit offset of a given pixel in the display coordinates (origin located in the top left corner of the screen; y increases positively in the downward direction; x increases positively in the rightward direction) may be calculated from x- and y-coordinates as follows:

Byte offset = ((y%4)*8192) + ((y/4)*90) + (x/8)

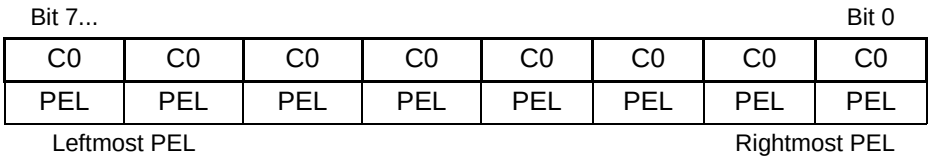
C0 Bit offset = 7 - (x%8)

where:

/ is integer division with truncation

% is the integer modulus (remainder) operator

Figure 20-7 Memory Byte Format



Following are the data formats for the HGA graphics mode. 16-level or 4-level grayscaling may be selected when using 1- or 2-BPP flat-mapped (linear packed-pixel) modes. *The grayscale palette (see Section 20.4.7.2.2) should be used for color mapping in the HGA graphics mode.*

Figure 20-8 16-Grayscale Palette Mapping (1 Pixel)

Red	Green	Blue	Intensity
0	0	0	PEL Bit C0

20.4.5 CGA/MDA Text Modes

20.4.5.1 Data Structures

The text modes support emulation of CGA or MDA text attributes and addressing. Standard registers 03D8h/03B8h, 03D9h/03B9h and 03DAh/03BAh are emulated in CGA/MDA modes. Cursor positioning and sizing are performed through the 6845-compatible cursor control registers. The cursor attributes can be programmed as either blinking at a 1 Hz rate or nonblinking, with full or half intensity. Character underlining is supported. The number of the row scan line used for character underlining is programmable at the Underline Location Register (graphics index 3Fh).

In the text modes, display characters are represented in memory as a two-byte data structure: the character byte followed by the attribute byte.

The graphics memory space is partitioned into a 16 Kbyte block of display data and an independent off-screen font area.

20.4.5.1.1 Display Data Memory Space

In the display-data portion of memory:

- Even addresses contain character bytes (the ASCII code for the character to be displayed at that screen location) that are used by the graphics controller to point to the correct font in memory to display that character (refer to Section 20.4.5.3 for more information on fonts).
- Odd addresses contain attribute bytes that allow attributes such as blinking, background/foreground colors, intensity, and underlining to be manipulated on individual characters.

Each even/odd combination of bytes represents one character on the screen. For example, in CGA text modes, memory address 00B8000h is the character byte for the upper left character on the display, 00B8001h is the attribute for that character; address 00B8002h is the character byte for the next character to the right, 00B8003h is its attribute, etc.

Table 20-4 illustrates the memory mapping for page 0 of the CGA 80x25 text mode. Note that one page (or one screen of information) takes up 4 Kbytes of memory and there are 16 Kbytes of memory available for display data. Therefore, memory will hold four pages (or screens) of data at one time. Selection between pages can be performed using graphics index 0Ch and 0Dh (the 6845-compatible Start Address High and Low registers). The 40x25 text mode (CGA only) functions in the same manner, except that eight pages are provided, because each page uses only 2 Kbytes of memory.

Table 20-4 Text Mode Memory Display Data (CGA 80x25)

Display Row 0 -	00B8000h	C.0	A.0	C.1	A.1	. . .	C.79	A.79	00B809Fh
Display Row 1 -	00B80A0h	C.80	A.80	C.81	A.81	. . .	C.159	A.159	00B813Fh
Display Row 2 -	00B8140h	C.160	A.160	C.161	A.161	. . .	C.239	A.239	00B81DFh
.	.	.	.	.	.	. . .	.	.	.
.	.	.	.	.	.	. . .	.	.	.
.	.	.	.	.	.	. . .	.	.	.
Display Row 24 -	00B8FA0h	C.1920	A.1920	C.1921	A.1921	. . .	C.1999	A.1999	00B8F9Fh
	00B8FA0h	Unused							00B8FFFh

Notes:

C is Character byte

A is Attribute byte

The CGA-compatible buffer base address of 00B8000h must be programmed at mode setup through the Shared Memory Address registers. This buffer may also be relocated to any other 16-Kbyte boundary in the lower 16 Mbyte of memory if CGA memory address compatibility is not necessary.

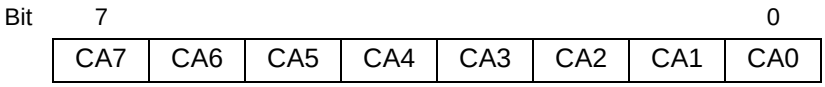
In MDA emulation mode, the screen pages begin at 00B0000h instead of 00B8000h. For compatibility, the Shared Memory Address registers must be programmed to the appropriate values at mode setup. Unlike the original IBM MDA mode, four pages of text are available instead of one.

20.4.5.1.2 Character Byte

The character byte can be any number from 00h to FFh to designate one of the 256 fonts stored in a font table in memory. For example, the ASCII code for the letter “A” is 41h, so, assuming the frame buffer base address has been set to 00B8000h, to display an “A” in

the upper left corner of the screen, one would write 41h into address 00B8000h. The character byte is used as by the graphics controller as a pointer to the appropriate font location in memory (see Section 20.4.5.3 for more information).

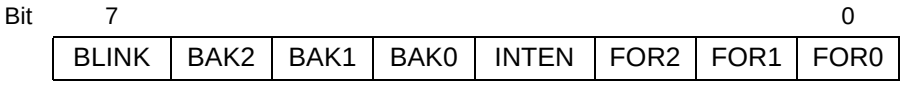
Figure 20-9 CGA/MDA Character



20.4.5.1.3 Attribute Byte

The attribute byte defines the qualities of a character as displayed on the screen, defining the character color, intensity, blinking, etc. The attribute byte is defined differently for CGA and MDA modes. Following are the byte definitions for CGA- and MDA-compatible attribute bytes:

Figure 20-10 CGA Attribute Byte



Bit	Name	R/W	Function
2–0	FOR0-2	R/W	Foreground color
3	INTEN	R/W	Intensity of character 0: Normal Intensity 1: High Intensity
6–4	BAK0-2	R/W	Background color
7	BLINK	R/W	Blinking if Port 03D8h bit 5 = 1. If Port 03D8h bit 5 = 0, then this is the background intensity bit: 0: Not Blinking 1: Blinking

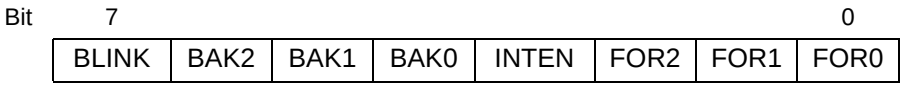
Table 20-5 CGA Attribute Byte: Foreground Color

FOR2	FOR1	FOR0	Color	
Red	Green	Blue	Intensity = 0	Intensity = 1
0	0	0	Black	Dark gray
0	0	1	Blue	Light Blue
0	1	0	Green	Light Green
0	1	1	Cyan	Light Cyan
1	0	0	Red	Light Red
1	0	1	Magenta	Light Magenta
1	1	0	Brown	Yellow
1	1	1	Light gray	White

Table 20-6 CGA Attribute Byte: Background Color

BAK2	BAK1	BAK0	Color	
Red	**Green**	**Blue**	**Port 03D8h[5] = 0 or Port 03D8h[5] = 1 and Blink = 0**	**Port 03D8h[5] = 1 and Blink = 1**
0	0	0	Black	Dark gray
0	0	1	Blue	Light Blue
0	1	0	Green	Light Green
0	1	1	Cyan	Light Cyan
1	0	0	Red	Light Red
1	0	1	Magenta	Light Magenta
1	1	0	Brown	Yellow
1	1	1	Light gray	White

Figure 20-11 MDA Attribute Byte

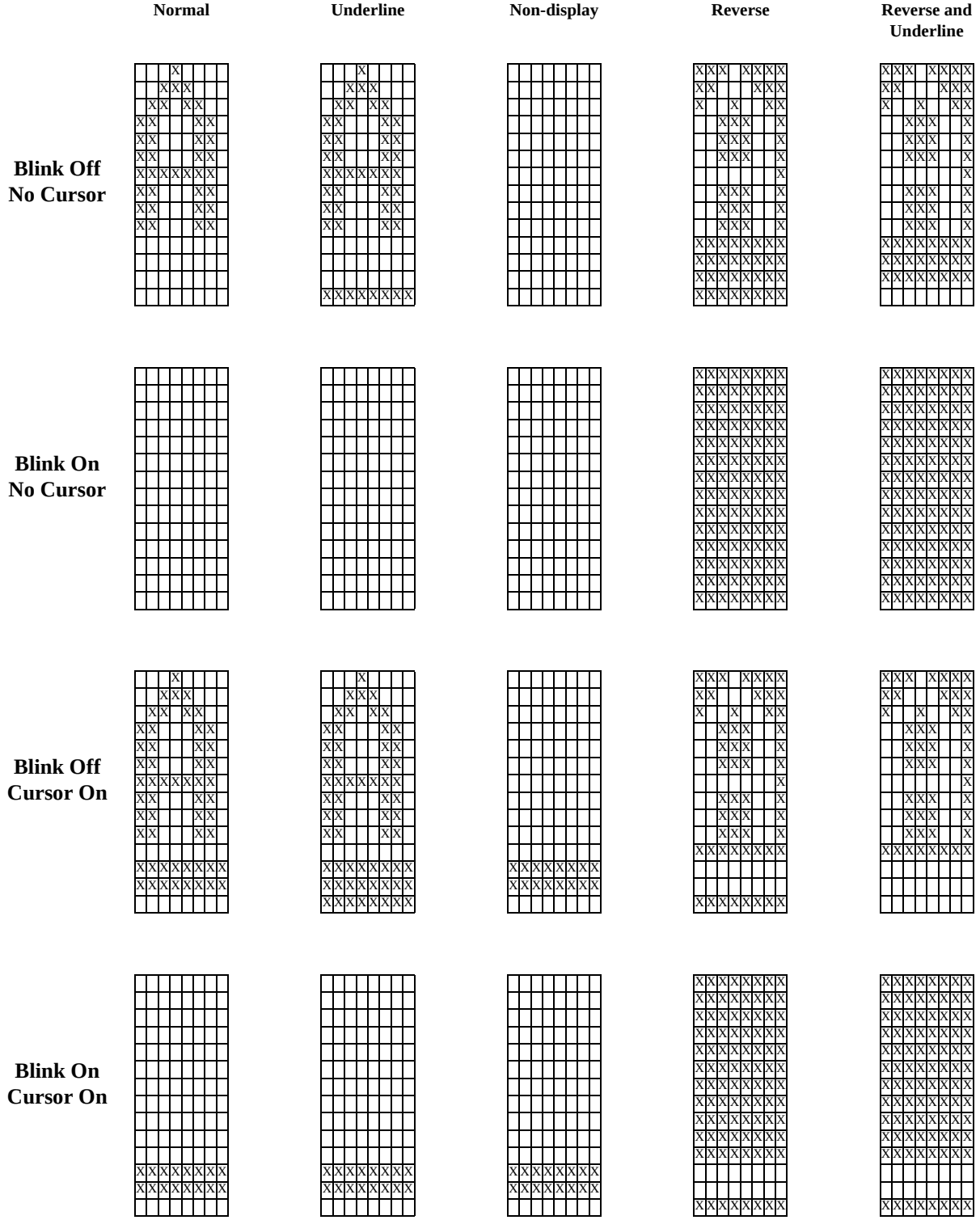


Bit	Name	R/W	Function
2–0	FOR2–0	R/W	Foreground definition
3	INTEN	R/W	Intensity of character 0: Normal Intensity 1: High Intensity
6–4	BAK2–0	R/W	Background definition
7	BLINK	R/W	Blinking (if Port 03B8h[5] is set to1) 0: Not Blinking 1: Blinking

BAK2	BAK1	BAK0	FOR2	FOR1	FOR0	Character Displayed As
0	0	0	0	0	0	Non-display
0	0	0	0	0	1	Underline
0	0	0	1	1	1	Normal display
1	1	1	0	0	0	Reverse video

Figure 20-12 illustrates the matrix of cursor and character attributes supported in MDA modes. For this example, the character “A” is displayed in an 8x14 character block. The Maximum Scan Line Register (graphics index 40h) is programmed to 0Eh, the Underline Location Register (graphics index 3Fh) is programmed to 0Eh, the Cursor Start Register (graphics index 0Ah) is programmed to 0Ch, and the Cursor End Register (graphics index 0Bh) is programmed to 0Dh. Note that underlining is only available in MDA mode. Alternating rows illustrate the appearance of the character when blink is on and off, and when the cursor is on and off.

Figure 20-12 Black-and-White Attributes Example for 8x14 Character Cell (MDA Mode Only)



20.4.5.2 Cursor Generation

The cursor position is set by use of the Cursor Address register pair to point to a character address within the currently displayed frame. If the address programmed in the Cursor Address registers is outside of the displayed area of memory, the cursor will not be visible on the screen.

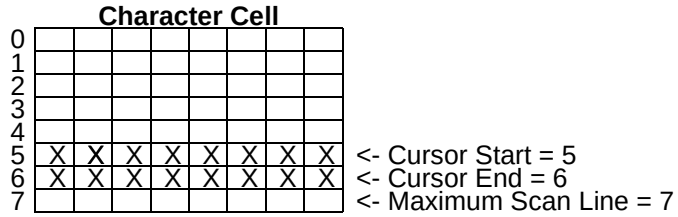
The shape of the cursor is determined by the setting of the Cursor Start and Cursor End registers. The Cursor Start Register defines the number of the first row line at which the cursor will be turned on. The Cursor End Register defines the last row line used for cursor display. The value of the Cursor Start and End registers must be less than or equal to the Maximum Scan Line Register, and the Cursor End Register must be greater than or equal to the Cursor Start Register for the cursor to be visible. The cursor causes the pixels underneath it to be turned on when it blinks on, or normal character data to be displayed when it blinks off. (i.e., it is added to the underlying pixel data.)

Cursor blinking may be programmed to one of four modes, defined by bits 6–5 in the Cursor Start Register (graphics index 0Ah). These modes are defined as in Table 20-7.

Table 20-7 Cursor Blinking

Bits 6–5	Function	Effect
0	Blinking	Cursor blinks at 1 Hz (2 Hz if graphics index 52h[3] is set to 1)
01	No-display	The cursor is not generated
10	Flashing	Cursor blinks at half of frame rate, which causes it to appear at half-intensity
11	Non-blink	The pixels of the cursor are always added to the pixels of the character

The following illustrates an example of programming the cursor setup registers for an 8x8 character cell:



20.4.5.3 Fonts

The character fonts are stored in memory as a bit map representing the shape of the character. 256 different font characters are stored in each font area, representing character codes from 00h to 0FFh.

A relocatable 16-Kbyte block of memory is allocated for font storage. The font memory is organized so as to maximize system DRAM page hits during text display refresh. The font memory may be independently write-protected.

The 16 Kbyte font memory area is divided into 32 pages of 256 words. Each page corresponds to the pixel information of a particular scan line. Up to 32 scan lines may be used in the vertical dimension of a font.

The Maximum Scan Line Register (graphics index 09h) is used by the graphics controller to determine the displayed vertical height of the font. The horizontal dimension is selectable

as 8,10, or 16 bits. The displayed pixel information is left-justified and the odd and even bytes are swapped (see the examples below). If the vertical height selected is 16 or less, the Font Table Register (graphics index 42h) may be used to select alternate fonts (only one font set is available if the number of row lines exceeds 16).

The total number of fonts available for a given number of row lines may be calculated by the formula:

fonts = INT(32/row_lines)

where:

fonts is the number of available fonts,

row_lines is the number of row lines used in the font, and

INT truncates the fractional part of the division result.

The address of the word corresponding to a given character and row line is given by the equation:

fontpixel_address = font_table_base_address + (512*(row_line + fontoffset) + 2*character)

Table 20-8 shows the bit mapping used for font addresses.

Table 20-8 Font Address Mapping

Byte Address Bit Position	Mapping
0	0
1	CA0
2	CA1
3	CA2
4	CA3
5	CA4
6	CA5
7	CA6
8	CA7
9	RA + FontOFF (bit 0)
10	RA + FontOFF (bit 1)
11	RA + FontOFF (bit 2)
12	RA + FontOFF (bit 3)
13	RA + FontOFF (bit 4)
23–14	Font table base
25–24	00

Notes:

The Character Address (CA7–0) is the character byte stored in the frame buffer. It is used by the graphics controller as an address to point to the position in memory where that character font resides.

The Row Address (RA) is generated by the graphics controller and used to point to the row scan line of the font to be displayed.

These bits from the Font Table Register (graphics index 42h) are used to select the offset within the font memory area to be used during display.

20.4.5.3.1 8x8 Font Example

The bit map for the letter “A” in an 8x8 font may look like that shown in Figure 20-13 (only shaded area is used for display).

Figure 20-13 8x8 Font Example

Bit -	7	6	5	4	3	2	1	0	15	14	13	12	11	10	9	8	Hex Data
row 0 -			X	X													0030h
row 1 -		X	X	X	X												0078h
row 2 -	X	X			X	X											00CCh
row 3 -	X	X			X	X											00CCh
row 4 -	X	X	X	X	X	X											00FCh
row 5 -	X	X			X	X											00CCh
row 6 -	X	X			X	X											00CCh
row 7 -																	0000h

The bit map for the letter “A” in a 10x12 font may look like that shown in Figure 20-14 (only shaded area is used for display).

Figure 20-14 10x12 Font Example

Bit -	7	6	5	4	3	2	1	0	15	14	13	12	11	10	9	8	Hex Data
row 0 -					X	X											000Ch
row 1 -				X	X	X	X										001Eh
row 2 -			X	X			X	X									0033h
row 3 -		X	X					X	X								8061h
row 4 -		X	X					X	X								8061h
row 5 -		X	X					X	X								8061h
row 6 -		X	X	X	X	X	X	X	X								807Fh
row 7 -		X	X					X	X								8061h
row 8 -		X	X					X	X								8061h
row 9 -		X	X					X	X								8061h
row 10 -																	0000h
row 11 -																	0000h

The bit map for the letter “A” in a 16x14 font may look like that shown in Figure 20-15 (shaded area is used for display).

Figure 20-15 16x14 Font Example

Bit -	7	6	5	4	3	2	1	0	15	14	13	12	11	10	9	8	Hex Data
row 0 -							X	X	X	X							C003h
row 1 -					X	X	X	X	X	X	X	X					F00Fh
row 2 -			X	X	X	X					X	X	X	X			3C3Ch
row 3 -		X	X	X	X							X	X	X	X		1E78h
row 4 -		X	X	X	X							X	X	X	X		1E78h
row 5 -		X	X	X	X							X	X	X	X		1E78h
row 6 -		X	X	X	X	X	X	X	X	X	X	X	X	X	X		FE7Fh
row 7 -		X	X	X	X	X	X	X	X	X	X	X	X	X	X		FE7Fh
row 8 -		X	X	X	X							X	X	X	X		1E78h
row 9 -		X	X	X	X							X	X	X	X		1E78h
row 10 -		X	X	X	X							X	X	X	X		1E78h
row 11 -		X	X	X	X							X	X	X	X		1E78h
row 12 -																	0000h
row 13 -																	0000h

20.4.6 Flat-Mapped Graphics Modes

In the flat-mapped graphics modes, the CPU views graphics memory as a flat, packed-pixel, linear map. Pixel data is organized in memory as a linear array, starting from the upper leftmost pixel and ending with the bottom rightmost pixel. The packed-pixel size may be set to 1, 2, or 4 bits. In all cases the leftmost displayed pixel uses the most significant bit(s) of a given byte in memory.

Table 20-9 shows some example memory configurations that are available for some screen/pixel resolutions and memory window sizes.

Because graphics memory is shared with system memory, the entire lower 16 Mbytes of system DRAM space is available for use as the graphics frame buffer. Any memory that is not used to refresh the display may be used for other purposes—there are no inherent boundaries between what may be considered “graphics memory” and “system memory”.

The base address of the frame buffer may be set to any 32-Kbyte boundary within the lower 16 Mbytes of memory by programming the Frame Buffer Base Address Register (graphics index 4Dh).

With all memory and pixel configurations, there will be some number of pages of screen memory (different screens of data stored simultaneously in memory). The screen controller address counter will wrap around to the beginning of the first page of the display buffer when the limit of the screen controller addressing range is reached (e.g., due to scrolling operations).

The graphics controller memory addressing range is 128 Kbytes in 4-BPP and 2-BPP modes, and 64 Kbytes in 1 BPP mode. This is the upper limit on the memory utilization of a screen or contiguous set of screens. The start address register and character counter are extended to 15 bits to allow for full scrolling within the addressing limits.

Note: *The "start address register" described in this section refers to a 10-bit internal register controlled by the Frame Buffer Base Address Register and the Frame/Font Buffer Base Address Register Low, graphics index 4Dh and 4Fh, respectively.*

In all flat-mapped configurations, each "character" address corresponds to a row of eight pixels.

Table 20-9 Example Memory Configurations

Screen Resolution	BPP	Memory Bytes/Screen	Maximum Number of Screens
640x200	1	16,000	4
	2	32,000	4
	4	64,000	2
480x320	1	19,200	3
	2	38,400	3
	4	76,800	1

20.4.6.1 Memory Configuration Example: 640x240 Panel, Flat-Mapped Mode

Figure 20-16, Figure 20-17, and Figure 20-18 illustrate one way screen memory may be used on a 640x240 panel in flat-mapped mode.

Another acceptable way to set up the memory map would be to define a virtual screen that is larger than the physical screen, and use the start address registers to move the physical screen "window" through the virtual screen. As long as the base address remains the same, the virtual screen cannot be larger than 128 Kbytes in 2-BPP mode and 64 Kbytes in 1-BPP mode.

These are not the only possible maps; other screens up to a maximum of 640x240 or 480x320 are also supported. The shared memory frame-buffer base address may be programmed to any 32-Kbyte boundary in the system DRAM address space.

Figure 20-16 Flat-Mapped, 1 BPP, 640x240

Start Addr Reg	Mem Address	Frame Buffer		
0000h	Base + 00000h	Screen 1, Row 1		
	Base + 00050h	Screen 1, Row 2	19200 bytes	
	. . .	. . .		
	Base + 04AB0h	Screen 1, Row 240		
4B00h	Base + 04B00h	Screen 2, Row 1		
	Base + 04B50h	Screen 2, Row 2	19200 bytes	
	. . .	. . .		
	Base + 095B0h	Screen 2, Row 240		64 Kbytes
9600h	Base + 09600h	Screen 3, Row 1		
	Base + 09650h	Screen 3, Row 2	19200 bytes	
	. . .	. . .		
	Base + 0E0B0h	Screen 3, Row 240		
E100h	Base + 0E100h	Unused	7936 bytes	

Note:

Set the start address register to the value shown to display the corresponding screen.

Figure 20-17 Flat-Mapped, 2 BPP, 640x240

Start Addr Reg	Mem Address	Frame Buffer		
0000h	Base + 00000h	Screen 1, Row 1		
	Base + 000A0h	Screen 1, Row 2	38400 bytes	
	. . .	. . .		
	Base + 09560h	Screen 1, Row 240		
4B00h	Base + 09600h	Screen 2, Row 1		
	Base + 096A0h	Screen 2, Row 2	38400 bytes	
	. . .	. . .		
	Base + 12B60h	Screen 2, Row 240		128 Kbytes
9600h	Base + 12C00h	Screen 3, Row 1		
	Base + 12CA0h	Screen 3, Row 2	38400 bytes	
	. . .	. . .		
	Base + 1C160h	Screen 3, Row 240		
E100h	Base + 1C200h	Unused	15872 bytes	

Note:

Set the start address register to the value shown to display the corresponding screen.

Figure 20-18 Flat-Mapped, 4 BPP, 640x240

Start Addr Reg	Mem Address	Frame Buffer		
0000h	Base + 00000h	Screen 1, Row 1	76800 bytes	128 Kbyte
	Base + 00140h	Screen 1, Row 2		
	. . .	. . .		
	Base + 12AC0h	Screen 1, Row 240		
	Base + 12C00h	Unused	54272 bytes	

Note:

Set the start address register to the value shown to display the corresponding screen

A section of the CPU memory map is allocated to the graphics frame buffer by programming a base address for the displayed graphics memory. The display controller has visibility into shared memory starting from the programmed base address and extending to the limit of the graphics address counter. The graphics address counter is 64 Kbytes for 1 BPP mode and 128 Kbyte for 2 and 4 BPP modes.

The address offset and pixel location offset for a given set of x and y coordinates (origin located in the top left corner of the screen; y increases positively in the downward direction; x increases positively in the rightward direction) may be calculated using the following formulae:

1 Bit-Per-Pixel Mode:

Byte offset = (y*(W/8)) + (x/8)
Bit position = 7 - (x%8)

2 Bits-Per-Pixel Mode:

Byte offset = (y*(W/4)) + (x*4)
Pixel Bit 1 position (msb) = 7 - ((x%4)*2)
Pixel Bit 0 position (msb) = 6 - ((x%4)*2)

4 Bits-Per-Pixel Mode:

Byte offset = (y*(W/2)) + (x*2)
Pixel Bit 3 position (msb) = 7 - ((x%2)*4)
Pixel Bit 2 position = 6 - ((x%2)*4)
Pixel Bit 1 position = 5 - ((x%2)*4)
Pixel Bit 0 position (lsb) = 4 - ((x%2)*4)

where:

W is the screen width in pixels
% is the integer modulus (remainder) operator
/ represents integer division

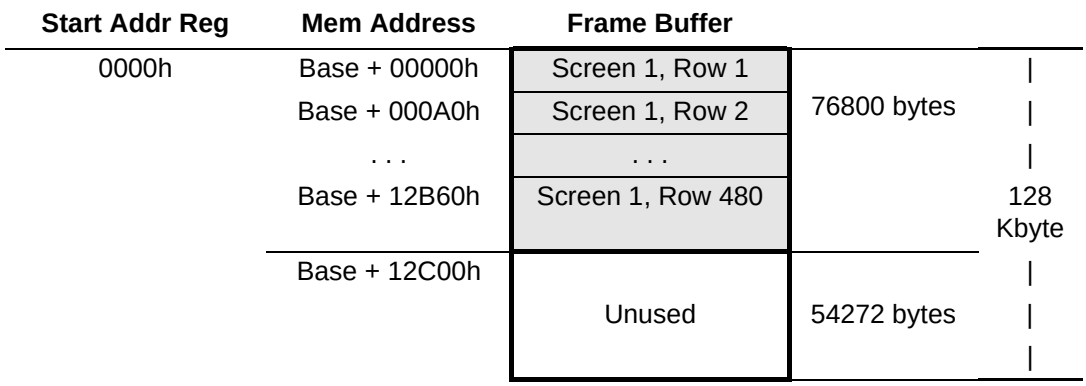
20.4.6.2 Memory Configuration Example: 640x480 Panel, Flat-Mapped Mode

Figure 20-19 illustrates the memory map for a 2-BPP 640x480 panel in flat-mapped mode.

Another acceptable way to set up the memory map would be to define a virtual screen that is larger than the physical screen, and use the start address registers to move the physical screen "window" through the virtual screen. As long as the base address remains the same, the virtual screen cannot be larger than 128 Kbytes in 2-BPP mode and 64 Kbytes in 1-BPP mode.

The shared memory frame-buffer base address may be programmed to any 32-Kbyte boundary in the system DRAM address space.

Figure 20-19 Flat-Mapped, 2 BPP, 640x480



Note:

Set the start address register to the value shown to display the corresponding screen

20.4.6.3 Flat-Mapped Graphics Mode Data Formats

Following are the data formats for the three flat-mapped graphics modes.

- 16-level or 4-level grayscaling may be selected when using 1 or 2 BPP flat-mapped modes.
- 16-level grayscaling should be used with the 4 BPP flat-mapped mode.

Note that the grayscale palette (see Section 20.4.7) should be used for color mapping in the flat-mapped modes.

Figure 20-20 Memory Byte Format: 1 BPP Flat-Mapped Graphics Mode

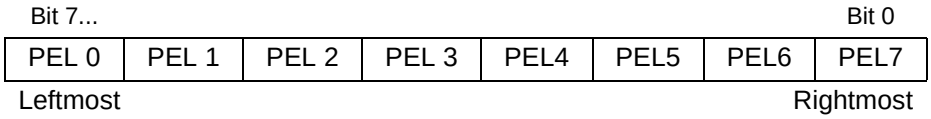


Figure 20-21 16-Grayscale Palette Mapping (1 Pixel): 1 BPP Flat-Mapped Graphics Mode

Red	Green	Blue	Intensity
0	0	0	PEL Bit 0

Figure 20-22 Memory Byte Format: 2 BPP Flat-Mapped Graphics Mode

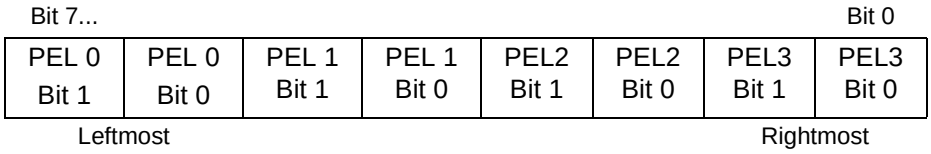


Figure 20-23 16-Grayscale Palette Mapping (1 Pixel): 2 BPP Flat-Mapped Graphics Mode

Red	Green	Blue	Intensity
0	0	PEL Bit 1	PEL Bit 0

Figure 20-24 Memory Byte Format: 4 BPP Flat-Mapped Graphics Mode

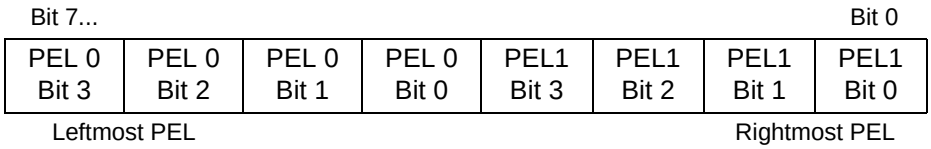


Figure 20-25 16-Grayscale Palette Mapping (1 Pixel): 4 BPP Flat-Mapped Graphics Mode

Red	Green	Blue	Intensity
PEL Bit 3	PEL Bit 2	PEL Bit 1	PEL Bit 0

20.4.7 Grayscale Generation

20.4.7.1 Four-Color Grayscale Encoding

Selecting grayscaling Option 1 via the Graphics Controller Grayscale Mode Register (graphics index 43h[1]) enables the four-color grayscaling options. In four-color mode, frame-rate shading creates four different levels of gray by varying the duty cycle of the “on” time for individual pixels as seen over successive frames. Table 20-10 lists the duty cycles available in the four-grayscale modes.

Table 20-10 Four-Color Grayscale Duty Cycles

Active RGBI	Map Select 1 Codes	Map Select 1 Duty Cycles (Monochrome Mapping Mode)	Map Select 2 Codes	Map Select 2 Duty Cycles (Color Mapping Mode)
(none)	1	0.33 (1/3)	0	0
I	0	0	0	0
B	2	0.667 (2/3)	0	0
IB	3	1	0	0
G	2	0.667 (2/3)	1	0.33 (1/3)
IG	3	1	1	0.33 (1/3)
GB	2	0.667 (2/3)	1	0.33 (1/3)
IGB	3	1	1	0.33 (1/3)
R	2	0.667 (2/3)	2	0.667(2/3)
IR	3	1	2	0.667(2/3)
RB	2	0.667 (2/3)	2	0.667(2/3)
IRB	3	1	2	0.667(2/3)
RG	2	0.667 (2/3)	3	1
IRG	3	1	3	1
RGB	2	0.667 (2/3)	3	1
RGBI	3	1	3	1

20.4.7.2 16-Color Grayscale Encoding

The ÉlanSC400 microcontroller’s grayscaling logic uses frame-rate shading and flicker-reduction techniques to generate 16 gray shades. All 16 shades may be individually remapped by programming the Graphics Controller Grayscale Remapping registers (graphics index 44–4Bh). For example, to remap RGBI codes 0 through 7 to code 0 and RGBI codes 8 through 15 to code 15, the first eight nibbles would be programmed to 0 and the second eight nibbles would be programmed to 0Fh. The default mapped duty cycles are given in Table 20-11.

Table 20-11 16-Color Grayscale Duty Cycles

Active RGBI	Code	Duty cycle
(none)	0	0
I	1	0.12
B	2	0.18
IB	3	0.24
G	4	0.29
IG	5	0.35
GB	6	0.41
IGB	7	0.47
R	8	0.53
IR	9	0.59
RB	10	0.65
IRB	11	0.71
RG	12	0.76
IRG	13	0.82
RGB	14	0.88
RGBI	15	1

20.4.7.2.1 Grayscale Remapping

The grayscale remapping feature allows system software to tune the look of the displayed graphics without the need to rewrite the application software that is writing bit patterns into the graphics buffer. This is done by allowing each bit pattern that represents a pixel in the graphics buffer to be arbitrarily mapped to one of the available grayscales. Remapping is available for 1-, 2-, or 4-BPP mode. The optimal mapping can vary based on the LCD manufacturer. This tuning is done via the eight color-mapping registers (containing 16 individual bit fields) located at graphics index 44h-4Bh, and only takes effect when graphics index 43h[0] = ‘1b.’

The graphics controller uses a pixel modulation scheme to allow either 4 or 16 grayscales to be present on the display at any one time (selected via graphics index 43h[1]). Grayscales are achieved by controlling the average time that a pixel is turned on over a series of refreshes of the LCD screen. The duty cycles that produce the grayscales are evenly spaced across the range of always off to always on. For example, when using 4-grayscale mode, the “pixel-on” average duty cycles are 0, 33%, 66%, and 100% for the 4 grayscales.

While graphics index 43h[1] selects the number of grayscales the graphics controller is capable of generating, the configuration of the graphics buffer dictates the maximum number of grayscales that can be displayed at any time. The graphics buffer can be configured so that either 1, 2, or 4 bits of data are required to define each pixel. This number of BPP (often referred to as the *color depth* of the graphics buffer), in conjunction with the grayscale mode (4/16), defines the maximum number of different grayscales which can be seen on the LCD at any time. The maximum grayscales is the lesser of (2^{BPP}) and the number of grayscales available.

Due to its roots in the CGA standard, the graphics controller on the ÉlanSC400 microcontroller considers each grayscale as having a Red, Green, Blue, and Intensity (RGBI) component. Each component is either on or off, and is each is nominally represented by a bit in the graphics buffer. The four RGBI bits taken together can be thought of as

representing a color code with a range of 0–15. Since CGA supported a 2-BPP graphics-buffer mapping, the other two bits had to come from somewhere else. In this case, the R and G components are controlled by bits 1–0 of the bitmap for a particular pixel in the graphics buffer, and the B and I components come from Port 03D9h[5–4] respectively.

A similar situation exists for 1-BPP (high-resolution) CGA mode. In this case, when the bit associated with a pixel = '0b', the RGBI components are each '0b' (color code 0). When the bit = '1b', the RGBI components come from 03D9h[2], 03D9h[1], 03D9h[0], and 03D9h[3] respectively.

Since flat-mapped graphics mode is custom, its 2-BPP mode uses a different scheme for specifying the RGBI components. B and I are represented by bits 1–0 of the bitmap for a particular pixel in the graphics buffer, and the R and G components are always assumed to be 0. For 4-BPP flat-mapped graphics mode, the RGBI color code is specified by bits 3–0 of the bitmap for each pixel.

RGBI color codes are mapped to one of the available grayscales per Table 20-12. On the left is each possible RGBI combination (which also presents each of the 16 RGBI color codes in binary). On the right is the register and bit field for specifying which grayscale will be present on-screen for a pixel with that RGBI color code associated with it.

Table 20-12 Grayscale Remapping

R	G	B	I	CSC Index	Bit Field (16-Color Grayscale Mode)	Bit Field (4-Color Grayscale Mode)
0	0	0	0	44h	3–0	1–0
0	0	0	1	44h	7–4	5–4
0	0	1	0	45h	3–0	1–0
0	0	1	1	45h	7–4	5–4
0	1	0	0	46h	3–0	1–0
0	1	0	1	46h	7–4	5–4
0	1	1	0	47h	3–0	1–0
0	1	1	1	47h	7–4	5–4
1	0	0	0	48h	3–0	1–0
1	0	0	1	48h	7–4	5–4
1	0	1	0	49h	3–0	1–0
1	0	1	1	49h	7–4	5–4
1	1	0	0	4Ah	3–0	1–0
1	1	0	1	4Ah	7–4	5–4
1	1	1	0	4Bh	3–0	1–0
1	1	1	1	4Bh	7–4	5–4

20.4.7.2.2 Color-to-Grayscales Mapping

In 16-color grayscales mode, color-to-grayscales mapping is always handled through the 16x4 grayscale palette, giving complete flexibility. The palette allows any individual RGBI pixel value to be mapped to any 16 grayscale code. The 16-color grayscales mode may be used in any memory setup (e.g., CGA text, 1 BPP, 2 BPP or 4 BPP). The invert bits in the Internal Graphics Control Register B (CSC index DEh) allow for selective inversion of all grayscales or colors in text and graphics modes. For example, grayscales may be inverted in graphics modes, but not text modes, or vice-versa.

In four-color grayscales mode, mapping is handled differently in text and CGA graphics modes. In CGA graphics modes, four-gray shading may be used in high- or low-resolution

modes. In 1 BPP modes, 0 maps to all pixels off, and 1 maps to all pixels on (inversion also may be applied). In 2-BPP modes, mapping is performed per Table 20-10, using the color mapping mode. Colors may also be inverted using the Internal Graphics Control Register B as is possible in 16-grayscales mode. In color text modes without contrast enhancement enabled, the R and G bits of the color value are used to select the shading value, with R the most significant and G the least significant. When contrast enhancement is enabled, the 16x4 grayscale palette becomes a 16x2 palette, allowing for full remapping of the grayscales.

In monochrome text modes, the logical OR of the RGB bits turns on a pixel. If the intensity bit is off, the on and off pixels of a character are mapped to shades 3 and 0, respectively. If the intensity bit is on, the on and off pixels are mapped to shades 2 and 1. When contrast enhancement is enabled, the 16x4 grayscale palette becomes a 16x2 palette, allowing for full remapping of the grayscales.

In linear-packed-pixel modes, 4- or 16-color gray shading may be used in 1- or 2-BPP modes. The 16x2 grayscales palette should be enabled in this case, allowing for full remapping of the grayscales. 16-color gray shading should be selected in 4-BPP flat-mapped mode.

20.4.7.2.3 Color STN Mode

In color STN mode, eight normal and eight intensified colors are supported under the CGA RGBI format. The colors are normal if the “I” (intensity) bit is set to 0. For a normal color, each of the R, G, and B signals is driven with a 2/3 duty cycle waveform when on. For an intensified color, each of the R,G, and B bits is driven with a constant one duty cycle when on. If monochrome mapping is selected, the 4- or 16-grayscale Frame Rate Control (FRC) is output to the RGB bits of the panel in unison. FRC is the method used to obtain gray shading in which individual pixels are turned on and off very rapidly, with the average duty cycle of the on-time of a pixel determining its shading.

20.4.8 Configuring Graphics Modes

20.4.8.1 Screen Controller Registers

The screen controller registers control the timing of vertical and horizontal display signals. Internally, the screen controller contains counters for horizontal character elements and vertical rows. The Horizontal Total and Vertical Border End registers determine the maximum values for their respective counters. Values in the Horizontal and Vertical Display End, Line Pulse Start, Vertical Adjust, and Border End registers are compared to the internal counters to generate internal and/or external control signals for their respective functions. Note that the actual horizontal line count is two greater than the value programmed into the Horizontal Total Register. For the last line of each frame, the horizontal end time is increased to allow time for flushing and reloading the internal FIFOs.

20.4.8.1.1 Example Configuration

Consider an example, where it is desired to display 20 rows of 64 characters, with a character cell of 10x11, on a single-scan panel of 640x240 pixels.

- The Maximum Scan Line Register (graphics index 40h) must be programmed with a value equal to the number of lines in a character minus 1, which would be 10 in this example.
- The character width is set to 10 dots by setting bits 6–5 of the Font Table Register (graphics index 42h) to 01b.
- The total number of lines required for display is 20x11 = 220 lines. This leaves 20 extra lines at the bottom of the panel to be blanked.

- The Vertical counter counts in character rows; the number of whole character rows in the panel display area may be calculated: Int(240/11) = 21 character rows.
- The Vertical Border End Register (graphics index 38h) should be programmed to a value of 21 - 1 = 20.
- There will be 240 - (21*11) = 9 extra lines at the bottom of the screen; therefore the Vertical Adjust Register (graphics index 35h) should be programmed to a value of 9.
- To begin blanking the screen after the 20th row, the Vertical Display End Register (graphics index 37h) should be programmed to 19 (=20 - 1).
- The number of horizontal pixels required is 64x10 = 640, which equals the number of horizontal pixels on the panel. Because no horizontal border is required, the Horizontal Total, the Horizontal Display End, and the Horizontal Border End registers (graphics index 30h, 31h, and 33h) should all be set to a value of 63 (= 64–1).
- If it is desired to slow down the frame refresh rate or if bit 3 of the Extended Feature Control Register (graphics index 52h) is set (see Section 20.4.8.2.3), the value in the Horizontal Total Register may be increased while maintaining the same value in the Horizontal Display End and the Horizontal Border End registers, thus increasing the "dead" time between active display of each horizontal line.
- If line doubling is enabled by setting the VERTDOUB bit in the Internal Graphics Control Register A, the Vertical Adjust, Vertical Display End and Vertical Border End registers must be recalculated using twice the number of lines in a character row. The Maximum Scan Line Register keeps its same value, regardless of the setting of VERTDOUB.
- For the example above, the number of lines in a character row would become 22, making the programmed values of the Vertical Border End, Vertical Adjust, and Vertical Display End registers change to 9, 20, and 9 respectively.
- If horizontal dot doubling is enabled, each pixel is sent to the display twice, making the effective character width double. This must be accounted for when setting up the Horizontal Total, the Horizontal Display End and Horizontal Border End registers.

20.4.8.2 Dual-Scan Panel Setup

When a dual-scan panel is being used, an additional set of registers must be programmed in order to facilitate the internal calculation of row/line numbers and refresh addresses. These are the Dual Scan Row Adjust and Dual Scan Offset Address High/Low registers.

20.4.8.2.1 Dual Scan Row Adjust Registers

The Dual Scan Row Adjust Register (graphics index 3Bh) is used in text modes and CGA graphics modes to determine row scan line numbers in the lower screen which correspond to equivalent upper screen row scan line numbers.

For example, a dual-scan 640x240 panel consists of two 640x120 panels joined together. If the font size (character box size) has been set to 8x14 (width x height) by programming the Maximum Scan Line Register to 13, and setting the character width to 8, the number of lines in a character is not an integer multiple of the number of lines in the half screen (i.e., 120/14 <> 0).

The Dual Scan Row Adjust Register should be programmed with the number of extra row scan lines at the top of the *lower* screen when a character box overlaps the upper and lower screens. This will happen whenever the number of lines in a half screen is not an integer multiple of the character box height.

Continuing the above example, there are 120 lines in a half screen, and the character box height is 14. Given that there are 8 whole character rows in the upper screen, this leaves

120 – (8*14) = 8 extra lines in the upper screen. These 8 lines are the upper portion of a 14-line character box overlapping the upper and lower screens. The number of extra lines in the lower screen is therefore 14 – 8 = 6 lines. In this case a value of 6 should be programmed into the Dual Scan Row Adjust Register. In cases where the number of lines in a half screen is an integer multiple of the character box height, the Dual Scan Row Adjust Register should be set to zero. In general:

Dual Scan Row Adjust = F*D - (H - (int(H/F*D) * (F*D)))

where:

F = font height in lines,

D = 2 for line doubling, 1 otherwise,

H = half the total number of lines in the panel

int = integer division.

In CGA graphics modes, the *character height* is 2--one even-addressed line and one odd-addressed line. Therefore, the Dual Scan Row Adjust Register would be set to 0, unless there were an odd number of lines in a half screen, in which case it would be programmed to 1.

In flat-mapped modes, the character height is 1. Therefore, the Dual Scan Row Adjust Register is always set to 0 in these modes.

20.4.8.2.2 Dual Scan Row Offset Address Registers

The Dual Scan Offset Address registers (graphics index 3C–3Dh) must be programmed with a value equal to the number of whole character rows in the upper screen, multiplied by the number of bytes in a character row.

Continuing the example above, there are 8 complete character rows in the upper screen (see calculation above). Each character is represented in memory by 2 bytes, and there are 640/8 = 80 characters in a row. This gives 160 bytes in each character row. Therefore, the Dual Scan Offset Address registers should be programmed with the product of 160 and 8, or 1280 decimal (500h). In general:

Dual Scan Offset Address = (#bytes in a character row or line) * int(H/(F*D))

where:

H equals half the total number of scan lines in the panel

F is the font height in lines

D = 2 when line doubling is enabled, 1 otherwise

int = integer division

There is always a direct correspondence between the value programmed into the Offset Register (graphics index 3Eh) and the number of bytes in a line or row. If virtual screen is being used, the number of bytes in a line/row is based on the size of the virtual screen, not the physical screen. Note that, in 1-BPP flat-mapped mode, a virtual screen must be an even number of bytes wide. If the logical screen and physical screen are the same width, the Offset Register may, in this case, be programmed to an odd value.

In graphics modes, the same principles apply as in text modes, except that the height of a *character row* will be 2 for CGA graphics modes, 4 for HGA modes, and 1 for flat-mapped modes. The character width is limited to 8 pixels (16 with horizontal doubling). The number of bytes in a horizontal line will depend on the pixel depth. For example, for 2 bits-per-pixel with a horizontal width of 640 pixels, each byte holds data for four pixels. Therefore the number of bytes in a line would equal 640/4, or 160 bytes.

If the number of horizontal lines is being doubled by setting the VERTDOUB bit in Internal Graphics Control Register A to a logic 1, the effective character box height is doubled, so the values programmed into the Dual Scan Row Adjust, and Dual Scan Offset Address High/Low registers must be calculated using the doubled character height as noted above, in addition to the modifications to the Vertical Adjust, Vertical Display End and Vertical Border End registers described above. Horizontal dot doubling is handled the same way as in the single-scan case (see above).

20.4.8.2.3 Frame-Refill Delay Configuration

The graphics controller must perform a FIFO flush/refill at the beginning of each frame. The time required to complete the flush and refill includes an arbitration delay plus a refill time. The total time required depends on the display configuration, as indicated in the table given under the description of bit 2 in the Extended Feature Control Register.

There are three options for accommodating the delay.

- If bits 2 and 7 of the Extended Feature Control Register are both set to 0, the delay is automatically added to the end of the last line of each frame as described in the description of bit 2 in the Extended Feature Control Register. This may cause contrast problems on some panels.
- If Bit 2 of the Extended Feature Control Register is set and bit 7 is cleared, the extra delay is not added automatically at the end of the last line of each line and must be accommodated by increasing the value of the Horizontal Total register so that the difference between the values programmed into the Horizontal Total and Horizontal Border End registers is sufficient to allow for the required delay. When this is done, all horizontal lines will have the same timing, but the dot rate will need to be increased in order to maintain the same frame rate obtained when Bit 2 of the Extended Feature Control Register is cleared. This option would be the one most frequently used.
- A third option, most useful when using text mode on a dual-screen panel, is enabled by setting both Bit 2 and Bit 7 of the Extended Feature Control Register. When this is done, the Non-display Lines Register must be set to a non-zero value. The graphics controller will then perform the FIFO flush/refill during one of the non-displayed lines. In this case no extra time is added to any horizontal lines; however, at least one extra line must be output at the end of the frame. Typically, this extra line has minimal or no impact on the contrast ratio of an LCD panel.

20.4.9 LCD Data Formatting

The examples given in the tables and figures in this section are for 320x240 resolution panels.

20.4.9.1 Monochrome, Single-Scan Panels

Table 20-13 Pixel Chart (Row:Column), Monochrome Single-Scan 320x240

ROW	COLUMN								
	COL 0				. . .				COL 319
ROW 1	D1:0	D1:1	D1:2	D1:3	D1:4	D1:5	. . .	D1:318	D1:319
ROW 2	D2:0	D2:1	D2:2	D2:3	D2:4	D2:5	. . .	D2:318	D2:319
. . .	. . .						. . .		. . .
. . .	. . .						. . .		. . .
ROW 240	D240:0	D240:1	D240:2	D240:3	D240:4	D240:5	. . .	D240:318	D240:319

Figure 20-26 Data Format for 4-Bit Single-Scan Monochrome Panel (First horizontal line shown)

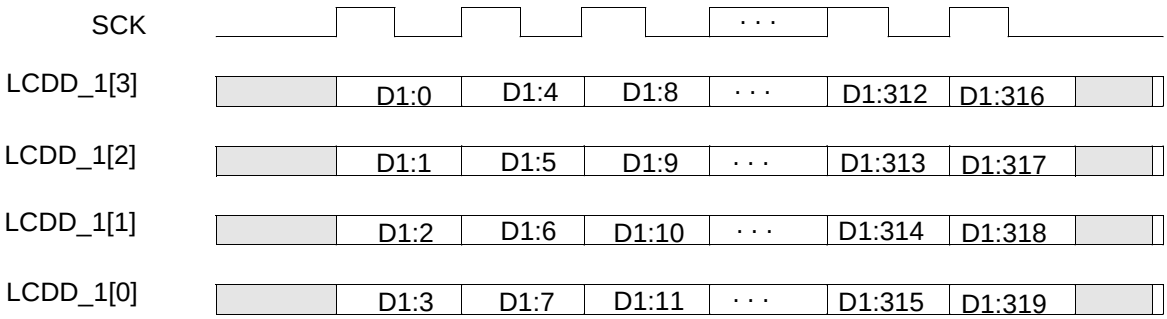
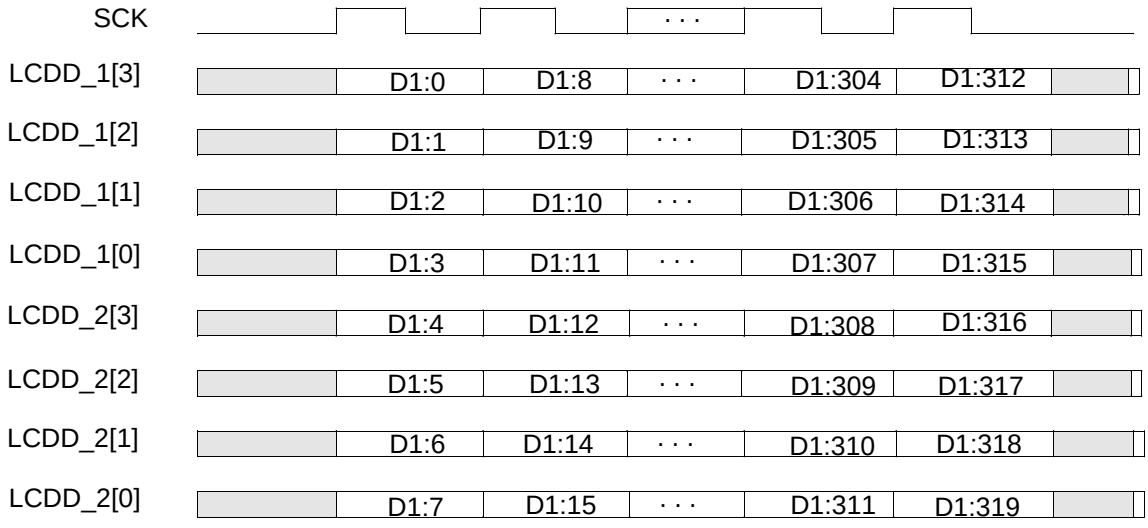


Figure 20-27 Data Format for 8-Bit Single-Scan Monochrome Panel (First horizontal line shown)

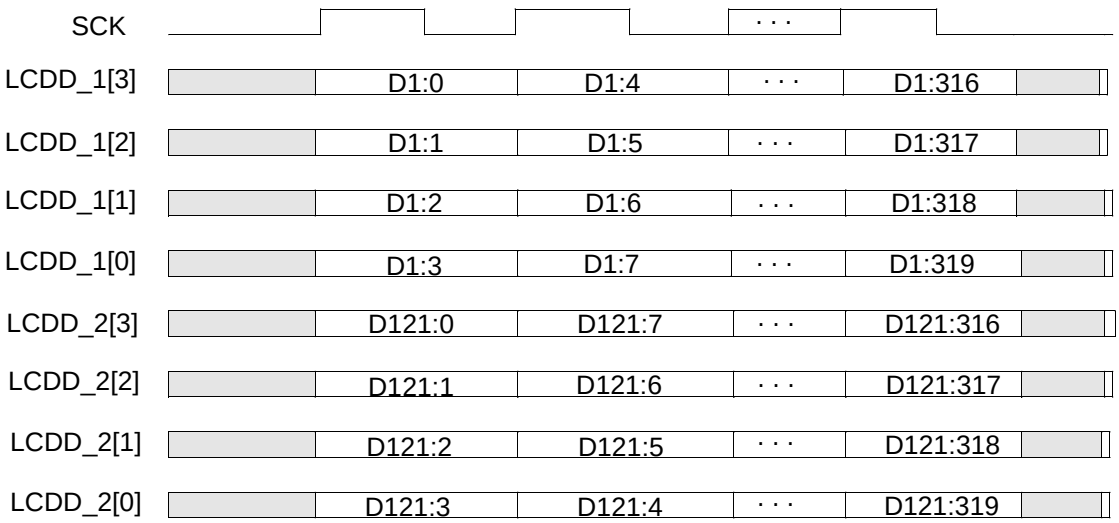


20.4.9.2 Monochrome, Dual-Scan Panels

Table 20-14 Pixel Chart (Row:Column), Monochrome Dual-Scan 320x240

	COLUMN						
ROW	**COL 0**			**. . .**			**COL 319**
Upper screen ROW 1	D1:0	D1:1	D1:2	. . .	. . .	D1:318	D1:319
. . .	D2:0	D2:1	D2:2	. . .	. . .	D2:318	D2:319
. . .	. . .	. . .	. . .			. . .	. . .
Upper screen ROW 120	D120:0	D120:1	D120:2	. . .	. . .	D120:318	D120:319
Lower screen ROW 121	D121:0	D121:1	D121:1	. . .	. . .	D121:318	D121:319
. . .	D122:1	D122:1	D122:1	. . .	. . .	D122:318	D122:319
. . .	. . .	. . .	. . .			. . .	. . .
Lower screen ROW 240	D240:0	D240:1	D240:2	. . .	. . .	D240:318	D240:319

Figure 20-28 Data Format for 2x4-Bit Dual-Scan Monochrome Panel (First horizontal line shown)

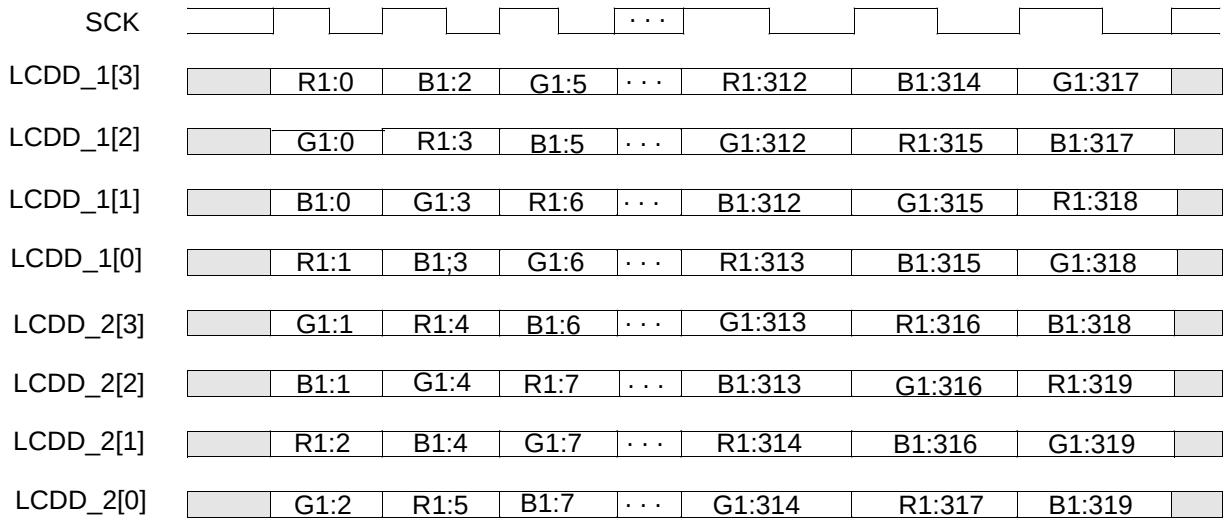


20.4.9.3 Color STN, Single-Scan Panels

Table 20-15 Pixel Chart (Row:Column), Color STN Single-Scan 320x240

	COLUMN									
ROW	**COL 0**					**. . .**				**COL 319**
ROW 1	R1:0	G1:0	B1:0	R1:1	G1:1	B1:1	. . .	R1:319	G1:319	B1:319
ROW 2	R2:0	G2:0	B2:0	R2:1	G2:1	B2:1	. . .	R2:319	G2:319	B2:319
. . .	. . .									. . .
. . .	. . .									. . .
ROW 240	R240:0	G240:0	B240:0	R240:1	G240:1	B240:1	. . .	R240:319	G240:319	B240:319

Figure 20-29 Data Format for 8-Bit Single-Scan Color STN Panel (First horizontal line shown)



20.5 INITIALIZATION

The graphics controller is disabled at power-on reset and must be configured by software before being enabled.

At power-on reset, $\overline{\text{LVDD}}$ and $\overline{\text{LVEE}}$ are both deasserted. The SCK, LC, FRM, M, and all LCDD signals are held Low. When bringing up the display from reset, software should use the following sequence:

1. Enable the graphics controller by setting the Internal Graphics Control Register A (CSC index DDh[2]) and disable the CSC indexed register lockout in the Internal Graphics Control Register B (CSC index DEh[6]).
2. Program all graphics controller registers, load initial memory image, and keep the display blanked (Port 03x8h[3]).
3. Set the CSC indexed register lockout bit (CSC index DEh[6]) and unblank the display (Port 03x8h[3]).

The PMU or software control bit can command the LCD controller to power up or power down in a normal mode, or power down in emergency mode. These three possible cases are described in Section 20.6.

Note: *The internal RTC must be initialized before the graphics controller can be used. This is particularly important for system designs that do not use the internal RTC.*

20.6 POWER MANAGEMENT

Operation of the LCD graphics controller is affected by the power-management functions shown in Table 20-16.

The graphics controller generates correct sequencing for the external LCD panel power control signals $\overline{\text{LVDD}}$ and $\overline{\text{LVEE}}$ and the LCD timing signals, so that power sequencing requirements for various LCD panels can be satisfied. The power-up and power-down sequencing can be activated either by a control signal from the system PMU or by writing to a bit. A special battery-failure power-down mode generates accelerated power-down timing, so that LCD power can be brought down gracefully under emergency battery-fail conditions. When enabled, this special sequencing is activated by an edge on the $\overline{\text{BL2}}$ pin.

The PMU or software control bit can command the LCD controller to power up or power down in a normal mode, or power down in emergency mode. This gives the following three cases.

20.6.1 Normal Power-Up

On initial power-up, $\overline{\text{LVDD}}$ and $\overline{\text{LVEE}}$ are both deasserted High. The SCK, LC, FRM, M, and all LCDD data signals are held Low.

Then, $\overline{\text{LVDD}}$ switches from High to Low. The SCK, LC, FRM, M, and all LCDD signals are held Low. After waiting for the delay programmed into bits 2–0 of PMU Control Register 1 (graphics index 50h), the screen controller is enabled so that LC, FRM, the LCDD bits, and M begin cycling. After waiting for the delay programmed into bits 5–3 of PMU Control Register 1, $\overline{\text{LVEE}}$ is asserted.

20.6.2 Normal Power-Down

First, $\overline{\text{LVEE}}$ switches from Low to High. SCK, LC, FRM, the LCDD bits, and M continue to run. After waiting for the delay programmed into bits 2–0 of PMU Control Register 2 (graphics index 51h), the screen controller is disabled and LC, FRM, the LCDD bits, and M are forced Low, coincident with the end of the current horizontal line. After waiting for the delay programmed into bits 5–3 of PMU Control Register 2, $\overline{\text{LVDD}}$ is asserted to complete the power-down.

20.6.3 Emergency Power-Down

First, $\overline{\text{LVEE}}$ switches from Low to High. SCK, LC, FRM, the LCDD bits, and M continue to run. After waiting for one graphics dot clock period, the screen controller is disabled and LC, FRM, the LCDD bits, and M are forced Low. After waiting again for one graphics dot clock period, $\overline{\text{LVDD}}$ is asserted to complete the power-down.

Table 20-16 Power Management in the LCD Graphics Controller

Graphics Controller Event	Description	Power Management Effect			
		Wake-Up	Activity	SMI	NMI
CPU access to graphics controller I/O	Triggered by the falling edge of I/O chip selects qualified with command		Programmable		
CPU access to DRAM within graphics controller memory range	When the VID_DRAM bit in graphics index 4Fh is asserted (rising edge) and the CPU accesses DRAM within graphics memory space		Programmable		
Graphics I/O access	I/O accesses to the graphics controller can cause an SMI through a trap. This includes the following addresses: 03B4h, 03B5h, 03B8h, 03BAh, or 03D4h, 03D5h, 03D8–03DCh			Yes	

CHAPTER

21 TEST AND DEBUGGING

21.1 OVERVIEW

The ÉlanSC400 and ÉlanSC410 microcontrollers provide test and debug features compatible with the standard Test Access Port (TAP) and Boundary-Scan Architecture (JTAG). The test logic provided allows for testing to ensure that components function correctly, that interconnections between various components are correct, and that various components interact correctly on the printed circuit board.

The boundary-scan test logic consists of a boundary scan register and support logic that are accessed through a test access port (TAP). The TAP provides a simple serial interface that makes it possible to test all signal traces with only a few probes.

The TAP can be controlled via a bus master. The bus master can be either automatic test equipment or a component (PLD) that interfaces to the four-pin test bus.

The test and debugging features on the ÉlanSC400 and ÉlanSC410 microcontrollers include the following elements:

- **Five pins**— BNDSCN_TDI, BNDSCN_TMS, BNDSCN_TCK, BNDSCN_TDO, and BNDSCN_EN. On the ÉlanSC400 microcontroller, only the BNDSCN_EN pin is dedicated; the other four are multiplexed with the PC Card controller signals. All five boundary-scan interface pins are dedicated on the ÉlanSC410 microcontroller.
- **Test Access Port (TAP) controller**—Decodes the inputs on the Test Mode Select (BNDSCN_TMS) line to control test operations.
- **Instruction Register (IR**)—The instruction codes select the specific test or debug operation to be performed and the test data register to be accessed.
- **Test Data Registers**—Boundary Scan Register (BSR), Device Identification Register (DID), and Bypass Register (BPR).

The instruction and test data registers are separate shift-register paths connected in parallel that have a common serial data input and a common serial data output connected to the TAP signals, BNDSCN_TDI and BNDSCN_TDO, respectively.

21.2 BOUNDARY-SCAN ARCHITECTURE

21.2.1 Enabling the Boundary-Scan Interface

Because the boundary-scan interface is shared with the PC Card function on the ÉlanSC400 microcontroller, the boundary-scan interface for either microcontroller is enabled by asserting the dedicated BNDSCN_EN configuration pin. (Using the BNDSCN_EN pin in this way makes this implementation on the ÉlanSC400 and ÉlanSC410 microcontrollers non-compliant with *IEEE Std 1149.1, Standard Test Access Port and Boundary-Scan Architecture*; otherwise the JTAG features on the ÉlanSC400 and ÉlanSC410 microcontrollers follow this IEEE standard.)

The following pins are configured for their boundary-scan function when BNDSCN_EN is asserted:

- BNDSCN_TCK, Test Clock (Input)—Test Clock is a JTAG input clock that is used to access the Test Access Port.
- BNDSCN_TDI, Test Data Input (Input)—Test Data Input is the serial input stream for JTAG scan input data.
- BNDSCN_TDO, Test Data Output (Three-State Output)—Test Data Output is the serial output stream for JTAG scan result data.
- BNDSCN_TMS, Test Mode Select (Input)—Test Mode Select is an input for controlling the Test Access Port.

21.2.2 Test Data Registers

The ÉlanSC400 and ÉlanSC410 microcontrollers contain the two required test data registers; Bypass Register and Boundary Scan Register. In addition, it includes a Device Identification Register.

Each test data register is serially connected to BNDSCN_TDI and BNDSCN_TDO, with BNDSCN_TDI connected to the most significant bit and BNDSCN_TDO connected to the least significant bit of the test data register. Data is shifted one stage (bit position within the register) on each rising edge of the test clock (BNDSCN_TCK).

21.2.2.1 Bypass Register (BPR)

The Bypass Register provides a path from BNDSCN_TDI to BNDSCN_TDO with one clock cycle latency. It helps to bypass a chip completely while testing boards containing many chips.

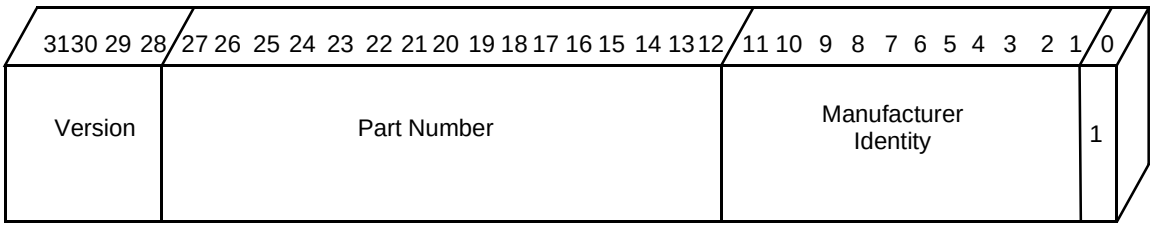
21.2.2.2 Boundary Scan Register (BSR)

The Boundary Scan Register is a single shift register path containing the boundary scan cells that are connected to all input and output pins of the ÉlanSC400 and ÉlanSC410 microcontrollers. Figure 21-2 shows the logical structure of the BSR. While output cells determine the value of the signal driven on the corresponding pin, input cells only capture data; they do not affect the normal operation of the device. Data is transferred without inversion from BNDSCN_TDI to BNDSCN_TDO through the BSR during scanning. The BSR can be operated by the EXTEST and SAMPLE instructions.

21.2.2.3 Device Identification Register (DID)

The Device Identification Register is a 32-bit register that contains AMD's ID code for the ÉlanSC400 and ÉlanSC410 microcontrollers: 00FFF003h. Figure 21-1 shows the format.

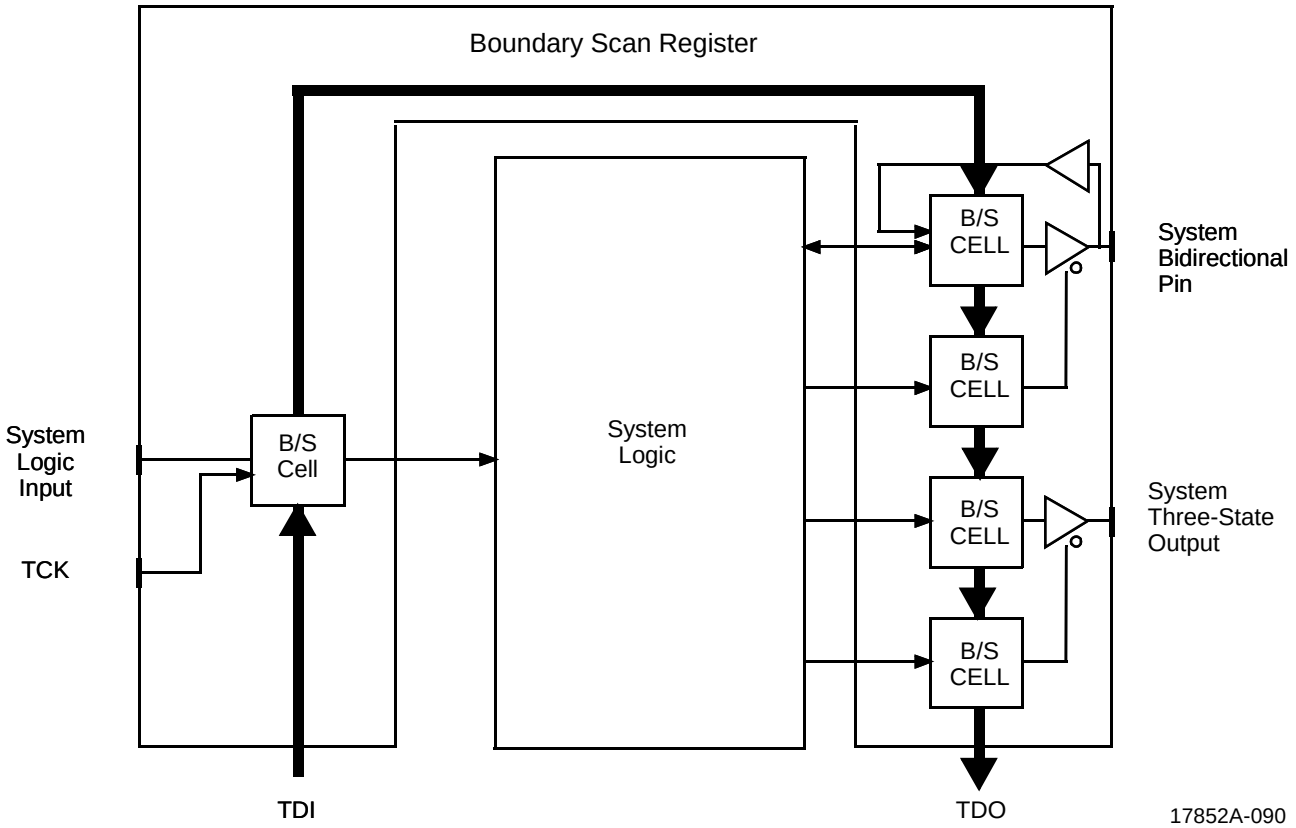
Figure 21-1 Format of Device Identification Register



21.2.3 Instruction Register and Implemented Instructions

The Instruction Register (IR) is a 4-bit register that allows instructions to be serially shifted into the device. The instruction determines the test to execute, the data register to access, or both. The least significant bit is nearest the BNDSCN_TDO output. When the TAP controller is reset, the Instruction Register is loaded with the default instruction IDCODE.

Figure 21-2 Logical Structure of Boundary Scan Register



21.2.3.1 Test Access Port Instruction Set

The ÉlanSC400 and ÉlanSC410 microcontrollers support all three mandatory boundary-scan instructions, BYPASS, SAMPLE/PRELOAD, and EXTEST, along with two additional instructions, IDCODE and HIGHZ.

Table 21-1 shows the TAP instructions that are supported on the ÉlanSC400 and ÉlanSC410 microcontrollers.

Table 21-1 Test Access Port Instruction Set

Instruction	IR3–IR0
EXTEST	0000
SAMPLE/PRELOAD	0001
IDCODE	0010
HIGHZ	0011
BYPASS	1111

- EXTEST—The instruction code is “0000". The EXTEST instruction allows testing of circuitry external to the component package, typically board interconnects. It does so by driving the values loaded into the microcontroller’s BSR out on the output pins corresponding to each boundary scan cell. It then captures the values on the microcontroller’s input pins to be loaded into their corresponding BSR locations. I/O pins are selected as input RUNBIST or output, depending on the value loaded into their control setting locations in the BSR. Values shifted into input latches in the BSR are never used by the internal logic of the ÉlanSC400 and ÉlanSC410 microcontrollers.

  Note: *After using the EXTEST instruction, the ÉlanSC400 and ÉlanSC410 microcontrollers must be reset before normal (non-boundary scan) use.*

- SAMPLE/PRELOAD—The instruction code is “0001". The SAMPLE/PRELOAD instruction has two functions that it performs. When the TAP controller is in the Capture-DR state, the SAMPLE/PRELOAD instruction allows a “snapshot” of the normal operation of the component without interfering with that normal operation. The instruction causes BSR cells associated with outputs to sample the value being driven by the microcontroller. It causes the cells associated with inputs to sample the value being driven into the microcontroller. On both outputs and inputs, the sampling occurs on the rising edge of BNDSCN_TCK. When the TAP controller is in the Update-DR state, the SAMPLE/PRELOAD instruction preloads data to the device pins to be driven to the board by executing the EXTEST instruction. Data is preloaded to the pins from the BSR on the falling edge of BNDSCN_TCK.

- IDCODE—The instruction code is “0010". The IDCODE instruction selects the DID to be connected to BNDSCN_TDI and BNDSCN_TDO, allowing the device identification code to be shifted out of the device on BNDSCN_TDO. Note that the DID is not altered by data being shifted in on BNDSCN_TDI.

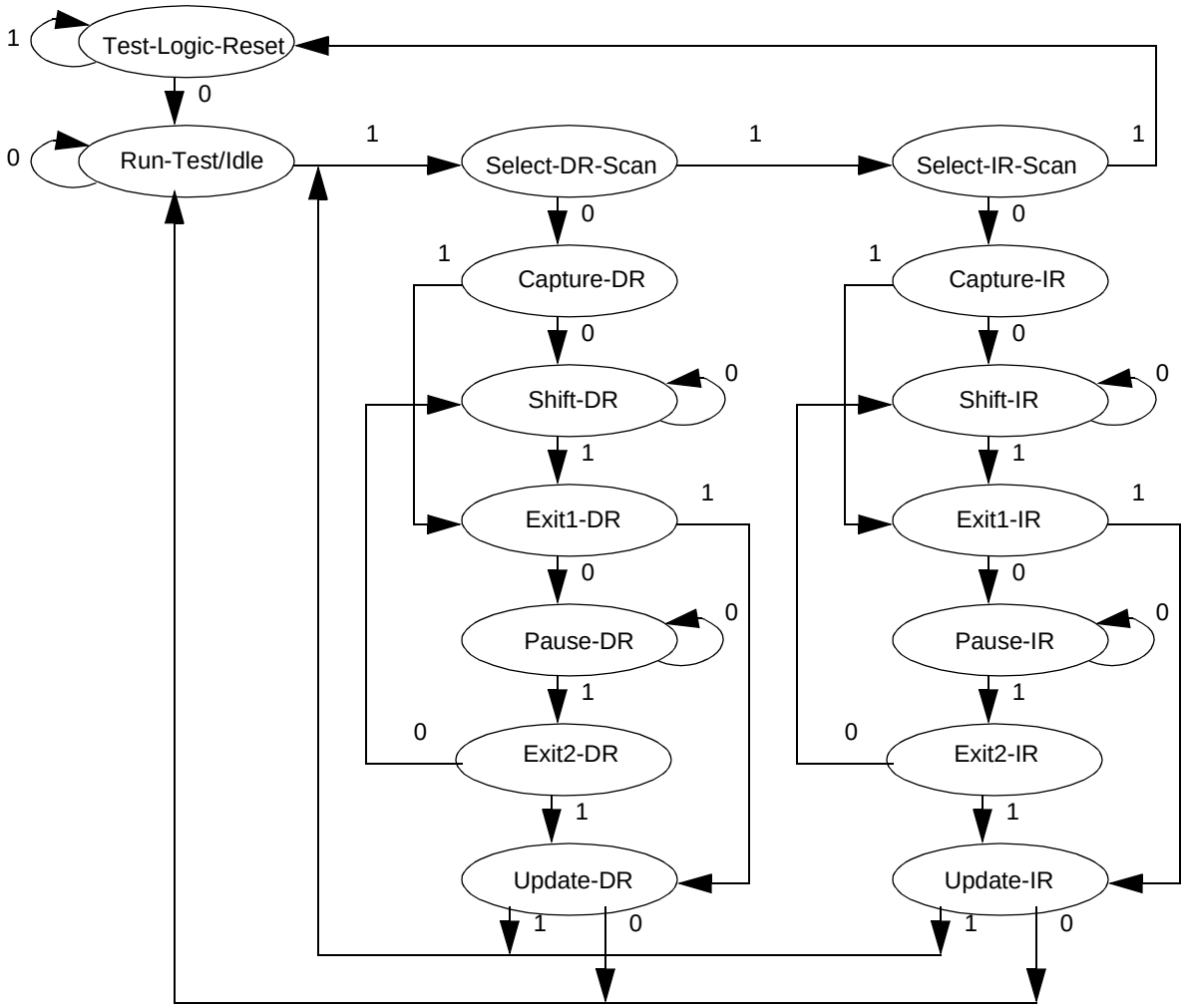
- HIGHZ—The instruction code is “0011”. The HIGHZ instruction connects the Bypass Register between BNDSCN_TDI and BNDSCN_TDO. This instruction makes all outputs (both two- and three-state) on the ÉlanSC400 and ÉlanSC410 microcontrollers disabled or puts them in a high-impedance state.

- BYPASS—The instruction code is “1111". The BYPASS instruction selects the bypass register to be connected to BNDSCN_TDI or BNDSCN_TDO, effectively bypassing the test logic on the ÉlanSC400 and ÉlanSC410 microcontrollers by reducing the shift length of the device to one bit. Note that an open circuit fault in the board-level test data path causes the Bypass Register to be selected following an instruction scan cycle due to the pull-up resistor on the BDNSCN_TDI input. This has been done to prevent any unwanted interference with the proper operation of the system logic.

21.3 TEST ACCESS PORT CONTROLLER OPERATION

The TAP controller is a synchronous, finite state machine that controls the sequence of operations of the test logic. The TAP controller changes state in response to the rising edge of BNDSCN_TCK and defaults to the Test-Logic-Reset state at power-up. Re-initialization to the Test-Logic-Reset state is accomplished by holding the BNDSCN_TMS pin High for five BNDSCN_TCK periods. The TAP controller is shown in Figure 21-3.

Figure 21-3 TAP Controller State Diagram



21.3.1 TAP Controller States

21.3.1.1 Test-Logic-Reset State

In this state, the test logic is disabled so that normal operation of the device can continue unhindered. This is achieved by initializing the instruction register such that the IDCODE instruction is loaded. No matter what the original state of the controller, the controller enters Test-Logic-Reset state when the BNDSCN_TMS input is held High (1) for at least five rising edges of BNDSCN_TCK. The controller remains in this state while BNDSCN_TMS is High. The TAP controller is also forced to enter this state at power-up.

21.3.1.2 Run-Test-Idle State

This is a controller state between scan operations. When in this state, the controller remains in this state as long as BNDSCN_TMS is held Low. For instructions not causing functions to execute during this state, no activity occurs in the test logic. The instruction register and all test data registers retain their previous state. When BNDSCN_TMS is High and a rising edge is applied to BNDSCN_TCK, the controller moves to the Select-DR state.

21.3.1.3 Select-DR-Scan State

This is a temporary controller state. The test data register selected by the current instruction retains its previous state. If BNDSCN_TMS is held Low and a rising edge is applied to BNDSCN_TCK when in this state, the controller moves into the Capture-DR state and a scan sequence for the selected test data register is initiated. If BNDSCN_TMS is held High and a rising edge is applied to BNDSCN_TCK, the controller moves to the Select-IR-Scan state.

The instruction does not change in this state.

21.3.1.4 Capture-DR State

In this state, the BSR captures input pin data if the current instruction is EXTEST or SAMPLE/PRELOAD. The other test data registers, which do not have parallel input, are not changed.

The instruction does not change in this state.

When the TAP controller is in this state and a rising edge is applied to BNDSCN_TCK, the controller enters the Exit1-DR state if BNDSCN_TMS is High, or the Shift-DR state if BNDSCN_TMS is Low.

21.3.1.5 Shift-DR State

In this controller state, the test data register connected between BNDSCN_TDI and BNDSCN_TDO as a result of the current instruction shifts data one stage toward its serial output on each rising edge of BNDSCN_TCK.

The instruction does not change in this state.

When the TAP controller is in this state and a rising edge is applied to BNDSCN_TCK, the controller enters the Exit1-DR state if BNDSCN_TMS is High, or remains in the Shift-DR state if BNDSCN_TMS is Low.

21.3.1.6 Exit1-DR State

This is a temporary state. While in this state, if BNDSCN_TMS is held High, a rising edge applied to BNDSCN_TCK causes the controller to enter the Update-DR state, which terminates the scanning process. If BNDSCN_TMS is held Low and a rising edge is applied to BNDSCN_TCK, the controller enters the Pause-DR state.

The test data register selected by the current instruction retains its previous value during this state. The instruction does not change in this state.

21.3.1.7 Pause-DR State

The pause state allows the test controller to temporarily halt the shifting of data through the test data register in the serial path between BNDSCN_TDI and BNDSCN_TDO. An example of using this state could be to allow a tester to reload its pin memory from disk during application of a long test sequence.

The test data register selected by the current instruction retains its previous value during this state. The instruction does not change in this state.

The controller remains in this state as long as BNDSCN_TMS is Low. When BNDSCN_TMS goes High and a rising edge is applied to BNDSCN_TCK, the controller moves to the Exit2-DR state.

21.3.1.8 Exit2-DR State

This is a temporary state. While in this state, if BNDSCN_TMS is held High, a rising edge applied to BNDSCN_TCK causes the controller to enter the Update-DR state, which terminates the scanning process. If BNDSCN_TMS is held Low and a rising edge is applied to BNDSCN_TCK, the controller enters the Shift-DR state.

The test data register selected by the current instruction retains its previous value during this state. The instruction does not change in this state.

21.3.1.9 Update-DR State

The BSR is provided with a latched parallel output to prevent changes at the parallel output while data is shifted in response to the EXTEST and SAMPLE/PRELOAD instructions. When the TAP controller is in this state and the BSR is selected, data is latched onto the parallel output of this register from the shift-register path on the falling edge of BNDSCN_TCK. The data held at the latched parallel output does not change other than in this state.

All shift-register stages in a test data register selected by the current instruction retain their previous values during this state. The instruction does not change in this state.

21.3.1.10 Select-IR-Scan State

This is a temporary controller state. The test data register selected by the current instruction retains its previous state. If BNDSCN_TMS is held Low and a rising edge is applied to BNDSCN_TCK when in this state, the controller moves into the Capture-IR state and a scan sequence for the instruction register is initiated. If BNDSCN_TMS is held High and a rising edge is applied to BNDSCN_TCK, the controller moves to the Test-Logic-Reset state.

The instruction does not change in this state.

21.3.1.11 Capture-IR State

In this controller state, the shift register contained in the instruction register loads the fixed value “0001" on the rising edge of BNDSCN_TCK.

The test data register selected by the current instruction retains its previous value during this state. The instruction does not change in this state.

When the controller is in this state and a rising edge is applied to BNDSCN_TCK, the controller enters the Exit1-IR state if BNDSCN_TMS is held High, or the Shift-IR state if BNDSCN_TMS is held Low.

21.3.1.12 Shift-IR State

In this state, the shift register contained in the instruction register is connected between BNDSCN_TDI and BNDSCN_TDO, and shifts data one stage towards its serial output on each rising edge of BNDSCN_TCK.

The test data register selected by the current instruction retains its previous value during this state. The instruction does not change in this state.

When the controller is in this state and a rising edge is applied to BNDSCN_TCK, the controller enters the Exit1-IR state if BNDSCN_TMS is held High, or remains in the Shift-IR state if BNDSCN_TMS is held Low.

21.3.1.13 Exit1-IR State

This is a temporary state. While in this state, if BNDSCN_TMS is held High, a rising edge applied to BNDSCN_TCK causes the controller to enter the Update-IR state, which terminates the scanning process. If BNDSCN_TMS is held Low and a rising edge is applied to BNDSCN_TCK, the controller enters the Pause-IR state.

The test data register selected by the current instruction retains its previous value during this state. The instruction does not change in this state.

21.3.1.14 Pause-IR State

The pause state allows the test controller to temporarily halt the shifting of data through the instruction register.

The test data register selected by the current instruction retains its previous value during this state. The instruction does not change in this state.

The controller remains in this state as long as BNDSCN_TMS is Low. When BNDSCN_TMS goes High and a rising edge is applied to BNDSCN_TCK, the controller moves to the Exit2-IR state.

21.3.1.15 Exit2-IR State

This is a temporary state. While in this state, if BNDSCN_TMS is held High, a rising edge applied to BNDSCN_TCK causes the controller to enter the Update-IR state, which terminates the scanning process. If BNDSCN_TMS is held Low and a rising edge is applied to BNDSCN_TCK, the controller enters the Shift-IR state.

The test data register selected by the current instruction retains its previous value during this state. The instruction does not change in this state.

21.3.1.16 Update-IR State

The instruction shifted into the instruction register is latched onto the parallel output from the shift-register path on the falling edge of BNDSCN_TCK. When the new instruction has been latched, it becomes the current instruction.

Test data registers selected by the current instruction retain their previous value.

21.3.2 Order of Scan Cells in Boundary-Scan Path

This section documents the scan paths and the order of scan cells in the paths. There are three scan paths from BNDSCN_TDI to BNDSCN_TDO in the ÉlanSC400 and ÉlanSC410 microcontrollers: 1) the instruction path, 2) the bypass path, and 3) the main data path through the BSR.

21.3.2.1 Instruction Path

This four-cell path is used to scan into the Instruction Register. This chain is loaded when the TAP controller is driven to the states Select-IR-Scan through Update-IR.
See Figure 21-3.

21.3.2.2 Bypass Path

This path bypasses the test logic on the microcontroller by reducing the shift length of the device to one bit.

21.3.2.3 Main Data Scan Path

Table 21-2 shows the main data scan path. The order shown is first-to-last; i.e., the first is closest to BNDSCN_TDI and the last is closest to BNDSCN_TDO. Control cells are used to control the enables of the three-state pads. They are part of the boundary-scan chain

that is connected between BNDSCN_TDI and BNDSCN_TDO. Their values are shifted serially through BNDSCN_TDI into the boundary-scan chain. If “1" is loaded into the control cell, the associated pins are three-stated or selected as inputs.

Each of the control cells shown in Table 21-2 contains the output enable control for the pads listed below the control cell and before the next control cell. The control cell for the first group is the last element in the scan-chain.

Table 21-2 Main Data Scan Path

Bit	Pad Name	JTAG Cell Type	Comment
281	$\overline{\text{CD_A}}$	Input	
280	$\overline{\text{RDY_A}}$	Input	
279	$\overline{\text{WAIT_AB}}$	Input	
278	WP_A	Input	
277	BVD2_A	Input	
276	BVD1_A	Input	
275	GPIO25	Input	
274	GPIO25	Output	
273	GPIO22	Input	
272	GPIO22	Output	
271	GPIO30	Input	
270	GPIO30	Output	
269	GPIO31	Input	
268	GPIO31	Output	
267	GPIO24	Input	
266	GPIO24	Output	
265	GPIO26	Input	
264	GPIO26	Output	
263	GPIO21	Input	
262	GPIO21	Output	
261	GPIO23	Input	
260	GPIO23	Output	
259	GPIO29	Input	
258	GPIO29	Output	
257	GPIO28	Input	
256	GPIO28	Output	
255	GPIO27	Input	
254	GPIO27	Output	
253	**N/A**	**Control cell**	**Controller for miscellaneous cells**
252	SPKR	Output	
251	$\overline{\text{RESET}}$	Input	
250	$\overline{\text{RTS}}$	Output	
249	SIROUT	Output	
248	$\overline{\text{DTR}}$	Output	
247	$\overline{\text{DCD}}$	Input	

Table 21-2 Main Data Scan Path (continued)

Bit	Pad Name	JTAG Cell Type	Comment
246	SIRIN	Input	
245	$\overline{\text{DSR}}$	Input	
244	$\overline{\text{CTS}}$	Input	
243	SOUT	Output	
242	SIN	Input	
241	$\overline{\text{RIN}}$	Input	
240	ACIN	Input	
239	RSTDRV	Output	
238	SUS_RES	Input	
237	$\overline{\text{BL2}}$	Input	
236	$\overline{\text{BL1}}$	Input	
235	$\overline{\text{BL0}}$	Input	
234	$\overline{\text{BL0}}$	Output	
233	GPIO19	Input	
232	GPIO19	Output	
231	GPIO18	Input	
230	GPIO18	Output	
229	GPIO17	Input	
228	GPIO17	Output	
227	**N/A**	**Control cell**	**Bus control**
226	GPIO16	Input	
225	GPIO16	Output	
224	GPIO15	Input	
223	GPIO15	Output	
222	GPIO_CS14	Input	
221	GPIO_CS14	Output	
220	GPIO_CS13	Input	
219	GPIO_CS13	Output	
218	GPIO_CS12	Input	
217	GPIO_CS12	Output	
216	GPIO_CS11	Input	
215	GPIO_CS11	Output	
214	GPIO_CS10	Input	
213	GPIO_CS10	Output	
212	GPIO_CS9	Input	
211	GPIO_CS9	Output	
210	GPIO_CS8	Input	
209	GPIO_CS8	Output	
208	GPIO_CS7	Input	
207	GPIO_CS7	Output	
206	GPIO_CS6	Input	
205	GPIO_CS6	Output	

Table 21-2 Main Data Scan Path (continued)

Bit	Pad Name	JTAG Cell Type	Comment
204	GPIO_CS5	Input	
203	GPIO_CS5	Output	
202	GPIO_CS1	Input	
201	GPIO_CS1	Output	
200	GPIO_CS0	Input	
199	GPIO_CS0	Output	
198	$\overline{\text{MEMR}}$	Output	
197	$\overline{\text{MEMW}}$	Output	
196	$\overline{\text{ROMWR}}$	Output	
195	$\overline{\text{ROMRD}}$	Output	
194	$\overline{\text{ROMCS0}}$	Output	
193	$\overline{\text{ROMCS1}}$	Output	
192	$\overline{\text{IOR}}$	Output	
191	$\overline{\text{IOW}}$	Output	
190	**N/A**	**Control cell**	**Control for address bus**
189	SA0	Output	
188	SA1	Output	
187	SA2	Output	
186	SA3	Output	
185	SA4	Output	
184	SA5	Output	
183	SA6	Output	
182	SA7	Output	
181	SA8	Output	
180	SA9	Output	
179	SA10	Output	
178	SA11	Output	
177	SA12	Output	
176	SA13	Output	
175	SA14	Output	
174	SA15	Output	
173	SA16	Output	
172	SA17	Output	
171	SA18	Output	
170	SA19	Output	
169	SA20	Output	
168	SA21	Output	
167	SA22	Output	
166	SA23	Output	
165	SA24	Output	
164	SA25	Output	
163	GPIO20	Input	

Table 21-2 Main Data Scan Path (continued)

Bit	Pad Name	JTAG Cell Type	Comment
162	GPIO20	Output	
161	**N/A**	**Control cell**	
160	SCK	Output	
159	LC	Output	
158	M	Output	
157	FRM	Output	
156	LCDD7	Output	
155	LCDD6	Input	
154	LCDD6	Output	
153	LCDD5	Output	
152	LCDD4	Input	
151	LCDD4	Output	
150	LCDD3	Output	
149	LCDD2	Output	
148	LCDD1	Output	
147	LCDD0	Output	
146	$\overline{\text{LVEE}}$	Input	
145	$\overline{\text{LVEE}}$	Output	
144	$\overline{\text{LVDD}}$	Output	
143	GPIO_CS3	Input	
142	GPIO_CS3	Output	
141	GPIO_CS2	Input	
140	GPIO_CS2	Output	
139	KBD_ROW0	Input	
138	KBD_ROW0	Output	
137	KBD_ROW1	Input	
136	KBD_ROW1	Output	
135	KBD_ROW2	Input	
134	KBD_ROW2	Output	
133	KBD_ROW3	Input	
132	KBD_ROW3	Output	
131	KBD_ROW4	Input	
130	KBD_ROW4	Output	
129	KBD_ROW5	Input	
128	KBD_ROW5	Output	
127	KBD_ROW6	Input	
126	KBD_ROW6	Output	
125	**N/A**	**Control cell**	
124	$\overline{\text{RAS1}}$	Output	
123	$\overline{\text{RAS0}}$	Output	
122	$\overline{\text{CASH1}}$	Output	

Table 21-2 Main Data Scan Path (continued)

Bit	Pad Name	JTAG Cell Type	Comment
121	$\overline{\text{CASH0}}$	Output	
120	$\overline{\text{CASL1}}$	Output	
119	$\overline{\text{CASL0}}$	Output	
118	MA11	Output	
117	MA10	Output	
116	MA9	Output	
115	MA8	Output	
114	MA7	Output	
113	MA6	Output	
112	MA5	Output	
111	MA4	Output	
110	MA3	Input	
109	MA3	Output	
108	MA2	Input	
107	MA2	Output	
106	MA1	Input	
105	MA1	Output	
104	MA0	Input	
103	MA0	Output	
102	$\overline{\text{MWE}}$	Output	
101	**N/A**	**Control cell**	**Control for data bus**
100	D0	Input	
99	D0	Output	
98	D1	Input	
97	D1	Output	
96	D2	Input	
95	D2	Output	
94	D3	Input	
93	D3	Output	
92	D4	Input	
91	D4	Output	
90	D5	Input	
89	D5	Output	
88	D6	Input	
87	D6	Output	
86	D7	Input	
85	D7	Output	
84	D8	Input	
83	D8	Output	
82	D9	Input	
81	D9	Output	
80	D10	Input	

Table 21-2 Main Data Scan Path (continued)

Bit	Pad Name	JTAG Cell Type	Comment
79	D10	Output	
78	D11	Input	
77	D11	Output	
76	D12	Input	
75	D12	Output	
74	D13	Input	
73	D13	Output	
72	D14	Input	
71	D14	Output	
70	D15	Input	
69	D15	Output	
68	KBD_COL7	Input	
67	KBD_COL7	Output	
66	GPIO_CS4	Input	
65	GPIO_CS4	Output	
64	KBD_ROW13	Input	
63	KBD_ROW13	Output	
62	KBD_COL2	Input	
61	KBD_COL2	Output	
60	KBD_COL3	Input	
59	KBD_COL3	Output	
58	KBD_COL4	Input	
57	KBD_COL4	Output	
56	KBD_COL5	Input	
55	KBD_COL5	Output	
54	KBD_COL6	Input	
53	KBD_COL6	Output	
52	**N/A**	**Control cell**	**Control for data bus**
51	KBD_ROW7	Input	
50	KBD_ROW7	Output	
49	KBD_ROW8	Input	
48	KBD_ROW8	Output	
47	KBD_ROW9	Input	
46	KBD_ROW9	Output	
45	KBD_ROW10	Input	
44	KBD_ROW10	Output	
43	KBD_ROW11	Input	
42	KBD_ROW11	Output	
41	KBD_ROW12	Input	
40	KBD_ROW12	Output	
39	KBD_COL0	Input	
38	KBD_COL0	Output	

Table 21-2 Main Data Scan Path (continued)

Bit	Pad Name	JTAG Cell Type	Comment
37	KBD_COL1	Input	
36	KBD_COL1	Output	
35	SD0	Input	
34	SD0	Output	
33	SD1	Input	
32	SD1	Output	
31	SD2	Input	
30	SD2	Output	
29	SD3	Input	
28	SD3	Output	
27	SD4	Input	
26	SD4	Output	
25	SD5	Input	
24	SD5	Output	
23	SD6	Input	
22	SD6	Output	
21	SD7	Input	
20	SD7	Output	
19	SD8	Input	
18	SD8	Output	
17	SD9	Input	
16	SD9	Output	
15	SD10	Input	
14	SD10	Output	
13	SD11	Input	
12	SD11	Output	
11	SD12	Input	
10	SD12	Output	
9	SD13	Input	
8	SD13	Output	
7	SD14	Input	
6	SD14	Output	
5	SD15	Input	
4	SD15	Output	
3	$\overline{OE}$	Output	
2	$\overline{WE}$	Output	
1	ICDIR	Output	
0	**N/A**	**Control cell**	

APPENDIX

A MULTIPLEXED PIN CONFIGURATION CONTROL

OVERVIEW

Many pins on the ÉlanSC400 and ÉlanSC410 microcontrollers have more than one function. Figure 4-1 and Figure 4-2 show the multiplexing of pins by function for each microcontroller.

Pins with multiplexed functions have their functions selected in one of two ways:

- By configuration pins that are latched during reset
- By firmware via programmed configuration registers

Table A-1 shows how to select the desired pin functions.

Note: *Signals noted with an asterisk (*) in Table A-1 are not supported on the ÉlanSC410 microcontroller.*

Table A-1 Multiplexed Pin Configuration Control

Signal You Want	Signals You Give Up	How to Configure the Signal You Want on the Pin
System Interface		
BALE	KBD_ROW10	Set CSC index 39h[2].
$\overline{\text{DBUFOE}}$	GPIO_CS4	Hardwire strap the CFG3 pin High.
$\overline{\text{DBUFRDH}}$	GPIO_CS3	Hardwire strap the CFG3 pin High.
$\overline{\text{DBUFRDL}}$	GPIO_CS2	Hardwire strap the CFG3 pin High.
$\overline{\text{MCS16}}$	KBD_ROW12	Set CSC index 39h[2].
$\overline{\text{PDACK1}}$	KBD_ROW7	Set CSC index 39h[2].
PDRQ1	KBD_ROW8	Set CSC index 39h[2].
PIRQ7	KBD_COL6	Set CSC index 3Ah[2].
PIRQ6	KBD_COL5	Set CSC index 3Ah[2].
PIRQ5	KBD_COL4	Set CSC index 3Ah[2].
PIRQ4	KBD_COL3	Set CSC index 3Ah[1].
PIRQ3	KBD_COL2	Set CSC index 3Ah[1].
PIRQ2	KBD_ROW9	Set CSC index 39h[2].
PIRQ1	GPIO_CS7	Set CSC index 38h[2].
PIRQ0	GPIO_CS8	Set CSC index 38h[1].
$\overline{\text{R32BFOE}}$	KBD_ROW13	Hardwire strapping both the CFG1 and CFG0 pins High enables the 32-bit ROM interface on $\overline{\text{ROMSC0}}$. This automatically enables $\overline{\text{R32BFOE}}$.
$\overline{\text{SBHE}}$	KBD_ROW11	Set CSC index 39h[2].

Table A-1 Multiplexed Pin Configuration Control (continued)

Signal You Want	Signals You Give Up	How to Configure the Signal You Want on the Pin
Memory Interface		
$\overline{\text{CASH3}}$	KBD_ROW3	Set bit 3 of the DRAM Bank x Configuration Register.
$\overline{\text{CASH2}}$	KBD_ROW2	
$\overline{\text{CASL3}}$	KBD_ROW1	
$\overline{\text{CASL2}}$	KBD_ROW0	
MA12	KBD_ROW6	
$\overline{\text{RAS3}}$	KBD_ROW5	
$\overline{\text{RAS2}}$	KBD_ROW4	
VL-Bus Control		
$\overline{\text{VL_ADS}}$	LCDD1*	Enable the VL-bus interface by setting CSC index 14h[3].
$\overline{\text{VL_BLAST}}$	$\overline{\text{LVDD}}$*	
VL_$\overline{\text{BE3}}$	LCDD7*	
VL_$\overline{\text{BE2}}$	M*	
$\overline{\text{VL_BE1}}$	LC*	
$\overline{\text{VL_BE0}}$	SCK*	
$\overline{\text{VL_BRDY}}$	$\overline{\text{LVEE}}$*	
VL_D/$\overline{\text{C}}$	LCDD5*	
VL_LCLK	FRM *	
$\overline{\text{VL_LDEV}}$	LCDD6*	
$\overline{\text{VL_LRDY}}$	LCDD4*	
VL_M/$\overline{\text{IO}}$	LCDD3*	
$\overline{\text{VL_RST}}$	LCDD0*	
$\overline{\text{VL_W/R}}$	LCDD2*	
ISA Bus		
AEN	GPIO_CS10	Set CSC index 38h[0].
IOCHRDY	GPIO_CS6	Set CSC index 38h[3].
$\overline{\text{IOCS16}}$	GPIO_CS5	Set CSC index 38h[4].
$\overline{\text{PDACK0}}$	GPIO_CS11	Set CSC index 38h[0]
PDRQ0	GPIO_CS12	Set CSC index 38h[0].
TC	GPIO_CS9	Set CSC index 38h[0].
GPIOs		
GPIO31	$\overline{\text{STRB}}$, $\overline{\text{MCEL_B}}$*	Clear CSC index 39h[1–0].
GPIO30	$\overline{\text{AFDT}}$, $\overline{\text{MCEH_B}}$*	Clear CSC index 39h[1–0].
GPIO29	$\overline{\text{SLCTIN}}$, RST_B*	Clear CSC index 39h[1–0].
GPIO28	$\overline{\text{INIT}}$, $\overline{\text{REG_B}}$*	Clear CSC index 39h[1–0].
GPIO27	$\overline{\text{ERROR}}$, $\overline{\text{CD_B}}$*	Clear CSC index 39h[1–0].
GPIO26	PE, RDY_B*	Clear CSC index 39h[1–0].
GPIO25	$\overline{\text{ACK}}$, BVD1_B*	Clear CSC index 39h[1–0].
GPIO24	BUSY, BVD2_B*	Clear CSC index 39h[1–0].
GPIO23	SLCT, WP_B*	Clear CSC index 39h[1–0].

Table A-1 Multiplexed Pin Configuration Control (continued)

Signal You Want	Signals You Give Up	How to Configure the Signal You Want on the Pin
GPIO22	$\overline{\text{PPOEN}}$	Clear CSC index 39h[1–0].
GPIO21	$\overline{\text{PPDWE}}$	Clear CSC index 39h[1–0].
GPIO20	$\overline{\text{CD_A2}}$*	Clear CSC index 3Ah[0].
GPIO19	$\overline{\text{LBL2}}$	Clear CSC index 39h[4].
GPIO18	PCMB_VPP2*	Clear CSC index 39h[6].
GPIO17	PCMB_VPP1*	Clear CSC index 39h[6].
GPIO16	$\overline{\text{PCMB_VCC}}$*	Clear CSC index 39h[6].
GPIO15	PCMA_VPP2*	Clear CSC index 39h[5].
GPIO_CS14	PCMA_VPP1*	Clear CSC index 39h[5].
GPIO_CS13	$\overline{\text{PCMA_VCC}}$*	Clear CSC index 39h[5].
GPIO_CS12	PDRQ0	Clear CSC index 38h[0].
GPIO_CS11	$\overline{\text{PDACK0}}$	Clear CSC index 38h[0].
GPIO_CS10	AEN	Clear CSC index 38h[0].
GPIO_CS9	TC	Clear CSC index 38h[0].
GPIO_CS8	PIRQ0	Clear CSC index 38h[1].
GPIO_CS7	PIRQ1	Clear CSC index 38h[2].
GPIO_CS6	IOCHRDY	Clear CSC index 38h[3].
GPIO_CS5	$\overline{\text{IOCS16}}$	Clear CSC index 38h[4].
GPIO_CS4	$\overline{\text{DBUFOE}}$	Hardwire-strap the CFG3 pin Low.
GPIO_CS3	$\overline{\text{DBUFRDH}}$	Hardwire-strap the CFG3 pin Low.
GPIO_CS2	$\overline{\text{DBUFRDL}}$	Hardwire-strap the CFG3 pin Low.
Parallel Port		
$\overline{\text{ACK}}$	GPIO25, BVD1_B*	Write CSC index 39h[1–0] to 10.
$\overline{\text{AFDT}}$	GPIO30, $\overline{\text{MCEH_B}}$*	
BUSY	GPIO24, BVD2_B*	
$\overline{\text{ERROR}}$	GPIO27, $\overline{\text{CD_B}}$*	
$\overline{\text{INIT}}$	GPIO28, $\overline{\text{REG_B}}$*	
PE	GPIO26, RDY_B*	
SLCT	GPIO23, WP_B*	
$\overline{\text{SLCTIN}}$	GPIO29, RST_B*	
$\overline{\text{STRB}}$	GPIO31, $\overline{\text{MCEL_B}}$*	
Keyboard Interfaces		
XT_CLK	KBD_COL1	Clear CSC index 39h[3].
XT_DATA	KBD_COL0	Clear CSC index 39h[3].
KBD_COL6	PIRQ7	Clear CSC index 3Ah[1].
KBD_COL5	PIRQ6	Clear CSC index 3Ah[1].
KBD_COL4	PIRQ5	Clear CSC index 3Ah[1].
KBD_COL3	PIRQ4	Clear CSC index 3Ah[1].
KBD_COL2	PIRQ3	Clear CSC index 3Ah[1].
KBD_COL1	XT_CLK	Clear CSC index 39h[3].

Table A-1 Multiplexed Pin Configuration Control (continued)

Signal You Want	Signals You Give Up	How to Configure the Signal You Want on the Pin
KBD_COL0	XT_DATA	Clear CSC index 39h[3].
KBD_ROW13	R32BFOE	Do not enable the 32-bit ROM interface on ROMCS0 (e.g., do not hardwire strap both the CFG1 and CFG0 pins High).
KBD_ROW12	MCS16	Clear CSC index 39h[2].
KBD_ROW11	SBHE	Clear CSC index 39h[2].
KBD_ROW10	BALE	Clear CSC index 39h[2].
KBD_ROW9	PIRQ2	Clear CSC index 39h[2].
KBD_ROW8	PDRQ1	Clear CSC index 39h[2].
KBD_ROW7	PDACK1	Clear CSC index 39h[2].
KBD_ROW6	MA12	Clear bit 3 of the DRAM Bank x Configuration Register.
KBD_ROW5	RAS3	Clear bit 3 of the DRAM Bank x Configuration Register.
KBD_ROW4	RAS2	Clear bit 3 of the DRAM Bank x Configuration Register.
KBD_ROW3	CASH3	Clear bit 3 of the DRAM Bank x Configuration Register.
KBD_ROW2	CASH2	Clear bit 3 of the DRAM Bank x Configuration Register.
KBD_ROW1	CASL3	Clear bit 3 of the DRAM Bank x Configuration Register.
KBD_ROW0	CASL2	Clear bit 3 of the DRAM Bank x Configuration Register.
PC Card Controller (ÉlanSC400 Microcontroller Only)		
BVD1_B*	GPIO25, ACK	Write CSC index 39h[1–0] to 01.
BVD2_B*	GPIO24, BUSY	Write CSC index 39h[1–0] to 01.
CD_A2*	GPIO20	Set CSC index 3Ah[0].
CD_B*	GPIO27, ERROR	Write CSC index 39h[1–0] to 01.
LBL2*	GPIO19	Set CSC index 39h[4].
MCEL_A*	BDNSCN_TCK	Pull the BNDSCN_EN pin Low.
MCEH_A*	BNDSCN_TMS	Pull the BNDSCN_EN pin Low.
MCEL_B*	GPIO31, STRB	Write CSC index 39h[1–0] to 01.
MCEH_B*	GPIO30, AFDT	Write CSC index 39h[1–0] to 01.
PCMA_VCC*	GPIO_CS13	Set CSC index 39h[5].
PCMA_VPP1*	GPIO_CS14	Set CSC index 39h[5].
PCMA_VPP2*	GPIO15	Set CSC index 39h[5].
PCMB_VCC*	GPIO16	Set CSC index 39h[6].
PCMB_VPP1*	GPIO17	Set CSC index 39h[6].
PCMB_VPP2*	GPIO18	Set CSC index 39h[6].
REG_A*	BNDSCN_TDO	Pull the BNDSCN_EN pin Low.
RST_A*	BNDSCN_TDI	Pull the BNDSCN_EN pin Low.
REG_B*	GPIO28, INIT	Write CSC index 39h[1–0] to 01.
RST_B*	GPIO29, SLCTIN	Write CSC index 39h[1–0] to 01.
RDY_B*	GPIO26, PE	Write CSC index 39h[1–0] to 01.
WP_B*	GPIO23, SLCT	Write CSC index 39h[1–0] to 01.

Table A-1 Multiplexed Pin Configuration Control (continued)

Signal You Want	Signals You Give Up	How to Configure the Signal You Want on the Pin
LCD Graphics Controller (ÉlanSC400 Microcontroller Only)		
FRM*	VL_LCLK	Enable the graphics controller by setting CSC index DDh[2].
LC*	$\overline{\text{VL_BE1}}$	
LCDD0*	$\overline{\text{VL_RST}}$	
LCDD1*	$\overline{\text{VL_ADS}}$	
LCDD2*	$\overline{\text{VL_W/R}}$	
LCDD3*	VL_M/$\overline{\text{IO}}$	
LCDD4*	$\overline{\text{VL_LRDY}}$	
LCDD5*	VL_D/$\overline{\text{C}}$	
LCDD6*	$\overline{\text{VL_LDEV}}$	
LCDD7*	VL_$\overline{\text{BE3}}$	
$\overline{\text{LVEE}}$*	$\overline{\text{VL_BRDY}}$	
$\overline{\text{LVDD}}$*	$\overline{\text{VL_BLAST}}$	
M*	VL_$\overline{\text{BE2}}$	
SCK*	$\overline{\text{VL_BE0}}$	
Boundary Scan Interface		
BDNSCN_TCK	$\overline{\text{MCEL_A}}$*	Pull the BNDSCN_EN pin High.
BNDSCN_TDI	RST_A*	Pull the BNDSCN_EN pin High.
BNDSCN_TDO	$\overline{\text{REG_A}}$*	Pull the BNDSCN_EN pin High.
BNDSCN_TMS	$\overline{\text{MCEH_A}}$*	Pull the BNDSCN_EN pin High.
Miscellaneous		
$\overline{\text{BL0}}$	CLK_IO	Write CSC index 38h[7–6] to 01.
CLK_IO	$\overline{\text{BL0}}$	Write CSC index 38h[7–6] to 10 to enable CLK_IO as an output or to 11 to enable as a timer clock input.
SUS_RES	KBD_ROW14	Clear bit 3 of the Keyboard Configuration Register.

Note:

** This signal is not supported on the ÉlanSC410 microcontroller.*

APPENDIX

B PIN TERMINATION

OVERVIEW

When a particular function on the microcontroller is configured to be available to the user or the system, the functions of the pins on the microcontroller change accordingly. When the pin function changes, the termination of the pin can, and often does change.

System firmware must activate the new termination as a separate operation from the actual pin function selection. This is done by setting the TERM_LATCH bit in the Suspend Mode Pin State Override Register (CSC index E5h[0]) after configuring one or more of the microcontroller's pin functions. The typical usage is to configure the chip at boot time from system firmware, and then set the termination latch bit one time after all the configuration is complete. When any of the pin functions shown in Table B-1 are changed, the TERM_LATCH bit must be set. A more complete discussion of pin termination can be found in Section 2.4.2.

Note: *Signals noted with an asterisk (*) in Table B-1 are not supported on the ÉlanSC410 microcontroller.*

Table B-1 Pin Termination Control

Control Bit	CSC Index	Pins Affected
WIDTH0, BNK_ENBL0	00h[3,7]	KBD_ROW6 [MA12]
WIDTH1, BNK_ENBL1	01h[3,7]	KBD_ROW5 [$\overline{\text{RAS3}}$]
BNK_ENBL2	02h[7]	KBD_ROW4 [$\overline{\text{RAS2}}$]
BNK_ENBL3	03h[7]	KBD_ROW3 [$\overline{\text{CASH3}}$] KBD_ROW2 [$\overline{\text{CASH2}}$] KBD_ROW1 [$\overline{\text{CASL1}}$] KBD_ROW0 [$\overline{\text{CASL0}}$]
VL_ENB	14h[3]	LCDD7* [$\overline{\text{VL_BE3}}$]
VID_ENB	DDh[2]	LCDD6* [$\overline{\text{VL_LDEV}}$] LCDD5* [$\overline{\text{VL_D_C}}$] LCDD4* [$\overline{\text{VL_LRDY}}$] LCDD3* [$\overline{\text{VL_M_IO}}$] LCDD2* [$\overline{\text{VL_W_R}}$] LCDD1* [$\overline{\text{VL_ADS}}$] LCDD0* [$\overline{\text{VL_RST}}$] M* [$\overline{\text{VL_BE2}}$] LC* [$\overline{\text{VL_BE1}}$] SCK* [$\overline{\text{VL_BE0}}$] FRM* [$\overline{\text{VL_LCLK}}$] $\overline{\text{LVEE}}$* [$\overline{\text{VL_BRDY}}$] $\overline{\text{LVDD}}$* [$\overline{\text{VL_BLAST}}$]

Table B-1 Pin Termination Control (continued)

Control Bit	CSC Index	Pins Affected
GP_EQU_DMA	38h[0]	GPIO_CS9 [TC] GPIO_CS10 [AEN] GPIO_CS11 [$\overline{\text{PDACK0}}$] GPIO_CS12 [PDRQ0]
GP_EQU_PIRQ0	38h[1]	GPIO_CS8 [PIRQ0]
GP_EQU_PIRQ1	38h[2]	GPIO_CS7 [PIRQ1]
GP_EQU_IOCHRDY	38h[3]	GPIO_CS6 [IOCHRDY]
GP_EQU_IOCS16	38h[4]	GPIO_CS5 [$\overline{\text{IOCS16}}$]
BL0_CLKIO_SLCT	38h[7–6]	$\overline{\text{BL0}}$ [CLK_IO]
PP_PCMB_SLCT	39h[1–0]	GPIO21 [$\overline{\text{PPDWE}}$] GPIO22 [$\overline{\text{PPOEN}}$] GPIO23 [SLCT] [WP_B]* GPIO24 [BUSY] [BVD2_B]* GPIO25 [$\overline{\text{ACK}}$] [BVD1_B]* GPIO26 [PE] [$\overline{\text{RDY_B}}$]* GPIO27 [$\overline{\text{ERROR}}$] [$\overline{\text{CD_B}}$]* GPIO28 [$\overline{\text{INIT}}$] [$\overline{\text{REG_B}}$]* GPIO29 [$\overline{\text{SLCTIN}}$] [RST_B]* GPIO30 [$\overline{\text{AFDT}}$] [$\overline{\text{MCEH_B}}$]* GPIO31 [$\overline{\text{STRB}}$] [$\overline{\text{MCEL_B}}$]*
ISA_KBDROW_SLCT	39h[2]	KBD_ROW7 [$\overline{\text{PDACK1}}$] KBD_ROW8 [PDRQ1] KBD_ROW9 [PIRQ2] KBD_ROW10 [BALE] KBD_ROW11 [$\overline{\text{SBHE}}$] KBD_ROW12 [$\overline{\text{MCS16}}$]
GPIO_LBL2_SLCT	39h[4]	GPIO19 [$\overline{\text{LBL2}}$]
GPIO_PCPWR_SLCTA	39h[5]	GPIO_CS13 [$\overline{\text{PCMA_VCC}}$]* GPIO_CS14 [PCMA_VPP1]* GPIO15 [PCMA_VPP2]*
GPIO_PCPWR_SLCTA	39h[6]	GPIO16 [$\overline{\text{PCMB_VCC}}$]* GPIO17 [PCMB_VPP1]* GPIO18 [PCMB_VPP2]*
GPIO_PCACD_SLCT	3Ah[0]	GPIO20 [$\overline{\text{CD_A2}}$]*
CS0_PUEN	3Bh[0]	GPIO_CS0
CS1_PUEN	3Bh[1]	GPIO_CS1
CS2_PUEN	3Bh[2]	GPIO_CS2 [$\overline{\text{DBUFRDL}}$]
CS3_PUEN	3Bh[3]	GPIO_CS3 [$\overline{\text{DBUFRDH}}$]
CS4_PUEN	3Bh[4]	GPIO_CS4 [$\overline{\text{DBUFOE}}$]
CS5_PUEN	3Bh[5]	GPIO_CS5 [$\overline{\text{IOCS16}}$]

Table B-1 Pin Termination Control (continued)

Control Bit	CSC Index	Pins Affected
CS6_PUEN	3Bh[6]	GPIO_CS6 [IOCHRDY]
CS7_PUEN	3Bh[7]	GPIO_CS7 [PIRQ1]
CS8_PUEN	3Ch[0]	GPIO_CS8 [PIRQ0]
CS9_PUEN	3Ch[1]	GPIO_CS9 [TC]
CS10_PUEN	3Ch[2]	GPIO_CS10 [AEN]
CS11_PUEN	3Ch[3]	GPIO_CS11 [$\overline{\text{PDACK0}}$]
CS12_PDEN	3Ch[4]	GPIO_CS12 [PDRQ0]
CS13_PDEN	3Ch[5]	GPIO_CS13 [$\overline{\text{PCMA_VCC}}$]*
CS14_PDEN	3Ch[6]	GPIO_CS14 [PCMA_VPP1]*
GPIO15_PDEN	3Ch[7]	GPIO15 [PCMA_VPP2]*
GPIO16_PDEN	3Dh[0]	GPIO16 [$\overline{\text{PCMB_VCC}}$]*
GPIO17_PDEN	3Dh[1]	GPIO17 [PCMB_VPP1]*
GPIO18_PDEN	3Dh[2]	GPIO18 [PCMB_VPP2]*
GPIO19_PUEN	3Dh[3]	GPIO19 [$\overline{\text{LBL2}}$]
GPIO20_PUEN	3Dh[4]	GPIO20 [$\overline{\text{CD_A2}}$]*
GPIO21_PUEN	3Dh[5]	GPIO21 [$\overline{\text{PPDWE}}$]
GPIO22_PUEN	3Dh[6]	GPIO22 [$\overline{\text{PPOEN}}$]
GPIO23_PUEN	3Dh[7]	GPIO23 [SLCT] [WP_B]*
GPIO24_PUEN	3Eh[0]	GPIO24 [BUSY] [BVD2_B]*
GPIO25_PUEN	3Eh[1]	GPIO25 [$\overline{\text{ACK}}$] [BVD1_B]*
GPIO26_PUEN	3Eh[2]	GPIO26 [PE] [$\overline{\text{RDY_B}}$]*
GPIO27_PUEN	3Eh[3]	GPIO27 [$\overline{\text{ERROR}}$] [$\overline{\text{CD_B}}$]*
GPIO28_PUEN	3Eh[4]	GPIO28 [$\overline{\text{INIT}}$] [$\overline{\text{REG_B}}$]*
GPIO29_PUEN	3Eh[5]	GPIO29 [$\overline{\text{SLCTIN}}$] [RST_B]*
GPIO30_PUEN	3Eh[6]	GPIO30 [$\overline{\text{AFDT}}$] [$\overline{\text{MCEH_B}}$]*
GPIO31_PUEN	3Eh[7]	GPIO31 [$\overline{\text{STRB}}$] [$\overline{\text{MCEL_B}}$]*
CS0_DIR	A0h[0]	GPIO_CS0
CS1_DIR	A0h[2]	GPIO_CS1
CS2_DIR	A0h[4]	GPIO_CS2 [$\overline{\text{DBUFRDL}}$]
CS3_DIR	A0h[6]	GPIO_CS3 [$\overline{\text{DBUFRDH}}$]
CS4_DIR	A1h[0]	GPIO_CS4 [$\overline{\text{DBUFOE}}$]
CS5_DIR	A1h[2]	GPIO_CS5 [$\overline{\text{IOCS16}}$]
CS6_DIR	A1h[4]	GPIO_CS6 [IOCHRDY]
CS7_DIR	A1h[6]	GPIO_CS7 [PIRQ1]

Table B-1 Pin Termination Control (continued)

Control Bit	CSC Index	Pins Affected
CS8_DIR	A2h[0]	GPIO_CS8 [PIRQ0]
CS9_DIR	A2h[2]	GPIO_CS9 [TC]
CS10_DIR	A2h[4]	GPIO_CS10 [AEN]
CS11_DIR	A2h[6]	GPIO_CS11 [$\overline{\text{PDACK0}}$]
CS12_DIR	A3h[0]	GPIO_CS12 [PDRQ0]
CS13_DIR	A3h[2]	GPIO_CS13 [$\overline{\text{PCMA_VCC}}$]*
CS14_DIR	A3h[4]	GPIO_CS14 [PCMA_VPP1]*
GPIO15_DIR	A3h[6]	GPIO15 [PCMA_VPP2]*
GPIO16_DIR	A4h[0]	GPIO16 [$\overline{\text{PCMB_VCC}}$]*
GPIO17_DIR	A4h[1]	GPIO17 [PCMB_VPP1]*
GPIO18_DIR	A4h[2]	GPIO18 [PCMB_VPP2]*
GPIO19_DIR	A4h[3]	GPIO19 [$\overline{\text{LBL2}}$]
GPIO20_DIR	A4h[4]	GPIO20 [$\overline{\text{CD_A2}}$]*
GPIO21_DIR	A4h[5]	GPIO21 [$\overline{\text{PPDWE}}$]
GPIO22_DIR	A4h[6]	GPIO22 [$\overline{\text{PPOEN}}$]
GPIO23_DIR	A4h[7]	GPIO23 [SLCT] [WP_B]*
GPIO24_DIR	A5h[0]	GPIO24 [BUSY] [BVD2_B]*
GPIO25_DIR	A5h[1]	GPIO25 [$\overline{\text{ACK}}$] [BVD1_B]*
GPIO26_DIR	A5h[2]	GPIO26 [PE] [$\overline{\text{RDY_B}}$]*
GPIO27_DIR	A5h[3]	GPIO27 [$\overline{\text{ERROR}}$] [$\overline{\text{CD_B}}$]*
GPIO28_DIR	A5h[4]	GPIO28 [$\overline{\text{INIT}}$] [$\overline{\text{REG_B}}$]
GPIO29_DIR	A5h[5]	GPIO29 [$\overline{\text{SLCTIN}}$] [RST_B]*
GPIO30_DIR	A5h[6]	GPIO30 [$\overline{\text{AFDT}}$] [$\overline{\text{MCEH_B}}$]*
GPIO31_DIR	A5h[7]	GPIO31 [$\overline{\text{STRB}}$] [$\overline{\text{MCEL_B}}$]*
COL0PULLUP	CAh[0]	KBD_COL0 [XT_DAT]
COL1PULLUP	CAh[1]	KBD_COL1 [XT_CLK]
COL2PULLUP	CAh[2]	KBD_COL2 [PIRQ3]
COL3PULLUP	CAh[3]	KBD_COL3 [PIRQ4]
COL4PULLUP	CAh[4]	KBD_COL4 [PIRQ5]
COL5PULLUP	CAh[5]	KBD_COL5 [PIRQ6]
COL6PULLUP	CAh[6]	KBD_COL6 [PIRQ7]
COL7PULLUP	CAh[7]	KBD_COL7

Table B-1 Pin Termination Control (continued)

Control Bit	CSC Index	Pins Affected
UART_ENB	D1h[0]	SIN $\overline{\text{RIN}}$ $\overline{\text{DSR}}$ $\overline{\text{DCD}}$ $\overline{\text{CTS}}$ SOUT $\overline{\text{RTS}}$ $\overline{\text{DTR}}$
PP_MODE	D2h[1–0]	GPIO23 [SLCT] [WP_B]* GPIO24 [BUSY] [BVD2_B]* GPIO25 [$\overline{\text{ACK}}$] [BVD1_B]* GPIO26 [PE] [$\overline{\text{RDY_B}}$]* GPIO27 [$\overline{\text{ERROR}}$] [$\overline{\text{CD_B}}$]* GPIO28 [$\overline{\text{INIT}}$] [$\overline{\text{REG_B}}$]* GPIO29 [$\overline{\text{SLCTIN}}$] [RST_B]* GPIO30 [$\overline{\text{AFDT}}$] [$\overline{\text{MCEH_B}}$]* GPIO31 [$\overline{\text{STRB}}$] [$\overline{\text{MCEL_B}}$]*
SIRIN_PD_DIS	EAh[6]	SIRIN
SKA_PU_EN	F2h[0]	GPIO20 [$\overline{\text{CD_A2}}$]* $\overline{\text{CD_A}}$* $\overline{\text{RDY_A}}$* $\overline{\text{BVD1_A}}$* $\overline{\text{BVD2_A}}$* WP_A* $\overline{\text{WAIT_AB}}$*
SKB_PU_EN	F2h[1]	GPIO23 [SLCT] [WP_B]* GPIO24 [BUSY] [BVD2_B]* GPIO25 [$\overline{\text{ACK}}$] [BVD1_B]* GPIO26 [PE] [$\overline{\text{RDY_B}}$]* GPIO27 [$\overline{\text{ERROR}}$] [$\overline{\text{CD_B}}$]*

** This signal is not supported on the ÉlanSC410 microcontroller.*

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