

CMOS Micropower Phase-Locked Loop

■ CD4046B CMOS Micropower Phase-Locked Loop (PLL) consists of a low-power, linear voltage-controlled oscillator (VCO) and two different phase comparators having a common signal-input amplifier and a common comparator input. A 5.2-V zener diode is provided for supply regulation if necessary.

The CD4046B types are supplied in 16-lead ceramic dual-in-line packages (D and F suffixes), 16-lead dual-in-line plastic packages (E suffix), and in chip form (H suffix).

VCO Section

The VCO requires one external capacitor C1 and one or two external resistors (R1 or R1 and R2). Resistor R1 and capacitor C1 determine the frequency range of the VCO and resistor R2 enables the VCO to have a frequency offset if required. The high input impedance ($10^{12}\Omega$) of the VCO simplifies the design of low-pass filters by permitting the designer a wide choice of resistor-to-capacitor ratios. In order not to load the low-pass filter, a source-follower output of the VCO input voltage is provided at terminal 10 (DEMODULATED OUTPUT). If this terminal is used, a load resistor (R_S) of 10 k Ω or more should be connected from this terminal to VSS. If unused this terminal should be left open. The VCO can be connected either directly or through frequency dividers to the comparator input of the phase comparators. A full CMOS logic swing is available at the output of the VCO and allows direct coupling to CMOS frequency dividers such as the RCA-CD4024, CD4018, CD4020, CD4022, CD4029, and CD4059. One or more CD4018 (Presettable Divide-by-N Counter) or CD4029 (Presettable Up/Down Counter), or CD4059A (Programmable Divide-by-N Counter), together with the CD4046B (Phase-Locked Loop) can be used to build a micropower low-frequency synthesizer. A logic 0 on the INHIBIT input "enables" the VCO and the source follower, while a logic 1 "turns off" both to minimize stand-by power consumption.

MAXIMUM RATINGS, Absolute-Maximum Values:

DC SUPPLY-VOLTAGE RANGE, (V_{DD})

Voltages referenced to V_{SS} Terminal) -0.5V to +20V

INPUT VOLTAGE RANGE, ALL INPUTS -0.5V to V_{DD} +0.5V

DC INPUT CURRENT, ANY ONE INPUT $\pm 10\mu A$

POWER DISSIPATION PER PACKAGE (P_D):

For $T_A = -55^\circ C$ to $+100^\circ C$ 500mW

For $T_A = +100^\circ C$ to $+125^\circ C$ Derate Linearly at 12mW/ $^\circ C$ to 200mW

DEVICE DISSIPATION PER OUTPUT TRANSISTOR

FOR T_A = FULL PACKAGE-TEMPERATURE RANGE (All Package Types) 100mW

OPERATING-TEMPERATURE RANGE (T_A) $-55^\circ C$ to $+125^\circ C$

STORAGE TEMPERATURE RANGE (T_{stg}) $-65^\circ C$ to $+150^\circ C$

LEAD TEMPERATURE (DURING SOLDERING):

At distance 1/16 $\pm$ 1/32 inch (1.59 $\pm$ 0.79mm) from case for 10s max $+265^\circ C$

Features:

- Very low power consumption:
70 μW (typ.) at VCO $f_o = 10$ kHz, $V_{DD} = 5$ V
- Operating frequency range up to 1.4 MHz (typ.) at $V_{DD} = 10$ V, $R_1 = 5$ k Ω
- Low frequency drift: 0.04%/ $^\circ C$ (typ.) at $V_{DD} = 10$ V
- Choice of two phase comparators:
Exclusive-OR network (I)
Edge-controlled memory network with phase-pulse output for lock indication (II)
- High VCO linearity: $<1\%$ (typ.) at $V_{DD} = 10$ V
- VCO inhibit control for ON-OFF keying and ultra-low standby power consumption
- Source-follower output of VCO control input (Demod. output)
- Zener diode to assist supply regulation
- Standardized, symmetrical output characteristics
- 100% tested for quiescent current at 20 V
- 5-V, 10-V, and 15-V parametric ratings
- Meets all requirements of JEDEC Tentative Standard No. 13B, "Standard Specifications for Description of 'B' Series CMOS Devices"

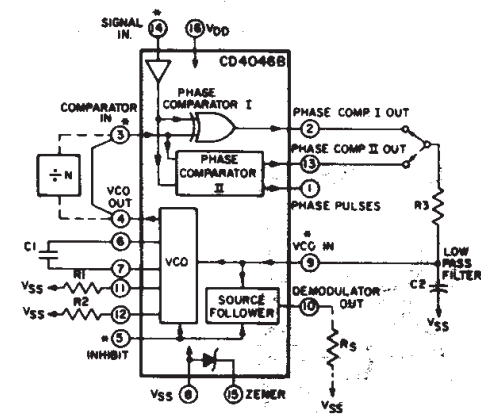
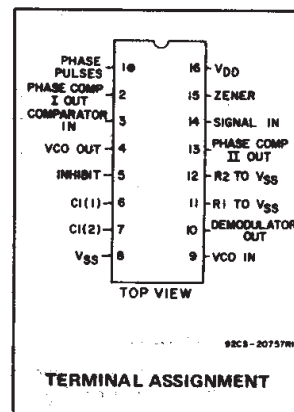
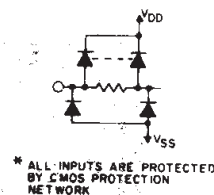


Fig. 1 - CMOS phase-locked loop block diagram.



Applications:

- FM demodulator and modulator
- Frequency synthesis and multiplication
- Frequency discriminator
- Data synchronization
- Voltage-to-frequency conversion
- Tone decoding
- FSK - Modems
- Signal conditioning
- (See ICAN-6101) "RCA COS/MOS Phase-Locked Loop - A Versatile Building Block for Micropower Digital and Analog Applications"



92CS-29172

Phase Comparators

The phase-comparator signal input (terminal 14) can be direct-coupled provided the signal swing is within CMOS logic levels [logic "0" $\leq 30\%$ ($V_{DD}-V_{SS}$), logic "1" $\geq 70\%$ ($V_{DD}-V_{SS}$)]. For smaller swings the signal must be capacitively coupled to the self-biasing amplifier at the signal input.

Phase comparator I is an exclusive-OR network; it operates analogously to an over-driven balanced mixer. To maximize the lock range, the signal- and comparator-input frequencies must have a 50% duty cycle. With no signal or noise on the signal input, this phase comparator has an average output voltage equal to $V_{DD}/2$. The low-pass filter connected to the output of phase comparator

CD4046B Types

RECOMMENDED OPERATING CONDITIONS at T_A = Full Package-Temperature Range
For maximum reliability, nominal operating conditions should be selected so that operation is always within the following ranges:

CHARACTERISTIC	LIMITS		UNITS
	Min.	Max.	
Supply-Voltage Range VCO Section: As Fixed Oscillator Phased-Lock-Loop Operation	3 5	18 18	V
Supply-Voltage Range Phase Comparator Section: Comparators VCO Operation	3 5	18 18	

DESIGN INFORMATION

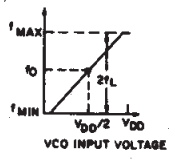
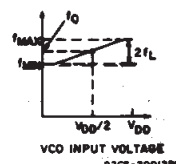
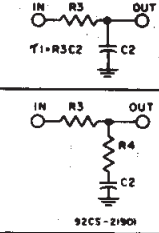
This information is a guide for approximating the values of external components for the CD4046B in a Phase-Locked-Loop system.

The selected external components must be within the following ranges:

$$5 \text{ k}\Omega \leq R_1, R_2, R_S \leq 1 \text{ M}\Omega$$

$$C_1 \geq 100 \text{ pF at } V_{DD} \geq 5 \text{ V;}$$

$$C_1 \geq 50 \text{ pF at } V_{DD} \geq 10 \text{ V}$$

Characteristics	Phase Comparator Used	Design Information
VCO Frequency		VCO WITHOUT OFFSET $R_2 = \infty$ 
		VCO WITH OFFSET 
For No. Signal Input	2	Same as for No. 1
	1	VCO will adjust to center frequency, f_0
Frequency Lock Range, $2f_L$	2	VCO will adjust to lowest operating frequency, f_{min}
	1	$2f_L = \text{full VCO frequency range}$ $2f_L = f_{max} - f_{min}$
Frequency Capture Range, $2f_C$	2	Same as for No. 1
	1	 $2f_C \approx \frac{1}{\pi} \sqrt{\frac{2\pi f_L}{\tau_1}}$ For $2f_C$, see Ref. (2)
Loop Filter Component Selection	2	$f_C = f_L$
Phase Angle Between Signal and Comparator	1	90° at center frequency (f_0) approximating 0° and 180° at ends of lock range ($2f_L$)
	2	Always 0° in lock
Locks On Harmonic of Center Frequency	1	Yes
	2	No
Signal Input Noise Rejection	1	High
	2	Low

For further information, see

- (1) F. Gardner, "Phase-Lock Techniques" John Wiley and Sons, New York, 1966
- (2) G. S. Moschytz, "Miniaturized RC Filters Using Phase-Locked Loop", BSTJ, May, 1965.

I supplies the averaged voltage to the VCO input, and causes the VCO to oscillate at the center frequency (f_0).

The frequency range of input signals on which the PLL will lock if it was initially out of lock is defined as the frequency capture range ($2f_C$).

The frequency range of input signals on which the loop will stay locked if it was initially in lock is defined as the frequency lock range ($2f_L$). The capture range is $\leq$ the lock range.

With phase comparator I the range of frequencies over which the PLL can acquire lock (capture range) is dependent on the low-pass-filter characteristics, and can be made as large as the lock range. Phase-comparator I enables a PLL system to remain in lock in spite of high amounts of noise in the input signal.

One characteristic of this type of phase comparator is that it may lock onto input frequencies that are close to harmonics of the VCO center-frequency. A second characteristic is that the phase angle between the signal and the comparator input varies between 0° and 180° , and is 90° at the center frequency. Fig. 2 shows the typical, triangular, phase-to-output response characteristic of phase-comparator I. Typical waveforms for a CMOS phase-locked-loop employing phase comparator I in locked condition of f_0 is shown in Fig. 3.

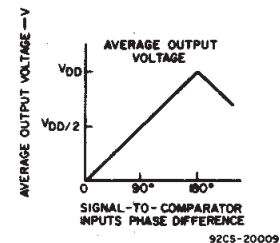


Fig. 2 - Phase-comparator I characteristics at low-pass filter output.

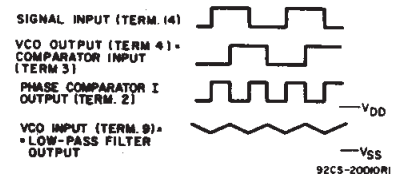


Fig. 3 - Typical waveforms for CMOS phase-locked loop employing phase comparator in locked condition of f_0 .

Phase-comparator II is an edge-controlled digital memory network. It consists of four flip-flop stages, control gating, and a three-state output circuit comprising p- and n-type drivers having a common output node. When the p-MOS or n-MOS drivers are ON they pull the output up to V_{DD} or down to V_{SS} , respectively. This type of phase-comparator acts only on the positive edges of the signal and comparator inputs. The duty cycles of the signal and comparator inputs are not important since positive transitions

CD4046B Types

STATIC ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	CONDITIONS			LIMITS AT INDICATED TEMPERATURES (°C)							UNITS
	V _O (V)	V _{IN} (V)	V _{DD} (V)	-55	-40	+85	+125	+25			
								Min.	Typ.	Max.	
VCO Section											
Output Low (Sink) Current I _{OL} Min.	0.4	0.5	5	0.64	0.61	0.42	0.36	0.51	1	—	mA
	0.5	0.10	10	1.6	1.5	1.1	0.9	1.3	2.6	—	
	1.5	0.15	15	4.2	4	2.8	2.4	3.4	6.8	—	
Output High (Source) Current, I _{OH} Min.	4.6	0.5	5	-0.64	-0.61	-0.42	-0.36	-0.51	-1	—	mA
	2.5	0.5	5	-2	-1.8	-1.3	-1.15	-1.6	-3.2	—	
	9.5	0.10	10	-1.6	-1.5	-1.1	-0.9	-1.3	-2.6	—	
	13.5	0.15	15	-4.2	-4	-2.8	-2.4	-3.4	-6.8	—	
Output Voltage: Low-Level, V _{OL} Max.	Term. 4 driving CMOS	0.5	5	0.05				—	0	0.05	V
		0.10	10	0.05				—	0	0.05	
		0.15	15	0.05				—	0	0.05	
Output Voltage: High-Level, V _{OH} Min.	e.g. Term. 3	0.5	5	4.95				4.95	5	—	V
		0.10	10	9.95				9.95	10	—	
		0.15	15	14.95				14.95	15	—	
Input Current I _{IN} Max.	—	0.18	18	±0.1	±0.1	±1	±1	—	±10 ⁻⁵	±0.1	μA
Phase Comparator Section											
Total Device Current, I _{DD} Max. Term. 14 open, Term. 5 = V _{DD}	—	0.5	5	0.2				—	0.1	0.2	mA
	—	0.10	10	1				—	0.5	1	
	—	0.15	15	1.5				—	0.75	1.5	
	—	0.20	20	4				—	2	4	
Term. 14 = V _{SS} or V _{DD} , Term. 5 = V _{DD}	—	0.5	5	20				—	10	20	μA
	—	0.10	10	40				—	20	40	
	—	0.15	15	80				—	40	80	
	—	0.20	20	160				—	80	160	
Output Low (Sink) Current I _{OL} Min.	0.4	0.5	5	0.64	0.61	0.42	0.36	0.51	1	—	mA
	0.5	0.10	10	1.6	1.5	1.1	0.9	1.3	2.6	—	
	1.5	0.15	15	4.2	4	2.8	2.4	3.4	6.8	—	
Output High (Source) Current I _{OH} Min.	4.6	0.5	5	-0.64	-0.61	-0.42	-0.36	-0.51	-1	—	mA
	2.5	0.5	5	-2	-1.8	-1.3	-1.15	-1.6	-3.2	—	
	9.5	0.10	10	-1.6	-1.5	-1.1	-0.9	-1.3	-2.6	—	
	13.5	0.15	15	-4.2	-4	-2.8	-2.4	-3.4	-6.8	—	
DC-Coupled Signal Input and Comparator Input Voltage Sensitivity Low Level V _{IL} Max.	0.5, 4.5	—	5	1.5				—	—	1.5	V
	1.9	—	10	3				—	—	3	
	1.5, 13.5	—	15	4				—	—	4	
High Level V _{IH} Min.	0.5, 4.5	—	5	3.5				3.5	—	—	V
	1.9	—	10	7				7	—	—	
	1.5, 13.5	—	15	11				11	—	—	

control the PLL system utilizing this type of comparator. If the signal-input frequency is higher than the comparator-input frequency, the p-type output driver is maintained ON most of the time, and both the n and p drivers OFF (3 state) the remainder

of the time. If the signal-input frequency is lower than the comparator-input frequency, the n-type output driver is maintained ON most of the time, and both the n and p drivers OFF (3 state) the remainder of the time. If the signal- and comparator-

input frequencies are the same, but the signal input lags the comparator input in phase, the n-type output driver is maintained ON for a time corresponding to the phase difference. If the signal- and comparator-input frequencies are the same, but

CD4046B Types

STATIC ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	CONDITIONS			LIMITS AT INDICATED TEMPERATURES (°C)							UNITS
	V _O (V)	V _{IN} (V)	V _{DD} (V)	-55	-40	+85	+125	+25			
								Min.	Typ.	Max.	
Phase Comparator Section (cont'd)											
Input Current I _{IN} Max. (except Term. 14)	—	0.18	18	±0.1	±0.1	±1	±1	—	±10 ⁻⁵	±0.1	μA
3-State Leakage Current, I _{OUT} Max.	0.18	0.18	18	±0.1	±0.1	±0.2	±0.2	—	±10 ⁻⁵	±0.1	μA

*Limit determined by minimum feasible leakage current measurement for automatic testing.

ELECTRICAL CHARACTERISTICS at T_A = 25°C

CHARACTERISTIC	TEST CONDITIONS		V _{DD} (V)	LIMITS			UNITS
				ALL TYPES			
				Min.	Typ.	Max.	
VCO Section							
Operating Power Dissipation, P _D	f _o = 10 kHz R ₂ = ∞ VCO _{IN} = $\frac{V_{DD}}{2}$	R ₁ = 1 MΩ	5	—	70	140	μW
			10	—	800	1600	
			15	—	3000	6000	
Maximum Operating Frequency f _{max}	C ₁ = 50 pF R ₂ = ∞ VCO _{IN} = V _{DD}	R ₁ = 10 kΩ	5	0.3	0.6	—	MHz
			10	0.6	1.2	—	
			15	0.8	1.6	—	
	C ₁ = 50 pF R ₂ = ∞ VCO _{IN} = V _{DD}	R ₁ = 5 kΩ	5	0.5	0.8	—	
			10	1	1.4	—	
			15	1.4	2.4	—	
Center Frequency (f _o) and Frequency Range (f _{max} —f _{min})	Programmable with external components R1, R2, and C1 See Design Information						
Linearity	VCO _{IN} = 2.5 V ± 0.3V, R ₁ = 10 kΩ		5	—	1.7	—	%
		$\pm 5\text{ V} \pm 1\text{ V}$, = 100 kΩ	10	—	0.5	—	
		$\pm 5\text{ V} \pm 2.5\text{ V}$, = 400 kΩ	10	—	4	—	
		$\pm 7.5\text{ V} \pm 1.5\text{ V}$, = 100 kΩ	15	—	0.5	—	
		$\pm 7.5\text{ V} \pm 5\text{ V}$, = 1 MΩ	15	—	7	—	
Temperature - Frequency Stability: No Frequency Offset f _{MIN} = 0			5	—	±0.12	—	% / °C
			10	—	±0.04	—	
			15	—	±0.015	—	
Frequency Offset f _{MIN} ≠ 0			5	—	±0.09	—	% / °C
			10	—	±0.07	—	
			15	—	±0.03	—	
Output Duty Cycle			5, 10, 15	—	50	—	%
Output Transition Times, t _{THL} , t _{TLH}			5	—	100	200	ns
			10	—	50	100	
			15	—	40	80	

the comparator input lags the signal in phase, the p-type output driver is maintained ON for a time corresponding to the phase difference. Subsequently, the capacitor voltage of the low-pass filter connected to this phase comparator is adjusted until the signal and comparator inputs are equal in both phase and frequency. At this stable point both p- and n-type output drivers remain OFF and thus the phase comparator output becomes an open circuit and holds the voltage on the capacitor of the low-pass filter constant. Moreover the signal at the "phase pulses" output is a high level which can be used for indicating a locked condition. Thus, for phase comparator II, no phase difference exists between signal and comparator input over the full VCO frequency range. Moreover, the power dissipation due to the low-pass filter is reduced when this type of phase comparator is used because both the p- and n-type output drivers are OFF for most of the signal input cycle. It should be noted that the PLL lock range for this type of phase comparator is equal to the capture range, independent of the low-pass filter. With no signal present at the signal input, the VCO is adjusted to its lowest frequency for phase comparator II. Fig. 10 shows typical waveforms for a CMOS PLL employing phase comparator II in a locked condition.

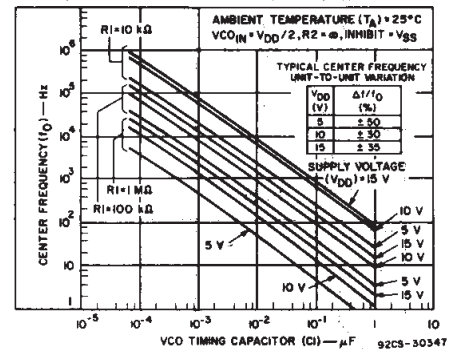


Fig. 4 - Typical center frequency as a function of C₁ and R₁ at V_{DD} = 5 V, 10 V, and 15 V.

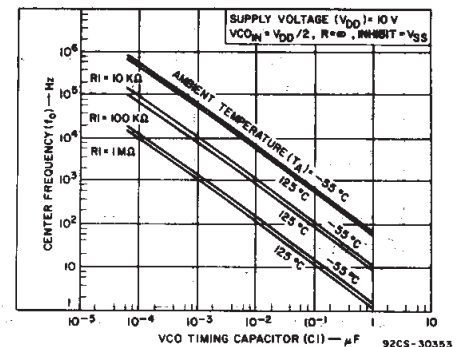


Fig. 5 - Center frequency as a function of C₁ and R₁ for ambient temperatures of -55°C to 125°C.

CD4046B Types

ELECTRICAL CHARACTERISTICS at $T_A = 25^\circ\text{C}$

CHARACTERISTIC	TEST CONDITIONS	V _{DD} (V)	LIMITS			UNITS
			ALL TYPES			
			Min.	Typ.	Max.	
VCO Section (cont'd)						
Source-Follower Output (Demodulated Output): Offset Voltage $ V_{COIN}-V_{DEM} $	$R_S > 10\text{ k}\Omega$	5 10 15	— — —	1.8 1.8 1.8	2.5 2.5 2.5	V
Linearity	$R_S=100\text{ k}\Omega$ $=300\text{ k}\Omega$ $=500\text{ k}\Omega$ $V_{COIN}=2.5\pm0.3\text{ V}$ $=5\pm2.5\text{ V}$ $=7.5\pm5\text{ V}$	5 10 15	— — —	0.3 0.7 0.9	— — —	%
Zener Diode Voltage (V_Z)	$I_Z = 50\text{ }\mu\text{A}$		4.45	5.5	6.15	V
Zener Dynamic Resistance, R_Z	$I_Z = 1\text{ mA}$		—	40	—	Ω
Phase Comparator Section						
Term. 14 (SIGNAL IN) Input Resistance R_{14}		5 10 15	1 0.2 0.1	2 0.4 0.2	— — —	M Ω
AC Coupled Signal Input Voltage Sensitivity* (peak-to-peak)	$f_{IN} = 100\text{ kHz}$, sine wave	5 10 15	— — —	180 330 900	360 660 1800	mV
Propagation Delay Times, Terms. 14 to 1: High to Low Level, t_{PHL}		5 10 15	— — —	225 100 65	450 200 130	ns
Low to High Level, t_{PLH}		5 10 15	— — —	350 150 100	700 300 200	ns
3-State Propagation Delay Times, Terms. 3 to 13: High Level to High Impedance, t_{PHZ}		5 10 15	— — —	225 100 95	450 200 190	ns
Terms. 14 to 13: Low Level to High Impedance, t_{PLZ}		5 10 15	— — —	285 130 95	570 260 190	ns
Input Rise or Fall Times, t_r , t_f Comparator Input, Term. 3	See Fig. 5 for Phase Comp. II output loading	5 10 15	— — —	— — —	50 1 0.3	μs
Signal Input, Term. 14		5 10 15	— — —	— — —	500 20 2.5	μs
Output Transition Times, t_{THL} , t_{TLH}		5 10 15	— — —	100 50 40	200 100 80	ns

* For sine wave, the frequency must be greater than 10 kHz for Phase Comparator II.

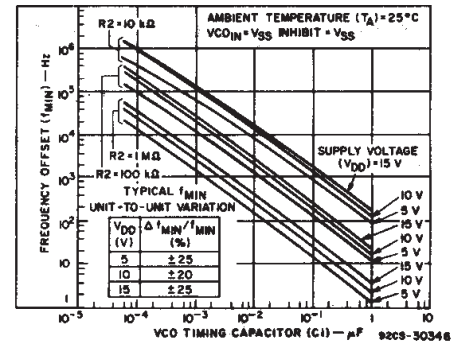


Fig. 6 - Typical frequency offset as a function of C_1 and R_2 for $V_{DD} = 5\text{ V}$, 10 V , and 15 V .

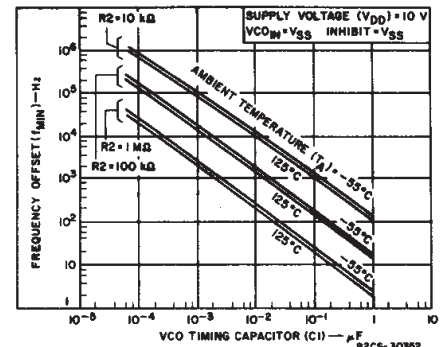


Fig. 7 - Frequency offset as a function of C_1 and R_2 for ambient temperatures of -55°C to 125°C .

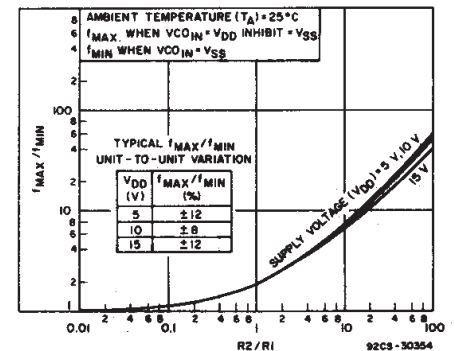


Fig. 8 - Typical f_{MAX}/f_{MIN} as a function of R_2/R_1 .

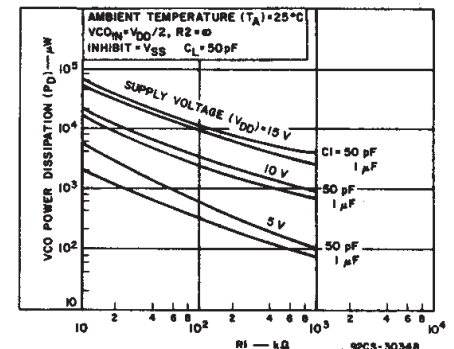


Fig. 9 - Typical VCO power dissipation at center frequency as a function of R_1 .

CD4046B Types

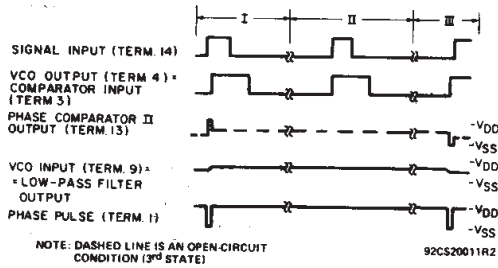


Fig. 10 - Typical waveforms for COS/MOS phase-locked loop employing phase comparator II in locked condition.

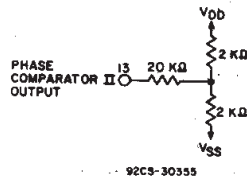


Fig. 11 - Phase comparator II output loading circuit.

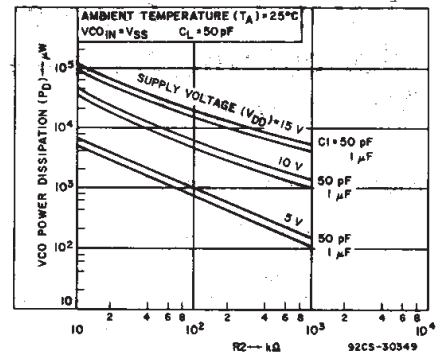


Fig. 12 - Typical VCO power dissipation at f_{MIN} as a function of $R2$.

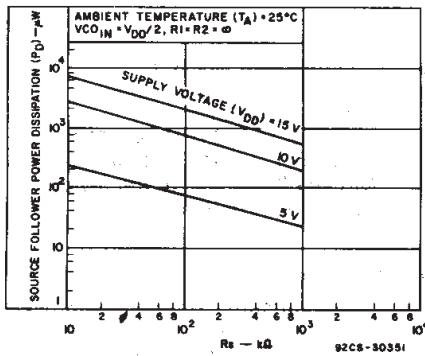


Fig. 13 - Typical source follower power dissipation as a function of R_s .

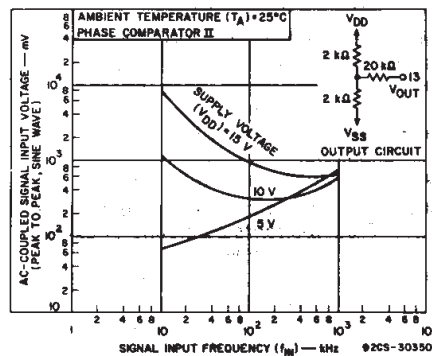


Fig. 14 - AC-coupled signal input voltage as a function of signal input frequency.

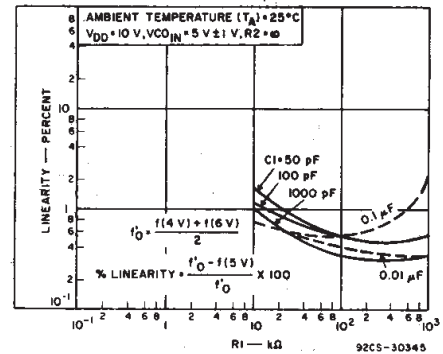


Fig. 15 - Typical VCO linearity as a function of $R1$ and $C1$ at $V_{DD} = 10$ V.

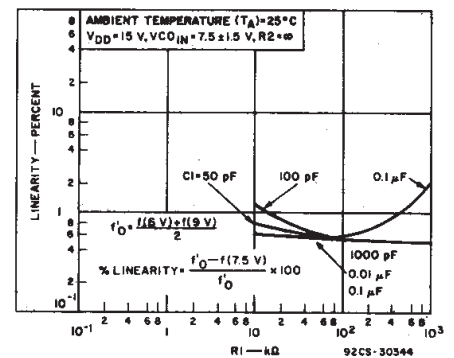
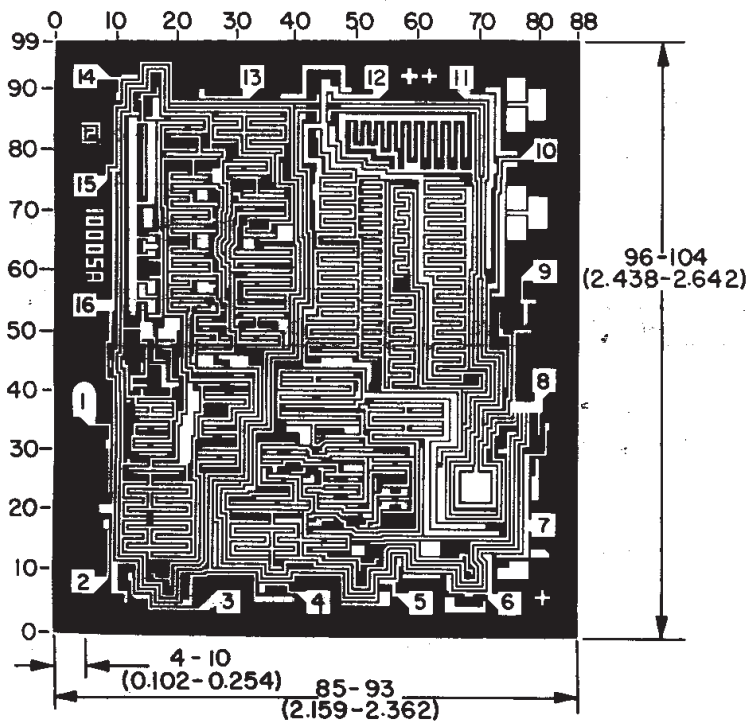


Fig. 16 - Typical VCO linearity as a function of $R1$ and $C1$ at $V_{DD} = 15$ V.



Dimensions and pad layout for CD4046BH.

Dimensions in parentheses are in millimeters and are derived from the basic inch dimensions as indicated. Grid graduations are in mils (10^{-3} inch).

3
COMMERCIAL CMOS
HIGH VOLTAGE ICs

IMPORTANT NOTICE

Texas Instruments and its subsidiaries (TI) reserve the right to make changes to their products or to discontinue any product or service without notice, and advise customers to obtain the latest version of relevant information to verify, before placing orders, that information being relied on is current and complete. All products are sold subject to the terms and conditions of sale supplied at the time of order acknowledgement, including those pertaining to warranty, patent infringement, and limitation of liability.

TI warrants performance of its semiconductor products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are utilized to the extent TI deems necessary to support this warranty. Specific testing of all parameters of each device is not necessarily performed, except those mandated by government requirements.

CERTAIN APPLICATIONS USING SEMICONDUCTOR PRODUCTS MAY INVOLVE POTENTIAL RISKS OF DEATH, PERSONAL INJURY, OR SEVERE PROPERTY OR ENVIRONMENTAL DAMAGE ("CRITICAL APPLICATIONS"). TI SEMICONDUCTOR PRODUCTS ARE NOT DESIGNED, AUTHORIZED, OR WARRANTED TO BE SUITABLE FOR USE IN LIFE-SUPPORT DEVICES OR SYSTEMS OR OTHER CRITICAL APPLICATIONS. INCLUSION OF TI PRODUCTS IN SUCH APPLICATIONS IS UNDERSTOOD TO BE FULLY AT THE CUSTOMER'S RISK.

In order to minimize risks associated with the customer's applications, adequate design and operating safeguards must be provided by the customer to minimize inherent or procedural hazards.

TI assumes no liability for applications assistance or customer product design. TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right of TI covering or relating to any combination, machine, or process in which such semiconductor products or services might be or are used. TI's publication of information regarding any third party's products or services does not constitute TI's approval, warranty or endorsement thereof.