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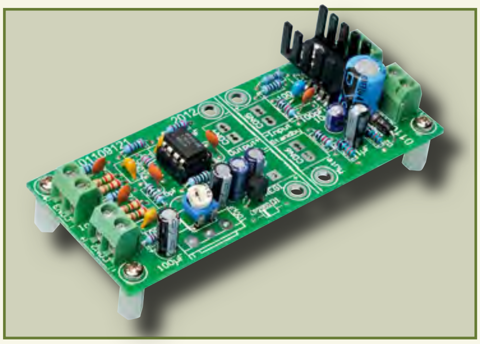

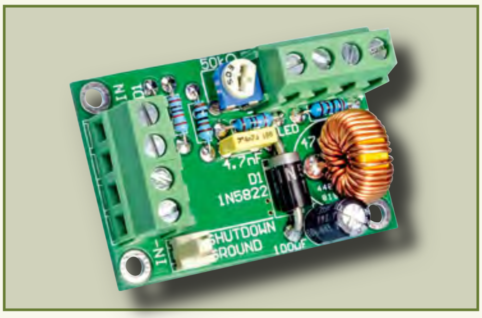

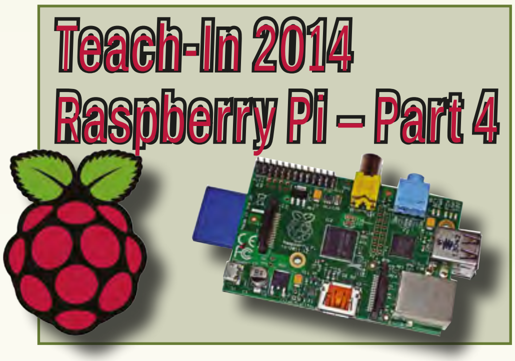

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EPE EVERYDAY PRACTICAL ELECTRONICS

Atomic-clock accuracy

We have some excellent projects lined up for you in this, the first issue of 2014's volume 43. Top of the list is out superb *2.5GHz 12-digit frequency counter with add-on GPS accuracy*. Jim Rowe has really excelled himself in the design of this super-accurate piece of test equipment. The real clincher is the addition of an external timebase that accepts 1Hz signals from a GPS receiver, allowing you to achieve accuracy that approaches atomic clocks – not bad for a home constructor project.

Switch to a switcher

The *MiniSwitcher*, our simple little switching regulator is something many of you have asked for – an easy-to-build and efficient switch-mode regulator. From a surprisingly compact package you can output up to 1.5A with not so much of a hint of those over-sized scary heatsinks associated with linear regulators. We're sure you'll build hundreds of these handy little power packs into your projects

Pi goes analogue

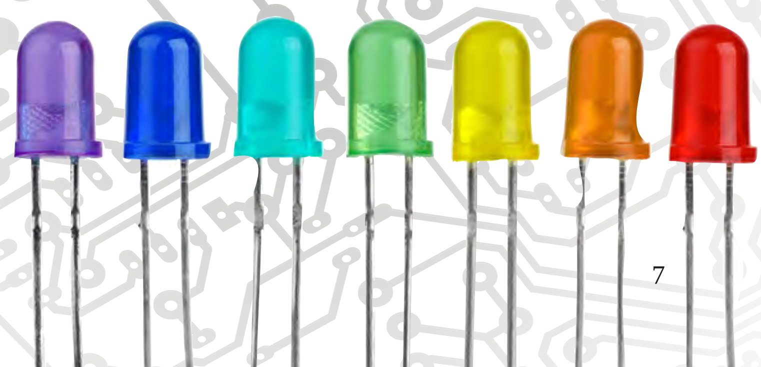
Hard to believe, but already we've reached Part 4 of our Raspberry Pi *Teach-In 2014* series. For many of you, this is where Pi starts to get really interesting, as we investigate connecting Pi to the real, analogue world. Mike and Richard Tooley show you how to construct a simple eight-channel analogue input circuit based on the 'Humble Pi' add-on board. It's an elegant, but powerful project, based around the MCP3008, a 10-bit analogue-to-digital converter (ADC) with on-board sample-and-hold circuitry. Perfect for interfacing the Pi to the world of electronic sensors.

Happy anniversary

I've received a note from Mike Hibbett to say that he wrote his first magazine article 30 years ago this month – for *Practical Computing*. He still has a copy of that issue, and says the best thing about it now is the ancient adverts! Never being one to rush things, Mike's next piece was two decades later – for *EPE* in January 2004. This means Mike has been entertaining and educating us for ten years, so this seems like a suitable time to publicly thank Mike for all his hard work and excellent articles. Here's to the next ten years from him and our other magnificent contributors: Mark Nelson, Max Maxfield, Barry Fox, Ian Bell, Alan Winstanley, Mike and Richard Tooley and Robert Penfold.

Christmas inspiration

Are you being pestered for Christmas presents ideas? If so, why not ask for something that you will genuinely enjoy and use all year – a subscription to your favourite electronics magazine, *EPE*. If you are already lucky enough to have a paper subscription, then why not try the electronic version. Either way, I hope Santa brings you everything what you want – not just another pair of socks.



NEWS

A roundup of the latest Everyday News from the world of electronics

Cloud storage options – by Barry Fox

The very word 'cloud' creates suspicion – who would dare risk storing valuable data in something intangible that changes form and disappears? The 'cloud' is in reality a 'server farm' of hard drives and search software located on *terra firma* at secret locations owned by the likes of Amazon and IBM. The secret locations can be anywhere in the world where there is cheap electricity, high security and high-speed Internet access.

Users must assume that the farm is mirrored and well backed-up in case drives fail, earthquakes hit or terrorists strike. However, the more real risk is that the company offering the cloud service stops renting space on the servers.

One of the first cloud stores, Kodak's Gallery photo repository, disappeared forever – along with any images still stored there – at the end of August 2012. Kodak gave plenty of warning, and helpfully offered transfer strategies, but other companies may just go bust and shut down without a moment's notice.

Kodak Gallery closed down responsibly – other 'clouds' may not give notice

MyCloud from Western Digital

Hard disc manufacturer Western Digital is capitalising on this very significant fear, with a new product called MyCloud – a NAS or 'network attached storage' hard drive that sits in the owner's home or office, for access by the owner and anyone the owner authorises, from anywhere in the world, using a desktop PC or mobile device with MyCloud App installed. 'There's no place like home for the cloud,' says WD.

The MyCloud service is free to use, after purchase of the drive at £129.00 for 2TB and £159.00 for 3TB. There are still risks though, albeit different from the pitfalls of using a third-party cloud. If the hard drive fails or is stolen, and the owner has not backed it up, their cloud is gone.

In many respects, the WD system resembles MyDitto, a private cloud server launched by French company DaneElec several years ago. MyDitto offered the option to use a pair of hard drives in RAID mode (Redundant Array of Independent Disks, with data duplicated) as a safeguard against disc failure. But MyDitto was far from user-friendly. Software setup and updating required a master USB dongle. This was intended to enhance security, but actually created more opportunities for user problems. When I tried to access MyDitto after changing PCs I got the error message: 'Client version is incompatible with MyDitto version. Automatic software update procedure failed. Please ask the network administrator (who is me) to unblocking (sic) UDP protocol to port 443. OK."

It took me many hours of research with DaneElec's documentation and online FAQ to find a way to force matching firmware and software updates and make a new USB key to get me access to my MyDitto cloud again.

Keep it simple

For most users, the simpler WD MyCloud will be a better bet.

But there is still a lot to be said for physical storage, on disc or memory card. At the Apps World exhibition and conference on Internet applications at Earls Court, in late October, the Wi-Fi Internet connection in the small Press and Speakers room became unusable when more than four or five people tried to use it at the same time.

So I had to leave the venue to report on what Steve Wozniak, co-founder of Apple, had said in a keynote 'fireside chat', used to 'share his views on the evolution of personal computing, from its beginnings at Apple through to smartphones, tablets and wearables; discuss how app developers and entrepreneurs can innovate and create in the current market, while also sharing anecdotes and ideas built from a lifetime as a Silicon Valley icon and philanthropist.'

'Woz' is lively, bubbling over with ideas and a fluent talker. He skipped through a wide range of topics, including his personal rejection of the new iPad Air because it 'only' has 128GB of storage space – he travels a lot and likes to watch TV sitcoms. He also, perhaps inadvertently, put the argument against too much dependence on cloud storage; he doesn't have wired broadband at home and doesn't trust hotel connections, so prefers to rely on his own storage.

FUZE for Raspberry Pi

FUZE is a new product aimed at the computer education market. It offers programming and electronics via a simple platform designed for exploration and investigation.

From writing and testing simple programs, to using two or more programming languages and understanding advanced programming logic and structures, the FUZE is ideal for beginners and the more experienced.

FUZE provides an ideal workstation to house the Pi, and retains all the Pi's original connectivity via the easily accessible back panel. The unit can be supplied complete with a UK keyboard, mouse, pass-through electronic interface and solder-less breadboard for electronic projects. Prices range from £69.99 to £179.99; more details from: **www.fuze.co.uk**

Closing in on practical quantum computing

Researchers at the University of Sussex in Brighton, working to produce the world's fastest, most powerful computers, have moved a step closer to creating a practical prototype using microwaves to shield the atoms driving this new generation of computers from the harmful effects of noise.

The ability to store and process huge amounts of data in a quantum way (on an atomic scale) would revolutionise computing, making it possible to carry out massive calculations and enabling computers to understand chemical reactions, create new medicines and carry out seemingly impossible simulations, such as the creation of our universe.

To build a quantum computer, scientists trap electrically charged atoms (ions) and control them so that they can be harnessed to form the 'atomic highways' that would build the computer network.

The first small-scale ion trap quantum computers have already been built using lasers to carry out calculations within the 'quantum processor', but the number of lasers needed to make a large-scale quantum computer would make this a substantial engineering challenge.

A new generation of quantum computers is now being devised using microwaves instead, which are easier to use and which should bring the construction of a large-scale ion-trap quantum-information processor much closer.

But there is a problem. The quantum effects that give a quantum computer its tremendous power (such as quantum superposition, where a single object can be at two different places simultaneously) are easily destroyed by any external noise. Now, Dr Winfried Hensinger and colleagues, who form part of the Sussex Ion Quantum Technology Group, have come up with an extremely efficient and easy way to shield the quantum computer from external noise, effectively enabling large-scale operation of a microwave quantum computer.

By applying a special combination of microwaves and radio frequency fields, the team were able to modify the atoms so that they became more resilient to external noise. Dr Hensinger says: 'While large-scale quantum computers might be still 10-30 years away, we have now managed to clear another big hurdle and we are highly excited about the opportunities that arise from this discovery.'

RFiD development kit

If you've ever fancied tackling RFiD technology, but were put off by the cost and complexity, then Beta-Layout may have the answer for you. They have developed 'easy-to-use tools and designs to enable developers to trial and consider the advantages of RFiD'. The kit uses Murata's 'Magicstrap', which combines a conventional UHF RFiD IC (currently the UCODE IC by NXP Semiconductors) with a ceramic multilayer structure carrying an adaptive matching circuit. The integrated matching circuit enables the ground plane of a PCB to be used as an antenna to achieve read ranges of up to several meters. 279 euros from: **www.beta-layout.com/btuk**

The route to RFiD projects from Beta-Layout

Supercaps take off

The global market for supercapacitors – devices with energy storage approaching that of batteries – will more than double to $836 million in 2018, up from $466 million in 2013, according to recent findings by Lux Research. Supercapacitors represent an emerging energy storage solution that bridges the gap between conventional capacitors and rechargeable batteries, and which will grow based mainly on adoption in transportation applications like hybrid buses. Consumer electronics and wind turbines make up the other significant opportunities.

More for less

Lux Research examined current applications where supercapacitors have strong value, and the outlook for materials, cell, and system performance and cost improvements that may enable bigger and better opportunities down the road. They found:

- *Cell prices will steadily decline.* Materials innovation will lead to a 15% fall in cell prices – from $0.0096/F today to $0.0082/F in 2018, thanks to incremental performance improvements and manufacturing efficiency gains. 'High-voltage' operation at 3.5V instead of 2.7V could lower cell prices another 40%.
- *Graphene and nanostructured carbons offer higher capacity.* The key material inside supercapacitors is active carbon, with the standard grade providing capacitance of 100F/g and costing around $28/kg. However, developers are pursuing higher capacity materials like graphene and nanostructured carbon.

Dot London coming soon

The British capital will soon gets its own domain name, .london.

Registration for new addresses is to start in spring 2014, and the domain name will go live in the summer.

London Mayor Boris Johnson said: 'Adopting the .london suffix will enable organisations to more closely associate themselves with our great city's powerful global brand. This is also an excellent opportunity to expand London's digital presence, which in turn is set to generate funds to invest back into the city.'

EPE EVERYDAY PRACTICAL ELECTRONICS

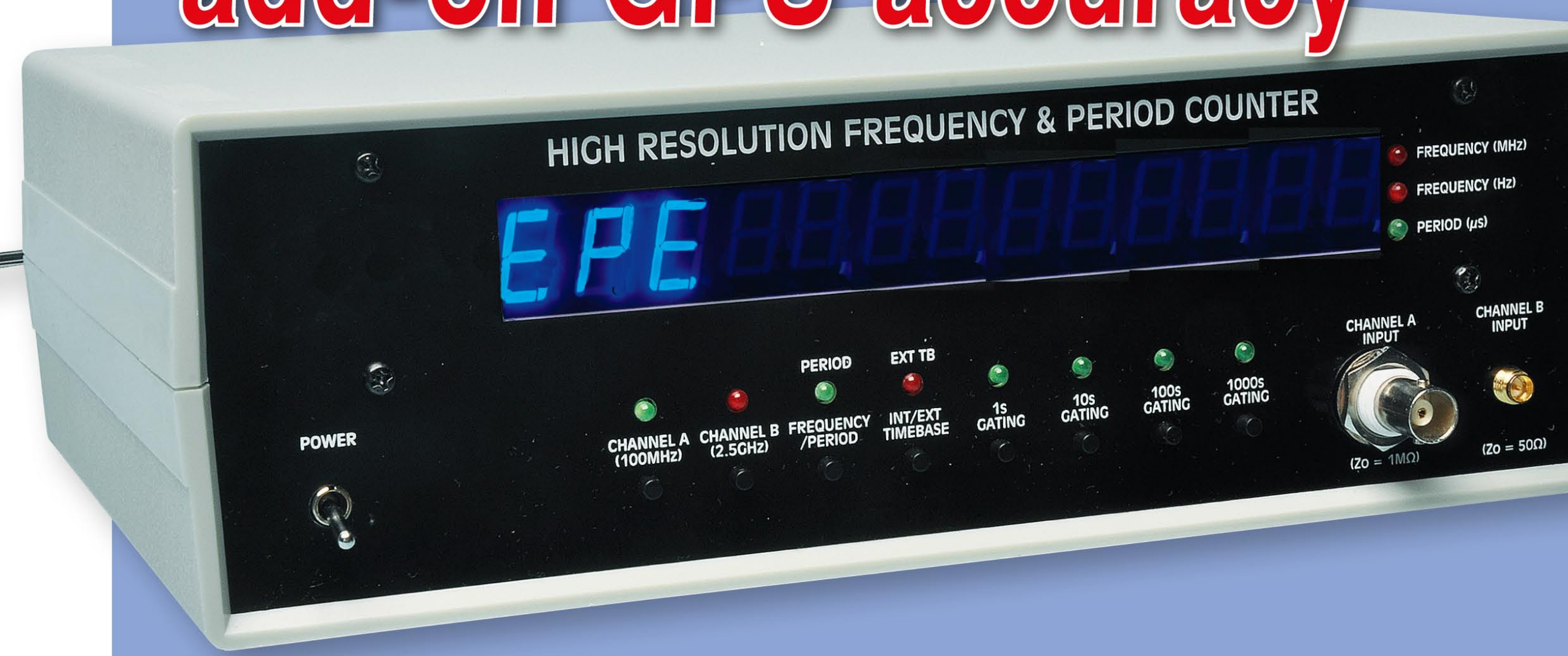
If you have some breaking news you would like to share with our readers, then please email:

editorial@wimborne.co.uk

PART 1: By JIM ROWE

World first!

2.5GHz 12-digit frequency counter with add-on GPS accuracy



We are very proud of this high-resolution frequency counter, which covers a range from below 10Hz to over 2.5GHz. It has an internal timebase (naturally) but also features an external timebase input that can accept 1Hz pulses from a GPS receiver, to achieve measurement accuracy approaching that of an atomic clock! And it doesn't cost a mint to build!

WE HAVE PUBLISHED a few digital frequency counters over the years, but they are just toys compared to this new design, which allows direct measurement of frequencies up to somewhere between 2.5GHz and 3GHz. This means it can be used to measure most of the frequencies used by Wi-Fi, mobile phones and microwave ovens.

And while high-quality commercial frequency counters often employ a temperature-compensated or oven-controlled crystal timebase, these are not in the race when compared to the very high accuracy 1Hz (1pps) signals available from many GPS receivers.

In order to make these more accurate measurements meaningful, you need a high-resolution display, which is why this new design has no less than 12 digits. Oh, by the way, because it will measure period, it can give high-resolution readout of low frequencies as well. Naturally, it uses a microcontroller and this is used in a clever way, to simplify the counting circuitry while still using high-speed logic for dealing with the UHF range up to 2.5GHz and over.

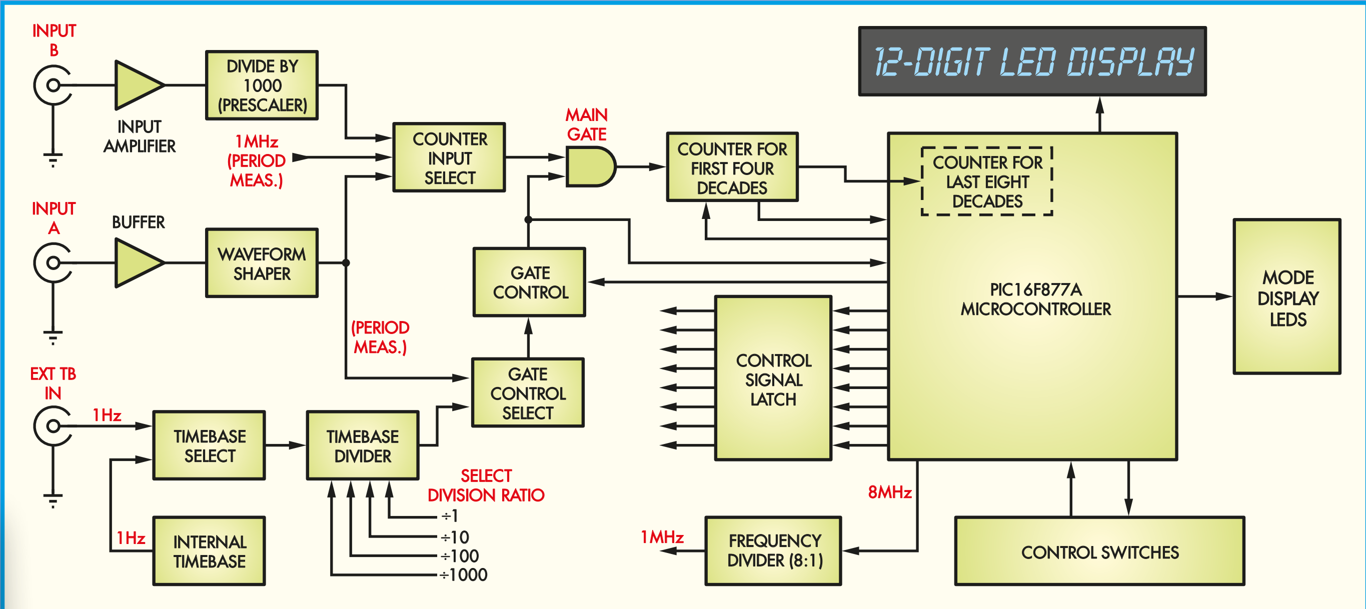


Fig.1: block diagram of the *2.5GHz 12-Digit Frequency Counter*. It uses a divide-by-1000 prescaler (to measure the higher frequencies) and a PIC16F877A microcontroller to process various signals and drive the display.

Left: this printed photo of the completed prototype really doesn't do the blue 7-segment LED displays justice – they really are nice and bright. The unit measures frequencies to over 2.5GHz and is also very easy to use.

In spite of the high accuracy and resolution, this is not a difficult instrument to use. Below the 12-digit display is a row of pushbuttons, each of which has an associated LED to show when it has been pushed. The buttons are used to select one of the inputs, the mode (frequency or period), the timebase (internal or external) and the gating period (from one second to 1000 seconds).

Finally, to the right of the digital display, there are three LEDs to indicate the frequency readout in hertz or megahertz, or period in microseconds.

We will explain all these features and how to use them later on in these articles. Overall though, it's a doddle to use.

The unit is housed in a standard plastic instrument case measuring 256 × 189 × 83mm. All components fit on two PCBs, linked by a short ribbon cable. The smaller PCB mounts behind the case front panel and supports the 12-digit display plus all of its management circuitry and components. The larger PCB sits inside the bottom of the case and supports the rest of the components and circuitry. The complete counter operates from a 9-12V DC plugpack, with a current drain of less than 650mA.

Now let's dive into the technology used in the new design.

Block diagram

Fig.1 shows the block diagram. It's based on a PIC16F877A microcontroller, chosen because of its reasonably large number of I/O ports – five in all, including three 8-bit ports, one 6-bit port and one 3-bit.

The PIC micro performs three important functions. The first is to control the overall operation, in response to the settings of the pushbutton switches on the front panel. The second is to manage the counter's 12-digit display and its associated mode and range display LEDs. Finally, it also performs some of the actual counting.

Counting of the first four 'fast' decades is done outside the PIC, but counting of the eight slower decades is done inside the PIC itself.

In Fig.1, the PIC is shown on the right with the 12-digit main LED display above it, the mode display LEDs to its right and the control switches below it. Although only single arrows are shown linking the PIC micro to the main LED display and the mode display LEDs, all of these are controlled via a shared multiplexing system.

To the lower left of the PIC is an 8-bit latch which is used to convey the various range and mode control signals to the counter's input and timebase circuitry. Then at upper left of the PIC you can see the counter circuit for the first four decades, fed from the main gate and with its output passing into the PIC as input for the internal 8-decade counter.

Moving right over to the left you can see the circuit blocks for the two main counter inputs, with channel A's input in the centre and channel B's input above it. Note that the channel B input block includes a 1000:1 prescaler, because this is the input channel for higher frequencies (100MHz to 2.5GHz).

At lower left you'll find the internal timebase block, the timebase selection block (internal/external timebase) and the programmable timebase divider.

Ahead of the counter's main gate (at upper centre in Fig.1) is a block labelled Counter Input Select, which is used to select which signal is fed to the counter gate: the input signal from channel A, that from channel B, or a 1MHz signal for period measurements. The 1MHz period measurement signal is actually derived from the PIC's 8MHz clock, via an 8:1 frequency divider (shown at lower centre, below the control signal latch).

Specifications

A digital frequency and period counter capable of making frequency measurements up to at least 2.5GHz and time period measurements to 12 digits of resolution. All circuitry is on two PCBs, linked by a short 20-way IDC ribbon cable. The counter is housed in an instrument case measuring 256 × 189 × 83mm.

Two frequency ranges: 10Hz – 100MHz (Channel A input); 100MHz – 2.5GHz or more (Channel B input; typically goes to 2.8GHz)

Period measurement range: 1µs – 999,999 seconds (Channel A input); resolution 1µs

Input sensitivity: <20mV 0-20MHz; <75mV 20-100MHz; <250mV 100MHz+

Input channel/Mode selection: eight pushbutton switches.

Four gating periods for frequency measurement: 1s, 10s, 100s, 1000s

Corresponding resolution: 1Hz, 0.1Hz, 0.01Hz, 0.001Hz (Channel A); 1kHz, 100Hz, 10Hz, 1Hz (Channel B)

Main display: 12 × 14mm-high blue 7-segment LED displays

Mode/range indicators: 11 × 3mm LEDs

Internal timebase: Based on a 32.768kHz crystal. Accuracy approx. ±1 × 10^{-5}

External timebase: Input for 1Hz pulses from GPS receiver, etc. Accuracy using GPS: 1Hz pulses approx. ±1 × 10^{-11}

Input impedance: Channel A, 1MΩ//25pF; Channel B, 50Ω//3pF; External timebase, 23kΩ//8pF

Power source: External 9 –12V DC supply **Current drain:** <650mA

The counter's main gate is enabled by the PIC, but counting does not actually start until the arrival of the next rising edge of the timebase gating control signal selected by the block below it. This will either be the internal or external timebase signal, divided down by the selected ratio in the case of frequency measurements, or the signal from the channel A input in the case of period measurements.

In response to the arrival of the first leading edge of the selected gating signal, the gate control circuit will enable the main gate to begin counting, but on the arrival of the next leading edge the gate control circuit will close the gate again, to stop counting. The PIC monitors the gate control signal and when counting stops, it then proceeds to process the count (from both the four external decades and the eight internal decades) and pass it to the display.

Circuit details

Now let's have a look at the full circuit. Because it is quite large, it is split into four sections: the input channels, shown in Fig.2; the timebase section (Fig.3); the main control and counting section (Fig.4) and the display multiplexing section (Fig.5).

The upper section of Fig.2 shows the channel A input circuitry which handles signals in the range from below 10Hz to above 100MHz. This is very similar to that used in our earlier counters, with an input buffer using a 2N5485 high-frequency JFET (Q3), feeding a 3-stage waveform shaper (squarer) using an MC10116P triple ECL (emitter-coupled logic) line driver device (IC5). The square-wave output from IC5a is then passed to a logic level shifter using transistors Q4 and Q5, to convert it into CMOS/TTL logic levels to feed the counter itself.

The lower section of Fig.2 shows the channel B input circuitry, which handles signals from 100MHz to 2.5GHz.

IC1 is an ERA-2SM+ broadband amplifier device which provides a gain of around +15dB with wideband frequency choke RFC3 (an ADCH-80A) as its output load.

The amplified signals from IC1 are then fed to IC2, an MC12095 very high speed divide-by-four ECL device, which forms the first stage of the channel B prescaling divider. IC2 feeds IC3, a programmable high-speed 8-bit ECL counter configured as a 125:1 divider. It then feeds IC4, an MC10EL32 high-speed ECL flipflop which performs the final division-by-two, to bring the overall frequency division to 1000 times. The outputs from IC4 are fed to a logic level shifter using Q1 and Q2, to convert them into a CMOS/TTL signal to feed the counter.

Timebase circuitry

Fig.3 shows the timebase circuitry. At upper left is the internal timebase generator which uses a 4060B oscillator/divider (IC6), together with a 32.768kHz crystal (X2) in the oscillator. It is followed by a 14-stage binary divider which delivers a 2Hz output signal from its O13 output (pin 3). This feeds IC7a, half of a 4518B dual 4-bit decade counter, where the 1Hz signal from the output of the first flipflop (pin 3) becomes our 1Hz internal timebase signal – fed to pin 1 of IC8a, one section of a 4093B quad Schmitt NAND gate.

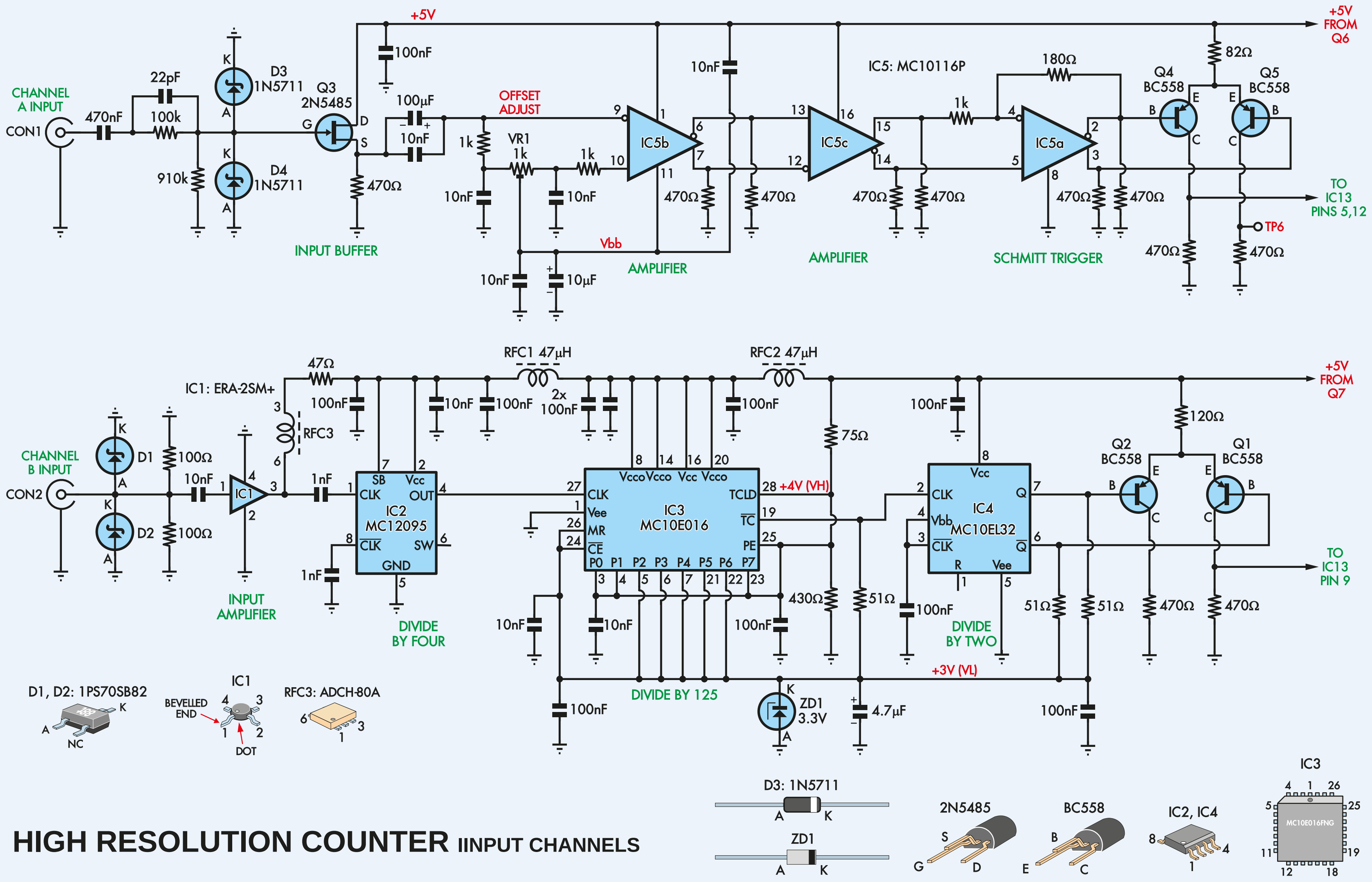
The external timebase signal (from a GPS receiver) arrives via CON3 and feeds IC8c, another section of the 4093B. IC8a and IC8c perform the internal/external timebase selection, under the control of a TB $\overline{\text{INT}}$/EXT control signal from the PIC micro, which arrives at lower right in Fig.3. This signal is inverted by IC8d to enable gate IC8a when the control signal is low, but it is also applied directly to pin 9 of IC8c, to enable this gate when the control signal is high.

So a low control signal selects the internal 1Hz timebase signal, while a high level selects the external timebase signal from CON3. The outputs of IC8a and IC8c are fed to IC8b, used here as a low-input OR gate.

The remaining section of Fig.3 shows the programmable timebase divider, which uses IC7b, IC9a and IC9b as three cascaded decade dividers and the four gates in IC10 (another 4093B quad Schmitt NAND) to select either the 1Hz signal from IC8b or the output of one of the three decade dividers – all under the control of the gating select signals which come from the PIC via control signal latch IC23 (see Fig.4).

Only one of these signals is high (logic 1) at any time, so if the 'Gating 1s' signal is high, gate IC10d is enabled to allow the 1Hz signal from IC8b to pass through to IC11b and then to the counter's gate control circuitry.

On the other hand, if the 'Gating 10s' signal is high, IC10a is enabled to allow the 0.1Hz signal from IC7b to pass through to IC11b. And the other two gating select signals work in the same way, enabling either IC10c or IC10b.



HIGH RESOLUTION COUNTER IINPUT CHANNELS

Fig.2: the input channel circuitry. Channel A handles signals up to 100MHz and is based on a 2N5485 JFET (Q3) and an MC10116P triple ECL line driver (IC5a-IC5c). IC5c's output is then fed to Q4 and Q5, to convert it into CMOS/TTL logic. The channel B input circuitry handles signals from 100MHz to 2.5GHz. IC1 is an ERA-2SM+ broadband amplifier and this feeds IC2, an MC12095 divide-by-four ECL device. IC2 in turn feeds IC3, a programmable 8-bit ECL counter configured as a 125:1 divider. This drives IC4, an MC10EL32 ECL flipflop, which performs the final division-by-two, to bring the overall frequency division to 1000 times. The outputs from IC4 are then fed to Q1 and Q2, to again convert them to CMOS/TTL signals suitable for feeding the counter circuitry.

Accuracy and resolution

Accuracy and resolution are equally important when you are making any kind of physical measurement. There's no point in having a measuring tool that's extremely accurate if it doesn't provide the resolution to allow reading its measurements with the same accuracy. That's why vernier callipers and micrometers were developed, to provide much greater length reading resolution than precision-etched steel rules.

Digital frequency counters are no exception. Since they operate by counting pulses at the input over a given period of time (the 'gating' period), this means that their reading resolution is inversely proportional to the gating period. With the usual gating period of one second, the resolution is clearly 1Hz.

The simplest way to achieve a higher resolution is to increase the gating period. For example a gating period of 10 seconds gives a resolution of 0.1Hz, while a gating period of 100 seconds gives a resolution of 0.01Hz and a gating period of 1000 seconds a resolution of 0.001Hz (1mHz).

So extending the gating period improves the frequency resolution. But there's no point in doing this unless the accuracy of the counter's timebase is high enough to make the improved resolution meaningful. That's why a typical frequency counter using a temperature-compensated crystal oscillator as its internal timebase reference doesn't attempt to provide a gating period of longer than 10 seconds, giving a resolution of 0.1Hz.

Nowadays, there's a relatively easy way to provide a counter with a timebase signal that's much more accurate than a local crystal oscillator. Many GPS receivers provide a 1pps or 1Hz signal output that is accurate to within about 1 part in 10^{11}, because each GPS satellite contains two atomic clocks which together provide a time accuracy of better than 1 part in 10^{12}.

If a counter uses the 1Hz pulses from a GPS receiver as its external timebase, it can therefore make meaningful frequency measurements with a gating period as long as 1000 seconds and a corresponding frequency resolution of 0.001Hz.

That's why our new counter provides a selection of four different gating periods (1s, 10s, 100s and 1000s) and an external timebase input intended to accept the 1Hz signals from a GPS receiver. It's also why the counter is provided with a 12-digit display, to take advantage of the higher resolution and accuracy.

The net result is that the circuitry in Fig.3 allows the PIC to select either the internal or external timebase signals and also whether the selected signal is divided by 1, 10, 100 or 1000. The selected timebase signal emerges from pin 13 of IC11b, to feed the counter gate control circuitry.

Control and counting

Fig.4 covers the main control and counting sections. The PIC micro is at upper right, shown as IC22. Don't worry too much about the righthand side of IC22 at this stage, except to note that the outputs from port B of the PIC (RB0-RB7) are brought down to connect to control switches S2-S9 and the inputs of control signal latch IC23 (a 74HC373).

The PIC scans the control switches to change the input channel, time-base mode and so on for the counter and stores the corresponding control signals in IC23. As you can see, the outputs of IC23 are labelled to indicate the various control signal functions.

Just above the control switches is the PIC's master clock circuit, based on an 8.0MHz crystal. This is entirely standard except for the addition of a 6-30pF trimcap (VC1) to allow the oscillator's frequency to be adjusted as closely as possible to 8.00MHz. This is not for the PIC's benefit, but because we take the 8MHz clock signal from pin 14 of the PIC and feed it down to IC24, a 74HC161 binary counter which divides it by eight to derive the 1MHz clock signal used to make the counter's period measurements.

Note that pins 9 and 10 of IC22 (RE1 and RE2) are used to control P-channel MOSFETs Q7 and Q6 over at far left. These transistors switch the +5V power to the input circuits for channels A and B (in Fig.2), allowing the PIC to turn off the power to the channel that is not currently in use.

Below Q6 and Q7 in Fig.4 you'll see the signals from the counter input channels (Fig.2) entering in the centre and feeding to selector gates IC13c, IC13b and IC13d. Then nearer the bottom, the timebase gating signal from IC11b (in Fig.3) enters and connects to input pins 3, 4 and 5 of IC11a.

To put things into perspective, gates IC13b, IC13c and IC12a are used to select which signal is fed to the counter's main gate (via IC12b), while gates IC11a and IC13d below them are used to select which signal is fed to the main gate control flipflops IC17a and IC17b (via IC12c).

In greater detail, in order to make frequency measurements, the PIC drops the $\overline{\text{FREQ}}$/PERIOD control signal line (from pin 12 of IC23) to logic 0, which disables gate IC12a but enables gate IC11a because of the logic 1 presented to pin 2 of IC11a from IC18d (used here as an inverter). So the timebase signal selected by the circuitry in Fig.3 is able to pass through IC12c and trigger the main gate control circuit around IC17.

At the same time, the PIC raises either the SEL I/P CHAN A control signal from pin 9 of IC23 or the SEL I/P CHAN B control from pin 15 of IC23, to enable either gate IC13b or IC13c. This allows one of the two input channel signals to pass through IC12b to the counter's main gate.

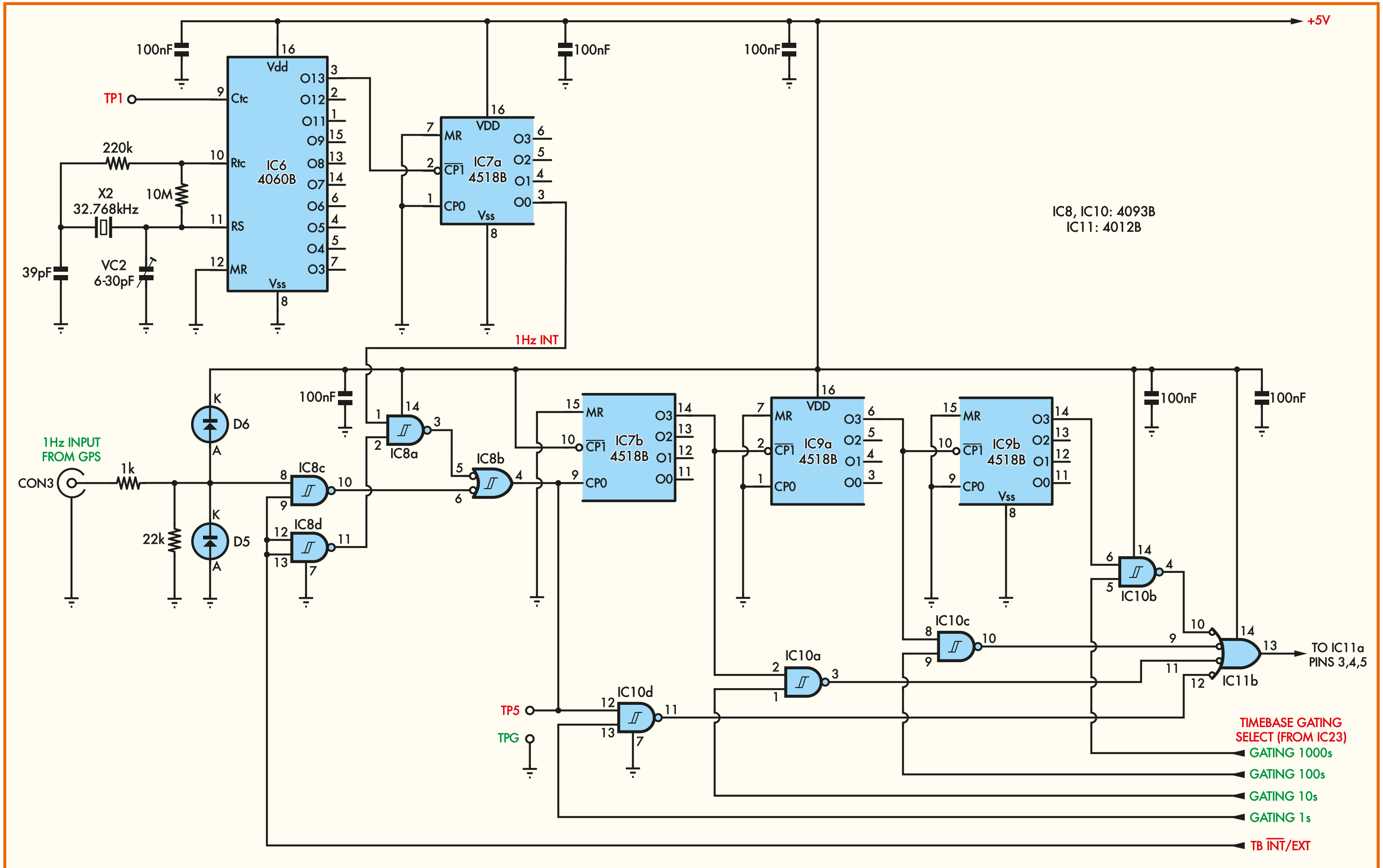
But where exactly *is* the counter's main gate? It's actually inside IC14, a very fast 74AC163 programmable synchronous 4-bit counter which we're using here as a decade counter – the very first decade of our 12-decade counter. The counter input signal is fed into the CP input of IC14 (pin 2), while the main gate control signal from pin 5 of IC17 is fed to the CEP and CET inputs (pins 7 and 10).

So IC14 can only begin counting the input signal when IC17 'opens the gate' by raising the CEP/CET inputs to a logic high.

IC14 is made to act as a decade counter by feedback applied via gate IC15a. The inputs of IC15a are connected to the '1' and '8' outputs of IC14, so that as soon as the count of IC14 reaches '9', the output of IC15a drops and pulls the synchronous reset pin ($\overline{\text{SR}}$, pin 1) of IC14 to logic 0. As a result, the very next pulse edge reaching the CP input of IC14 causes it to reset to '0' instead of incrementing to '10'.

Just before we continue to follow the signal path through the counter, let's explain how the gate control circuitry around IC17 works. Two very fast flipflops inside IC17 are interconnected in a kind of master/slave arrangement called a 'synchroniser'. The simplest way to understand it is to follow through one operating cycle, as follows:

Before counting begins, the PIC resets both IC17a and IC17b at the same



HIGH RESOLUTION COUNTER TIMEBASE AND CIRCUITRY

D5, D6: 1N4148

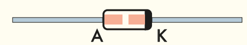
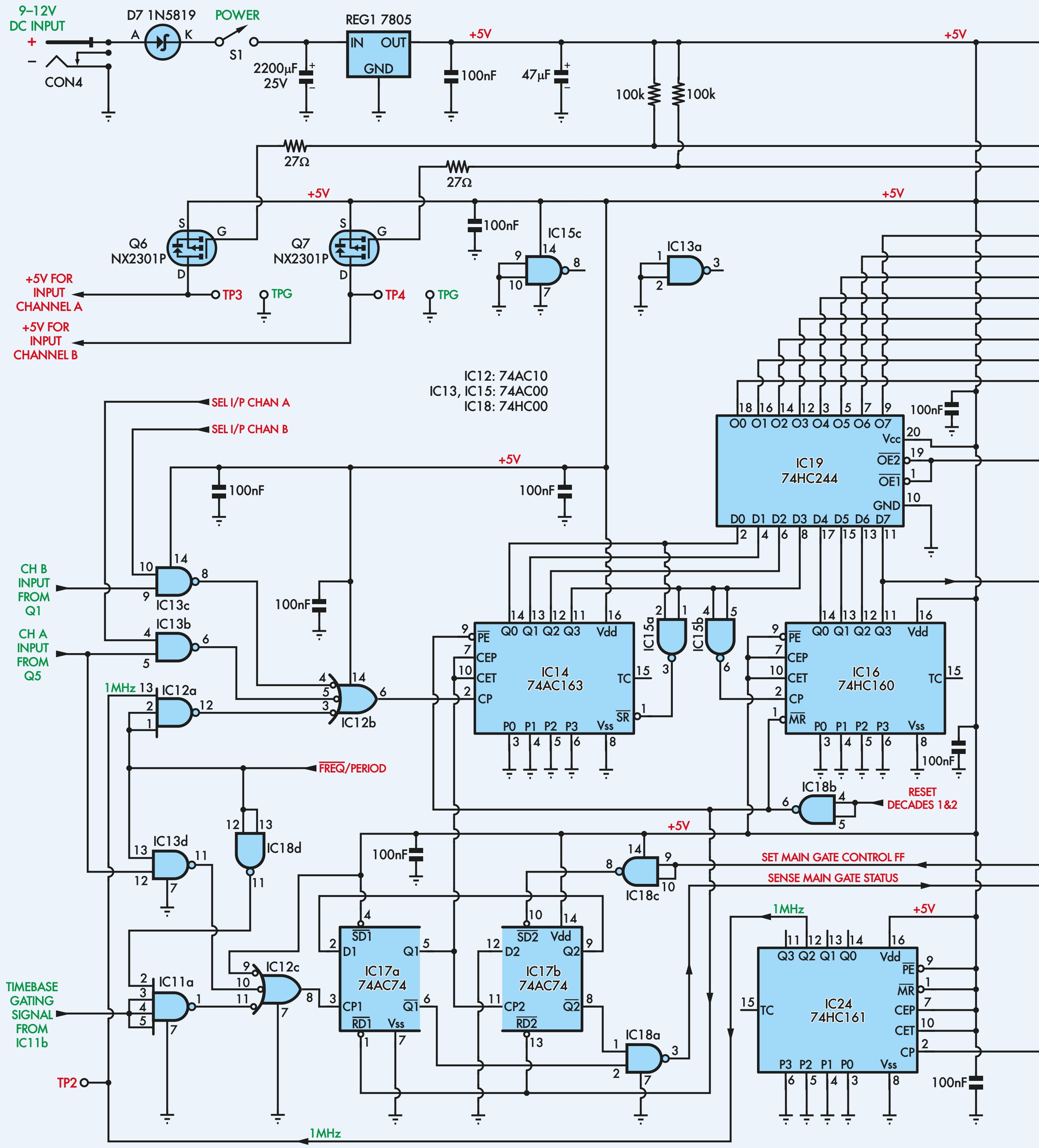
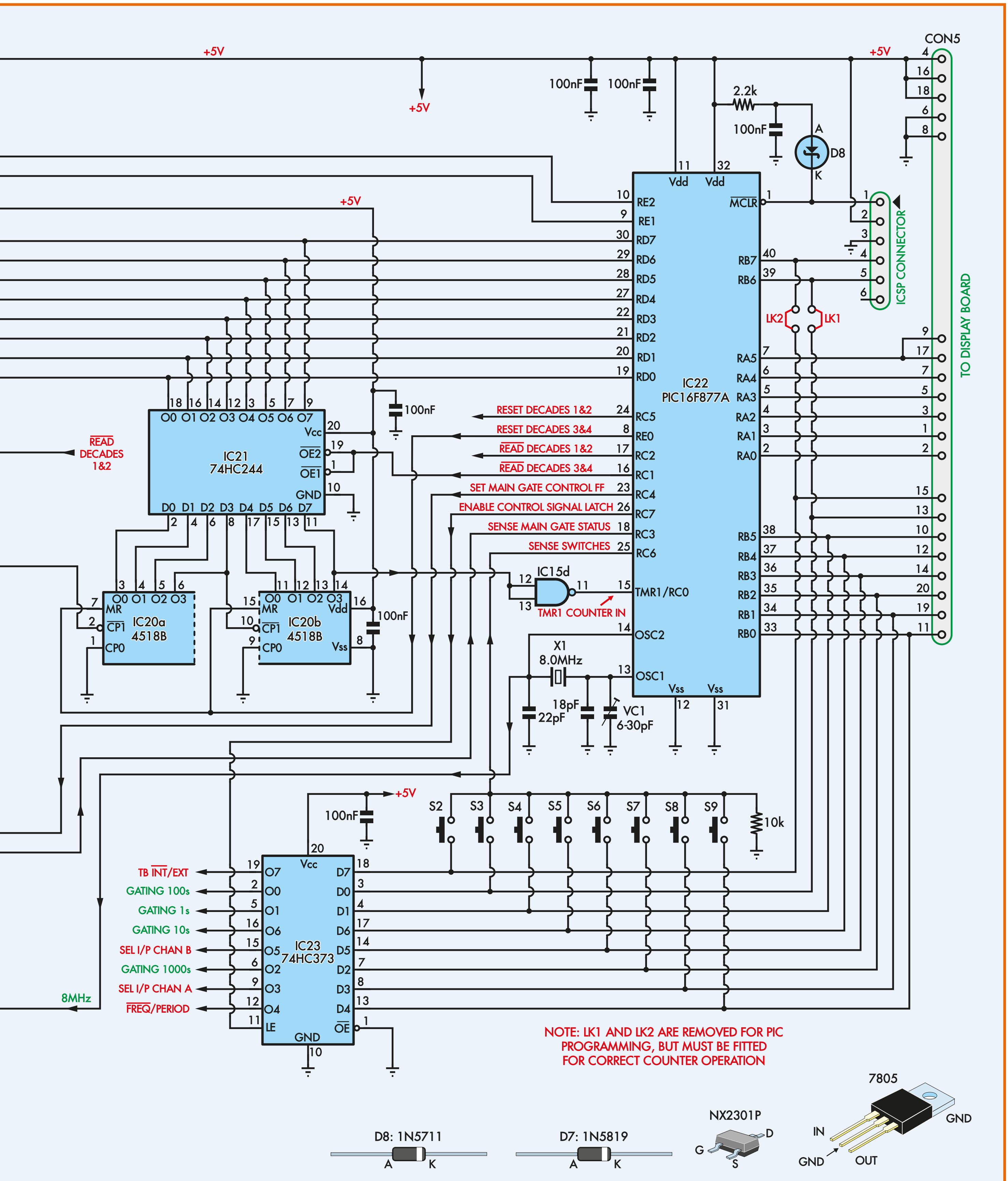


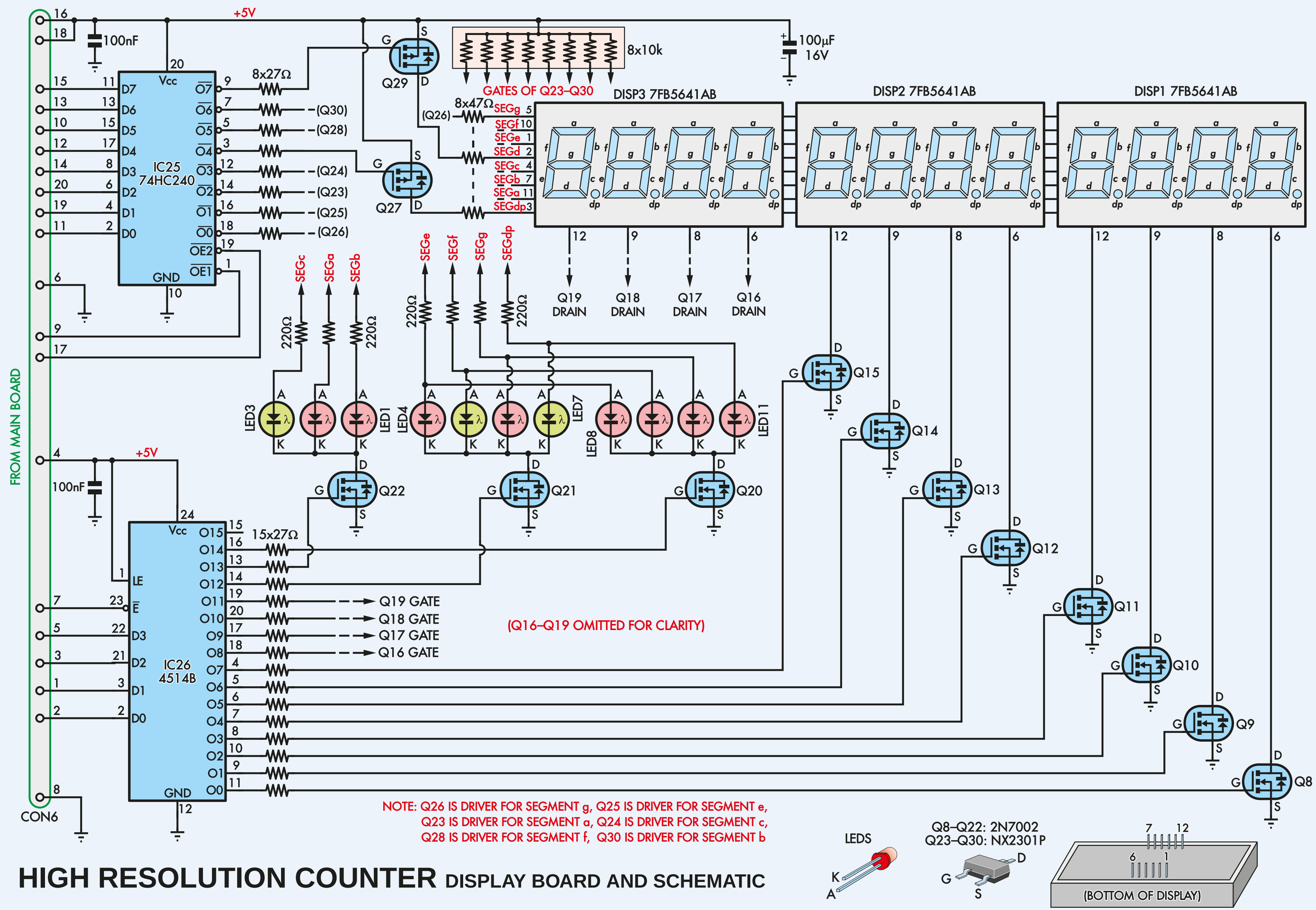
Fig.3: the timebase generator uses a 4060B (IC6) and a 32.768kHz crystal (X2) in the oscillator. IC6's internal 14-stage binary divider delivers a 2Hz output signal from its O13 output and this feeds IC7a, half of a 4518B dual 4-bit decade counter, The resulting 1Hz signal from pin 3 is then fed to pin 1 of Schmitt NAND gate IC8a. IC7b, IC9a and IC9b operate as cascaded decade dividers, while NAND gates IC10a-IC10d are used to select either the 1Hz signal from IC8b or the output of one of the three decade dividers. The gating select signals come from the PIC via control signal latch IC23 (see Fig.4).



HIGH RESOLUTION COUNTER CONTROL AND COUNTING CIRCUIT

Fig.4: the PIC micro (IC22) forms the heart of the main control and counting circuit. As shown, its port B outputs (RB0-RB7) connect to control switches S2-S9 and to the inputs of control signal latch IC23 (74HC373). In operation, the PIC scans the control switches to change the input channel, timebase mode, and so on for the counter, and stores the corresponding control signals in IC23. In addition, the PIC processes the Channel A and Channel B input signals and the timebase signals (after processing via various logic gates, flipflops and counters) and drives the display board via CON5.


+5V
100nF
2.2k
CON5
D8
ICSP CONNECTOR
TO DISPLAY BOARD
IC22
PIC16F877A
IC21
74HC244
READ DECADES 1&2
RESET DECADES 1&2
RESET DECADES 3&4
READ DECADES 1&2
READ DECADES 3&4
SET MAIN GATE CONTROL FF
ENABLE CONTROL SIGNAL LATCH
SENSE MAIN GATE STATUS
SENSE SWITCHES
IC20a
4518B
IC20b
4518B
IC15d
TMR1 COUNTER IN
X1
8.0MHz
18pF
22pF
VC1
6-30pF
LK2
LK1
S2
S3
S4
S5
S6
S7
S8
S9
10k
IC23
74HC373
TB INT/EXT
GATING 100s
GATING 1s
GATING 10s
SEL I/P CHAN B
GATING 1000s
SEL I/P CHAN A
FREQ/PERIOD
8MHz
NOTE: LK1 AND LK2 ARE REMOVED FOR PIC PROGRAMMING, BUT MUST BE FITTED FOR CORRECT COUNTER OPERATION
D8: 1N5711
D7: 1N5819
NX2301P
7805
IN
GND
OUT



HIGH RESOLUTION COUNTER DISPLAY BOARD AND SCHEMATIC

Fig.5: the displays are all driven in multiplexed fashion. As shown, the common cathodes of the three 4-digit blue LED displays, DISP1-DISP3, are switched by 2N7002 N-channel MOSFETs (Q8-Q19). These MOSFETs are controlled by the PIC's RA port pins via CON5 and CON6 and then via IC26, a 4514B 4-bit-to-16-bit decoder. The matching display segments are connected in parallel and are controlled from the PIC's RB port pins via IC25 (a 74HC240 octal buffer and line driver) and eight NX2301P P-channel MOSFETs (Q23-Q30). The mode and range indicator LEDs are multiplexed in similar fashion.

The display PCB carries the three 4-digit 7-segment LED readouts plus the various mode and indicator LEDs. The full assembly details are in Part 2, next month.

time as it resets the first two decades of the main counter (IC14 and IC16). So, to begin with, both IC17a and IC17b are in the reset state, with pins 6 and 8 both at logic 1 (high). As a result, pins 5 and 9 are both low, with pin 5 holding the main gate inside IC14 closed and pin 9 holding the D input of IC17a at logic 0 so that IC17a cannot switch to its set state in response to the leading edge of any timebase pulse arriving at the CP1 input (pin 3) from IC12c.

To initiate a counting sequence, the PIC provides a positive-going pulse at its RC4 output (pin 23) – which is labelled SET MAIN GATE CONTROL FF. This logic high is applied to both inputs of IC18c, which is used as an inverter.

As a result, a negative-going pulse is applied to the $\overline{\text{SD-2}}$ input of IC17b (pin 10), immediately switching IC17b into its set state with pin 9 high and pin 8 low. And since the D1 input of IC17a (pin 2) is tied to pin 9, this effectively 'primes' the main gate control flipflop IC17a.

The leading edge of the next timebase pulse to arrive at the CP1 input (pin 3) of IC17a will immediately trigger this flipflop into its set state. This in turn drives pin 5 high and opens the main counter gate in IC14 to begin counting.

At the same time, when the Q1 output of IC17a switches high, it also applies a clock edge to the CP2 input of IC17b (pin 11) and since the D2 input of IC17b is tied to logic 0 (ground), this causes IC17b to switch back to its reset state with pin 9 low and pin 8 high. This causes the D1 input of IC17a (pin 2) to be pulled low as well, preparing IC17a for the final part of the cycle.

Counting then continues, but only until the next timebase pulse leading edge arrives at pin 3 of IC17a. As soon as this happens, IC17a switches back to its reset state, with Q1 (pin 5) falling back to logic 0 and closing the main gate inside IC14.

So the result of this timing control cycle is that the counter's main gate is opened for exactly one timebase period and then closed again. And although the PIC kicks off the cycle by sending out the SET MAIN GATE CONTROL FF pulse, the actual gate timing is determined by the timebase signal applied to pin 3 of IC17a.

By the way, the PIC is able to determine when counting stops by monitoring the output of gate IC18a, which has its inputs connected to the $\overline{\text{Q}}$ outputs of IC17a and IC17b (pins 6 and 8). The output of IC18a only switches low when both $\overline{\text{Q}}$ outputs are high, which only happens at the end of a control cycle when counting stops. The output of IC18a is connected to the PIC's RC3 input (pin 18, with the label SENSE MAIN GATE STATUS). This allows the PIC to sense when counting stops.

As already noted, IC14 contains not only the counter's main gate, but also the first decade of the counter itself. And the next decade of counting is performed by IC16, a 74HC160 synchronous decade counter. The CP input of IC16 (pin 2) is connected to the output of IC15b (pin 6), while both inputs of IC15b (used here as a fast inverter) are connected to the '8' output (pin 11) of IC14.

As a result, a positive-going clock edge is fed to the CP input of IC16 when IC14's count falls to zero, causing IC16 to increment every time IC14 has counted 10 input pulses.

The third and fourth counting decades are based around IC20a and IC20b, two halves of another 4518B dual-decade counter. As you can see, the Q3 or '8' output of IC16 (pin 11) is connected directly to the $\overline{\text{CP1}}$ input of IC20a (pin 2), so that IC20a increments each time the count of IC16 returns to zero. Similarly, the Q3 output of IC20a is connected directly to the $\overline{\text{CP1}}$ input of IC20b (pin 10), so IC20b increments each time the count of IC20a returns to zero.

To recap, only the first four 'high speed' decades of the counter are implemented in hardware external to the PIC; ie, IC14, IC16 and the two halves of IC20. The rest of the counting is done inside the PIC itself, mainly by its internal timer/counter module TMR1. This is a 16-bit timer/counter, with its input brought out to the PIC's TMR1/RCO pin (pin 15).

Since TMR1 increments on the positive-going edge of the signal fed to pin 15, we need to invert the 'carry over' from pin 14 of IC20b to achieve correct counting. This is done by gate IC15d, which is connected as an inverter.

But how can we use the PIC's TMR1 counter module to count the remaining eight decades, when as a 16-bit counter it can clearly only count to 65536 – fewer than five decades? Well, we can do so because inside the PIC we can arrange for the overflow of TMR1 (when it rolls over from 65535 to zero) to trigger an interrupt and then use a small interrupt servicing routine to increment a further 8-bit counter register every time this happens.

Doing this effectively converts the counter inside the PIC into a 24-bit counter, able to count up to 16,777,215.

Power supply and ICSP

Just before we leave Fig.4, two sections not yet mentioned are the power supply circuitry and the ICSP (in circuit serial programming) interface.

The power supply is simple, with reverse-polarity protection diode D7

This is the view inside the completed frequency counter, from the rear. All the parts fit on two PCBs, which are linked together by a short ribbon cable. Power comes from a 9-12V DC plugpack supply.

in series with the front-panel power switch S1 and then a standard 7805 regulator (REG1) to provide a stabilised and filtered 5V supply for all of the counter circuitry.

The ICSP circuitry (upper right) enables the PIC to be programmed or reprogrammed with the counter firmware at any time. All the connections needed for programming are brought out to the usual 6-pin ICSP connector, while the PIC's RB7 and RB6 pins are isolated from the rest of the counter circuit during programming by removing links LK1 and LK2.

After programming is completed, these two links are then refitted so that the counter can use RB7 and RB6 in the normal way.

Finally, note that all the connections from the PIC's RA and RB I/O ports are brought out to 20-way DIL connector CON5, shown at far right in Fig.4. This allows the display PCB, shown in Fig.5, to be connected via a ribbon cable fitted with IDC headers.

Multiplexed display

All the displays are driven in multiplexed fashion – not just the 12 numeric digit displays, but the 11 indicator LEDs as well. The numeric displays consists of three 4-digit 7-segment blue LED displays, DISP1-DISP3, which have their common cathodes controlled by 2N7002 N-channel MOSFETs Q8-Q19. Note that only Q8-Q15 are shown, while Q16-Q19 are 'implied', with dotted lines. This is to save space on the diagram.

These MOSFETs are controlled by the PIC's RA port pins via CON5 and CON6 (linked by the ribbon cable) and then through IC26 – a 4514B 4-bit-to-16-bit decoder. This circuitry thus forms the 'digit drive' section of the display multiplexing system.

All matching segments of the display digits are connected in parallel and driven by NX2301P P-channel MOSFETs, Q23-Q30. Again, most of these connects are shown dotted, to save space on the diagram.

These P-channel MOSFETs are controlled by the eight outputs from IC25, a 74HC240 octal buffer and line driver. This is controlled in turn by the PIC's RB port pins, again via CON5 and CON6. So the circuitry at upper left in Fig.5 forms the 'segment drive' part of the display multiplexing.

As you can see, the 11 indicator LEDs (LED1-LED11) are part of the same multiplexing system, split into three groups forming three 'pseudo display digits'. The three groups are controlled by MOSFETs Q20-Q22, controlled in turn by outputs O12, O13 and O14 of IC26.

The anodes of the LEDs are connected to the display segment driver lines from Q23-Q30, so they can be controlled by the PIC as part of the multiplexing. For example, LED1 is addressed as segment b of 'digit' 15, while LED7 and LED11 are addressed as the DP (decimal point) segments of 'digits' 14 and 13 respectively. As far as the PIC's firmware is concerned, the indicator LEDs are simply specific segments of the three additional pseudo display digits.

That's all we have space for in this first article on our new high-resolution counter. Next month, we will present the construction details for both the main PCB and the display PCB and give the set-up procedure, which is simple and straightforward.

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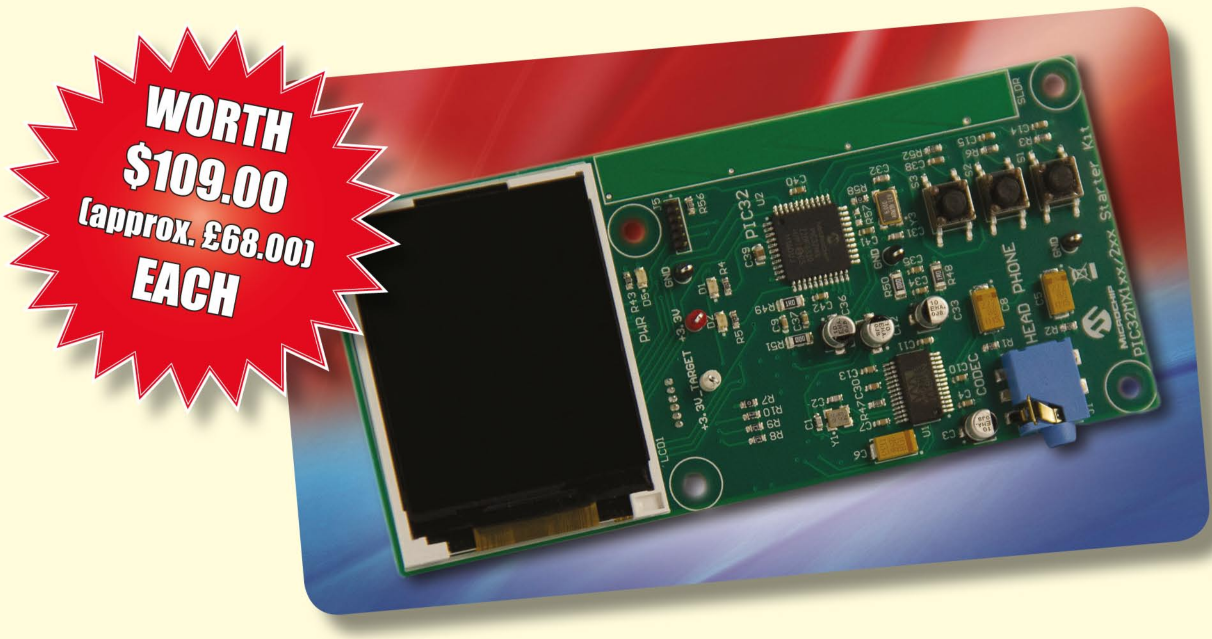

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At last, a worthy adversary to vanquish old-fashioned designs!

The Champion

. . . a tiny audio amplifier module that can deliver 7W peak power!

By Nicholas Vinen

We have offered many low-price, compact amplifiers. They have been very popular, but we have to admit that while their audio performance was acceptable, it was pretty ordinary. Now there's a new kid (module) on the block and we have dubbed it the 'Champion' because its performance is far superior. Plus, it can deliver up to 7W of hi-fi peak power. Read on and find out what makes this design so special.

OUR PREVIOUS COMPACT designs were typically cheap, easy to build and did the basic job required of them – to give just about anything the ability to drive a speaker and make a sound, be it a radio, sound effects generator, music player, communications receiver – whatever. But while they will no doubt continue to be popular, they are now over-shadowed by our new module, the *Champion*.

It dances all round older designs, evading all their jabs and delivering a knock-out combination of convenient connectors, higher power, lower minimal operating voltage, much lower distortion and noise, mute and standby features and input mixing.

Actually, the *Champion* doesn't have it all over the older designs. Sometimes the old guys have a few tricks up their sleeves. The young and energetic *Champion* is a bit power hungry, with a quiescent current of around 30mA, while some older amps pick at their meals with a quiescent current of just a handful of milliamps. Still, the *Champion* again wins out because it has a logic-level standby control pin to shut it down to a negligible 1µA!

New amplifier IC

The heart of the *Champion* is the AN7511 audio amplifier IC from Panasonic. Many older designs used the LM386, which was born in the mid-1970s and that makes it an old geezer by now. By comparison, the AN7511 isn't even a teenager yet, having been released in late 2001.

One of the main advantages of the AN7511 over the LM386 is the fact that it drives the speaker in a bridge-tied load (BTL) configuration. This allows the IC to deliver twice the RMS voltage to the speaker, for up to four times the power.

Thus, as already noted, the *Champion* punches well above its class, giving around 7W peak power into an 8Ω load from a 12V supply. Mind you, the *Champion* can't deliver that sort of power continuously. The small DIP chip package simply can't deal with the dissipation under those conditions continuously and thermal limiting quickly kicks in, even if a heatsink is fitted.

The continuous power available (depending on supply voltage) is around 2W. That's still quite a bit better than what's on offer from the LM386.

The LM386 also needs more external components than the AN7511, despite having fewer features. The LM386 needs a 'Zobel network' at its output (resistor and capacitor) for stability, whereas the AN7511 doesn't. The LM386 also needs a large DC-blocking capacitor between its output and the speaker, but because the AN7511 drives the speaker in bridge mode, no DC blocking capacitor is required. All we really need to build a working circuit around the AN7511 is a bypass capacitor, AC coupling for the signal input and some RC filters for the mute and standby control pins.

In standby mode, the AN7511's current consumption drops to just 1µA. So, if used in combination with (say) a microcontroller, the AN7511 won't draw any power unless you are actually using it. Also, the mute and standby features are designed to avoid clicks and pops when the unit goes into and out of standby.

Features and Specifications

Features

- Wide operating voltage range
- Bridged output gives high power at low supply voltages
- Low parts count
- Low distortion
- Preamplifier compatible with microphones and electric guitars
- Preamplifier has two inputs, mixed 1:1
- Mute and standby control
- Over-temperature protection (auto-limiting)

Specifications

Operating voltage range: 4-13.5V

Output power: up to 4W continuous (see Fig.3); 7W peak

Music power: 3W @ 9-12V

Signal-to-noise ratio: ~65dB

Frequency response: -2.5dB @ 20Hz, –0.3dB @ 20kHz (see Fig.5)

THD+N, 1kHz: ~0.25% (see Fig.4)

Gain: 34dB for Champion, up to 58dB with Pre-Champion

Input sensitivity, Champion **only:** 52mV RMS @ 5V, 125mV RMS @ 9-12V

Input sensitivity, Pre-Champion + Champion**:** 2mV RMS @ 5V, 5mV RMS @ 9-12V

Quiescent current: 2mA (Pre-Champion) + 30-60mA (Champion)

Standby current: 2mA (Pre-Champion) + 40-120µA (Champion)

The Pre-Champion

As good as the *Champion* is, we know that many readers will want a companion preamplifier to go with it. Whereas some previous preamps have been a very basic two-transistor circuit, the preamplifier for the *Champion* is a special low-voltage op amp IC that has considerably better performance. This will enable you to use the *Champion* with a microphone or many musical instruments, such as electric guitars.

We have designed a small PCB to accommodate the *Champion* and its companion preamp. If you don't need the preamp, you can cut off that section to make the PCB quite a bit smaller.

Circuit description

Fig.1 shows the complete circuit of both the *Pre-Champion* (left) and *Champion* (right). The signal is applied to either CON2 or CON3. If you apply a signal to both, they will be mixed together with a 1:1 ratio; ie, the apparent volume of both signals will be the same. This could be useful, for example, if you want to down-mix stereo to mono or if you want to combine music and voice. The two signal paths are identical until they are mixed.

Each signal passes through a low-pass filter consisting of a 100Ω resistor and 100pF capacitor, designed to attenuate RF signals. There is also a 2.2MΩ bias resistor to pull the input signal to ground. If you are going to feed the unit with an iPod or similar player you may need to reduce the value of that 2.2MΩ resistor dramatically, to say 1kΩ, to provide it with sufficient load current. However, as presented, the high-impedance inputs will suit microphones and some musical instruments, as well as general line-level signals.

The signals are then AC-coupled with 100nF capacitors and 2.2MΩ bias resistors, which go to a 2.5V half-supply rail. This biases the incoming signal so that it has a symmetrical swing within the supply rails of dual op amp IC1, running off a 5V rail. The two 2.2MΩ bias resistors for each channel, on either side of the 100nF AC-coupling capacitors, are in parallel as far as the signal source is concerned, setting the unit's input impedance to around 1MΩ.

IC1a buffers and amplifies the signal from CON2, while IC1b does the same for the signal from CON3. Gain is set at 23 times (27dB) by the 22kΩ and 1kΩ feedback resistors. The 10pF capacitors reduce the gain for high-frequency signals, giving a little extra stability and noise filtering.

Note that this high gain suits relatively low level signals such as those from microphones or musical instruments. To feed the unit with line-level signals, you will either need to knock back the gain for that channel by reducing the value of the 22kΩ feedback resistor or else connect the signal to its respective input via a potentiometer.

Parts List – The Champion

Pre-Champion
1 PCB, available from the *EPE PCB Service,* code 01109121, 57mm × 41mm
1 10kΩ log PCB-mount 16mm potentiometer (VR1) OR
1 10kΩ mini horizontal trimpot (VR2)
4 mini 2-way terminal blocks (CON1-CON4)*
1 8-pin DIL socket
4 M3 × 10mm tapped nylon spacers
4 M3 × 6mm machine screws

Semiconductors
1 LMC6482 dual op amp (IC1)
1 LP2950-5 5V LDO regulator (REG1)
1 1N5819 Schottky diode*

Capacitors
2 100µF 16V electrolytic
2 10µF 16V electrolytic
3 100nF MMC
2 100pF ceramic
2 10pF ceramic

Resistors (0.25W, 1%)

4 2.2MΩ	2 2.2kΩ
2 22kΩ	2 1kΩ
2 10kΩ	2 100Ω

Champion Amplifier
1 PCB, available from the *EPE PCB Service,* code 01109122, 42mm × 41mm
4 mini 2-way terminal blocks (CON5-8)*
1 micro-U TO-220 heatsink, 12.7 × 19mm (Futurlec Cat.TO220S)
1 TO-220 heatsink pad or thermal transfer compound
4 tapped nylon spacers
4 M3 × 6mm machine screws
1 M3 × 10mm machine screw
2 M3 nuts
1 M3 split washer
2 M3 shakeproof washers

Semiconductors
1 AN7511 bridge output amplifier (IC2)
1 BC557 PNP transistor (Q1)
1 1N5819 Schottky diode*

Capacitors
1 470µF 16V electrolytic
1 10µF 16V electrolytic
1 1µF 16V electrolytic
1 470nF MMC
1 100pF ceramic

Resistors (0.25W, 1%)

1 1MΩ	3 10kΩ
2 100kΩ	1 100Ω

* If building both Pre-Champion and Champion on a single PCB, omit one 1N5819 diode and four 2-way terminal blocks

The latter solution is probably the best one. It not only provides for a wide range of input signal levels, but also lets you adjust the ratio by which the two audio input signals are mixed (eg, by using a similar arrangement to that shown in Fig.6).

The outputs of the two op amp stages are mixed using a pair of 2.2kΩ resistors and then AC-coupled to potentiometer VR1 or VR2, depending on which is installed. One is a trimpot and the other is a full-size pot. Regardless of which is installed, they do the same job, allowing the output level to be adjusted. The 100µF coupling capacitor is specified for good low-frequency performance as this capacitor forms a high-pass filter, in combination with the pot's track resistance (10kΩ).

The LMC6482 dual op amp was chosen for this application because it can run off low voltages and has a rail-to-rail output swing. For example, when running from 5V, its output can be over 1.5V RMS while a standard op amp would be limited to about 0.5V RMS if it could operate from 5V at all.

The aforementioned 2.5V rail, which effectively acts as the signal ground in this circuit, is derived from the 5V supply rail by a pair of 10kΩ resistors acting as a 1:1 voltage divider. This rail is filtered with a 100µF capacitor, to reduce noise and keep its impedance low so that the feedback dividers can work effectively.

IC1 is powered via an LP2950 5V low-dropout regulator (REG1). This regulator is fed from either CON1 or CON8 via Schottky diode D1 or D2, which protect against reversed supply polarity (note: D1 is not installed if the preamp is built on a single PCB with the amplifier).

Amplifier

The signal from the volume control pot is fed via CON5, an RF filter network (100Ω/100pF) and a 470nF capacitor to IC2, the AN7511 chip input. This time, the input bias resistor is 1MΩ and there is no bias resistor at input pin 2 of IC2 since it has internal biasing (30kΩ to ground). The combination of the 470nF coupling capacitor and a 30kΩ input impedance gives a low-frequency roll-off of –3dB at around 11Hz.

The balanced outputs from IC2 are at pins 6 and 8. The pin 6 output signal is in-phase with the input signal, while the pin 8 output is inverted. The overall gain is typically 34dB, so a 30mV input will give an output of around 1V RMS or 125mW into 8Ω.

Note that due to this bridged output configuration, the recommended minimum speaker impedance is 8Ω.

Pin 1 of IC2 is the standby input (SBY) which, if pulled low, shuts down the amplifier and puts IC2 into a low-power mode where it consumes around 1µA rather than the typical quiescent current of 30-60mA. This can be controlled using an SPST switch or by a microcontroller.

The 10µF capacitor from pin 1 of IC2 to ground, combined with the associated 100kΩ resistor, forms a 'soft start' circuit which prevents clicks and pops from the speaker when power is first applied. The 10µF capacitor is initially discharged and so pin 1 is held at ground, enabling the standby feature. This capacitor charges through the 100kΩ resistor and so IC2 comes out of standby a short time after power is applied, when the circuit voltages have had time to settle.

Similarly, the 10kΩ resistor from pin 1 of CON6 to pin 1 of IC2 limits the rate at which the shutdown feature is enabled, preventing a sudden transition which would cause the output to also generate a transient, resulting in a loud sound from the speaker.

Note that these resistors consume some additional current in standby mode (V_{CC} ÷ 110kΩ), giving a total standby current of up to 120µA at maximum supply voltage.

There is also a separate mute input at pin 4 of IC2. This allows the output to be shut off while leaving the amplifier running, in case you just want to temporarily shut off the sound. This, however, is an active-high function, ie, pin 4 is pulled up to V_{CC} to enable the muting. For convenience, we have arranged the circuit so that the two control inputs at CON6 are both active-low and can be driven in the same manner.

The capacitor from pin 4 (mute) to ground is a lower value than for standby, at 1µF, but the 100kΩ pull-down resistor is the same value as the 100kΩ pull-up resistor for the standby pin. This ensures that when power is removed, the mute function engages before the amplifier goes into standby, preventing switch-off thumps.

IC2 has its own 100µF bypass capacitor plus a Schottky diode for reverse polarity protection. If the two units are built on a single PCB, power can be applied to CON8 for both the *Champion* and *Pre-Champion*. In this case, CON1 and D1 may be omitted. CON4 and CON5 can also be left out, as the output tracks from the *Pre-Champion* feed straight into the input of the *Champion*.

Construction

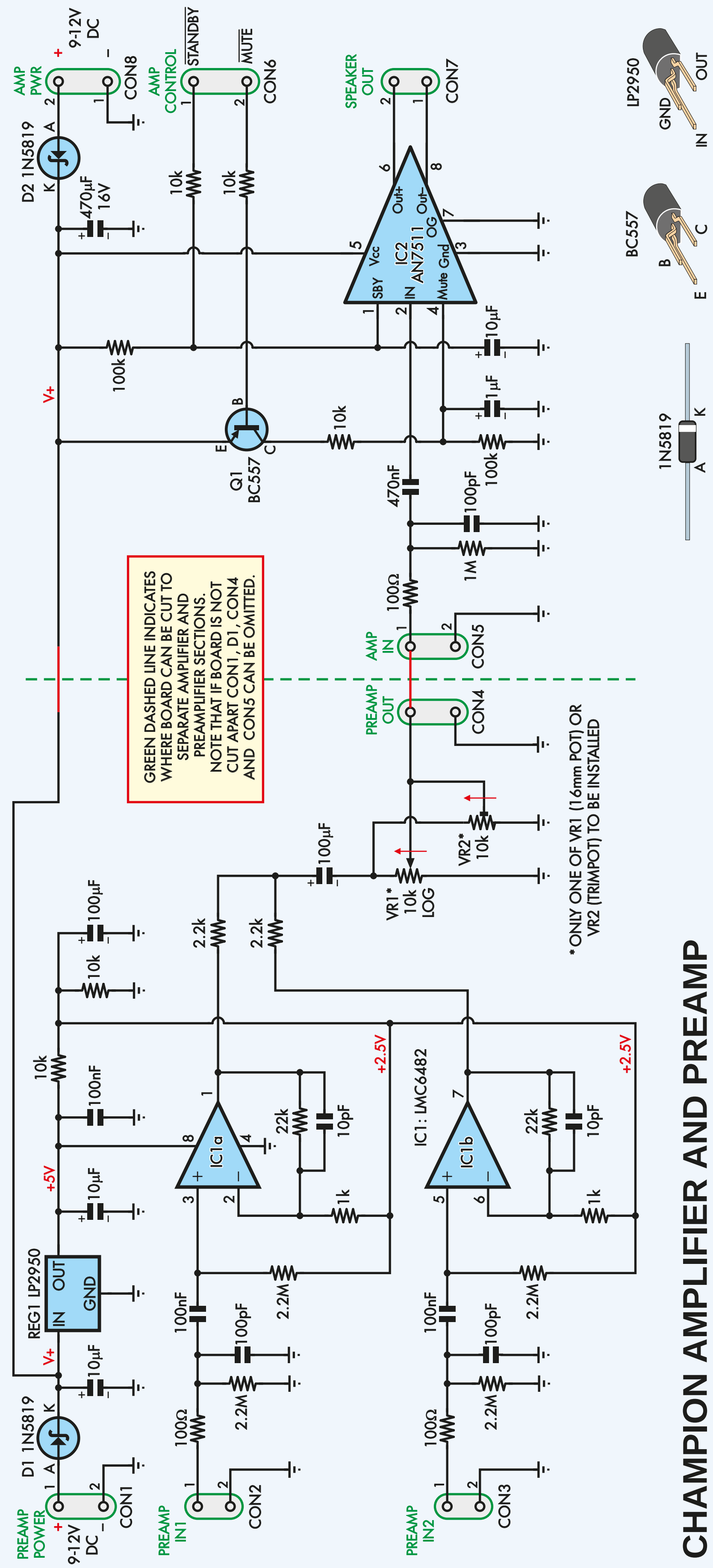
The PCB measures 100mm × 41mm and is available from the *EPE PCB Service,* coded 01109121/2. If you wish to build the *Champion* and its preamplifier separately (or build just one of these), cut the board between the dashed lines using a hacksaw.

The following instructions apply whether you are building one or both of the PCBs; simply repeat for each separate board.

Fig.2 shows the parts layout on the PCB. Start by fitting all the resistors. You should check the value of each one with a DMM before fitting it as some colour codes can be difficult to distinguish.

Follow with D2, but note that D1 will also have to be fitted if you build the preamp separately. Make sure that the diode(s) are oriented as shown.

Next, fit the ICs with the pin 1 dot or notch in the direction shown, ie, towards the top of the PCB. You can use a socket for the op amp but for best heat dissipation, the AN7511 should be soldered directly into circuit. Make sure that it's sitting all the way down on the PCB before soldering its leads, otherwise the heatsink won't mate properly when it is fitted later.



CHAMPION AMPLIFIER AND PREAMP

Fig.1: complete circuit diagram for the *Pre-Champion* (preamplifier) and *Champion* (amplifier). Dual op amp IC1 provides some gain for microphones and musical instruments connected to inputs CON2 and/or CON3. The signals are then mixed and either potentiometer VR1 or VR2 is used to adjust the volume. The signal then passes to the amplifier section at right, where IC2 provides a further 34dB of gain and drives the speaker in bridge mode.

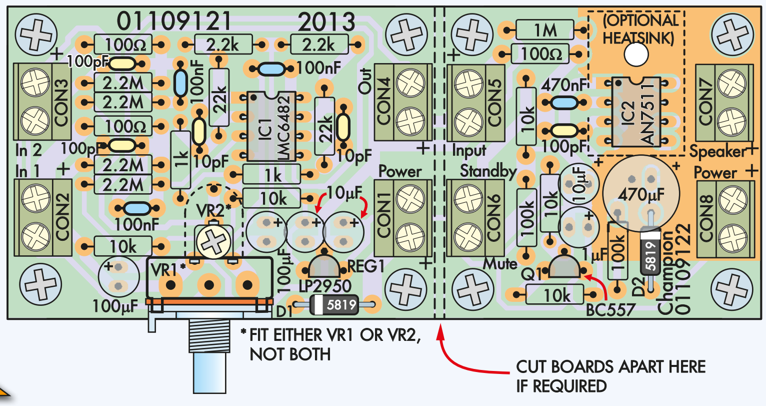
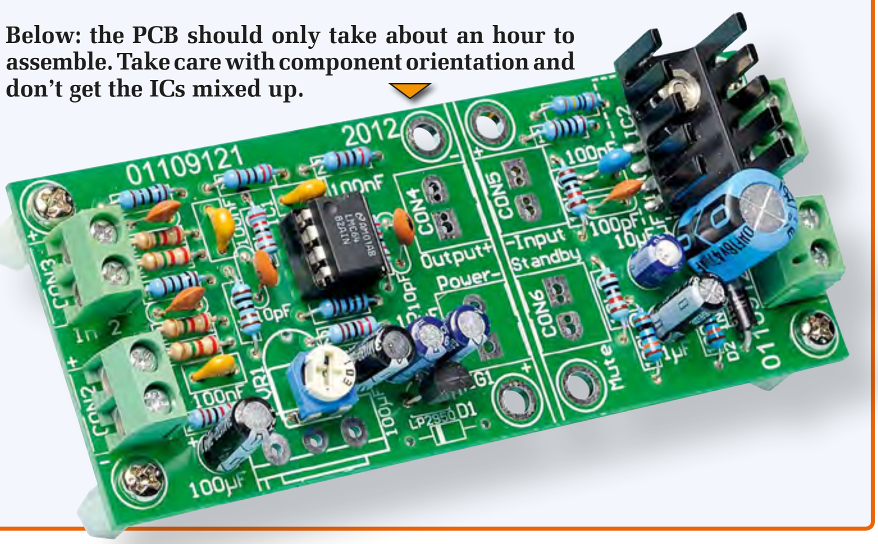


Fig.2: PCB overlay diagram for the *Pre-Champion* (left) and *Champion* (right). Potentiometer VR1 can be used for an externally accessible volume control or trimpot VR2 can be fitted instead for a one-time adjustment. A small heatsink is normally fitted to amplifier IC2 as it can dissipate quite a bit of power at higher supply voltages and output power levels.

Below: the PCB should only take about an hour to assemble. Take care with component orientation and don't get the ICs mixed up.



Next, fit the LP2950 regulator (REG1) and the BC557 transistor (Q1). You may need to bend the leads with small pliers to match the pad spacing on the PCB. Follow with all the ceramic and monolithic ceramic (MMC) capacitors.

The 2-way terminal blocks are next. These must be installed with their wire entry holes towards the adjacent outside edge of the PCB. There are four per board and this holds true even if you are building the two sections as a single unit. In other words, if you are building a single unit, leave out the terminal blocks in the middle of the combined PCB (ie, CON1, CON4, CON5 and CON6).

The next step is to decide whether you want to fit potentiometer VR1 or trimpot VR2 to adjust the volume from the *Pre-Champion* (you can fit one or the other but not both). If you intend using trimpot VR2 to set the volume, solder it in now. You can then fit all the electrolytic capacitors, except for the 470µF unit. In each case, the longer (positive) lead goes into the hole marked with a '+' sign.

The *Pre-Champion* section of the board can now be completed by fitting potentiometer VR1 (if this is to be used instead of VR2), plugging op amp IC1 into its socket and attaching M3 × 10mm tapped nylon spacers to the corner-mounting positions using M3 × 6mm machine screws.

Attaching the heatsink

For the *Champion*, the next step is to attach the heatsink. This is not strictly necessary but allows for a higher average output power level before the chip goes into thermal limiting.

A small TO-220 heatsink is specified and this is clamped on top of the DIP package. To do this, start by passing an M3 × 10mm machine screw up from the underside of the board, through the hole next to IC2. Fit a nut to hold this screw place, then place a split washer on top of this nut and then a shakeproof washer.

Next, spread a little thermal transfer compound on top of the IC. Alternatively, you can use a TO-220 thermal pad to ensure efficient heat transfer. This thermal pad is simply fitted over the screw shaft and pushed down so that it sits on top of the DIP chip.

Low-voltage performance

If you look at the graph of distortion vs frequency (Fig.4), you will see that for supply voltages below 6V, there is a large increase in distortion at signal frequencies below 1kHz. This is only an issue if you are using the Pre-Champion; if you look at the low supply voltage distortion figures without the preamp (orange and lavender lines), it is actually quite good.

The reason for this is that when the supply is below about 5.3V, REG1 enters dropout and this allows ripple on the supply line, due to the current demand of amplifier IC2, to affect the operation of op amp IC1. It only has a limited amount of supply rejection and so a small amount of the supply ripple makes it though to its output. This is further amplified by IC2, producing the relatively large amount of distortion.

The easy solution, if you are going to use the Champion and Pre-Champion at 5V or below, is to change REG1 to a 3.3V LDO regulator such as the LM2936-3.3 (Jaycar Cat. ZV1650). The pin-out is identical, so it's just a matter of substituting one for the other. The supply rail for IC1 should then remain in regulation down to the minimum supply of 4V.

This will reduce the maximum signal handling of the Pre-Champion, but you are only likely to be using this combination with low-level signal sources anyway (eg, microphones) so it should not be an issue. It will not affect the amount of power the amplifier can generate, nor should any other circuit changes be required.

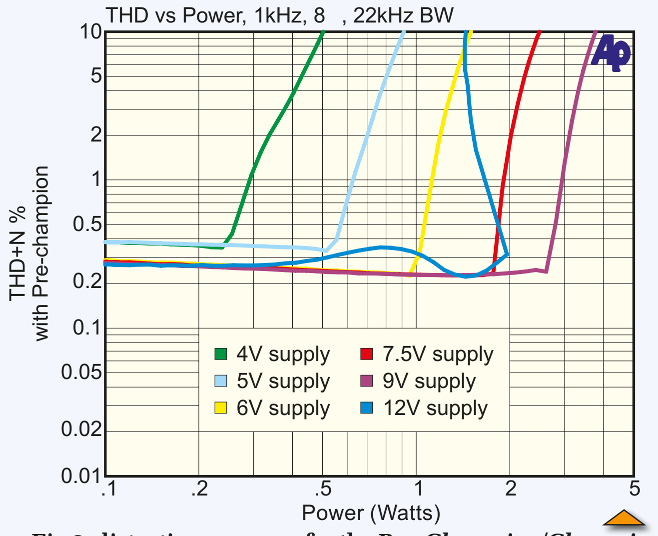


Fig.3: distortion vs power for the *Pre-Champion*/*Champion* combination for various supply voltages. With a higher voltage supply, the power output increases and distortion drops except for 12V. This curve is unusual because the increased dissipation resulting from the higher supply voltage causes thermal overload and the chip's self-limiting kicks in, reducing the power output to prevent damage. Maximum continuous power is therefore at a lower voltage, ie, around 9V.

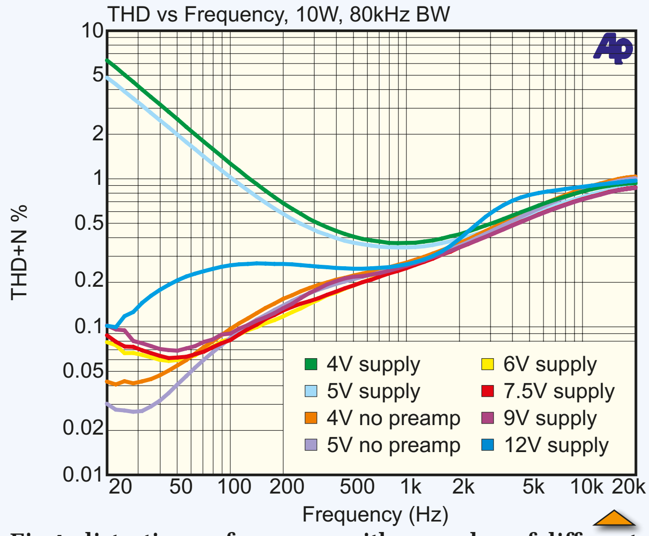
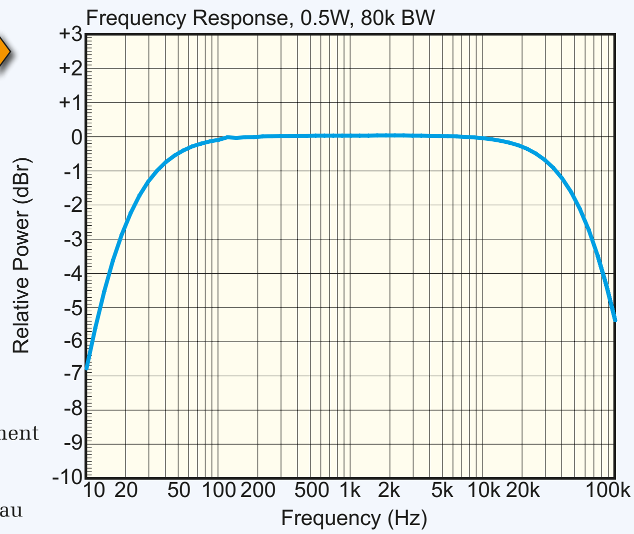


Fig.4: distortion vs frequency with a number of different supply voltages. As is typical, distortion increases with frequency. The output power level is 500mW in each case except with the 4V supply, where the output power is 200mW. Note that the THD performance vs frequency is much the same for the various supply voltages. Refer to the panel on the previous page for an explanation as to why distortion increases at low frequencies when the preamp is used.

Fig.5: the frequency response for the *Pre-Champion* and *Champion* combination. It's quite flat from 20Hz-20kHz, being down by just 0.3dB at 20kHz and around 2.6dB at 20Hz.



That done, place the heatsink on top of the chip and thread a second nut onto the end of the screw. Do it up tightly with small pliers, while holding the heatsink so it can't rotate.

Check that the heatsink sits flat against the IC when the nut is fully tightened. If it's sitting proud, then remove the star washer.

Now solder the 470µF capacitor in place. This will be too large to fit right down onto the PCB, especially with the heatsink alongside. If so, it can just sit on top of the adjacent diode. Simply angle its leads down through their holes, then push it down as far as it will go before soldering it in place.

Finally, fit the tapped spacers to this PCB using M3 × 6mm machine screws and the PCB assembly is complete.

Wiring it up

For the speaker, simply connect its two wires to the corresponding terminals on CON7. The polarity doesn't matter if you are building a single *Champion*. If using two modules for stereo, ensure that the speaker polarity is the same for each.

The DC power is fed in via CON8; ie, if you have a combined *Pre-Champion*/*Champion* then both units get power from the same connector.

If you are using the *Champion* by itself, you will probably need to fit some kind of volume control/input attenuator. This can be arranged using a 10kΩ log pot and a 1µF capacitor, as shown in Fig.6. Even if you don't need an externally adjustable volume, it's still a good idea to have this pot in order to match the input signal level to the input sensitivity of the *Champion*. For a stereo amplifier, you can use a dual 10kΩ log pot.

The mute and standby pins of CON6 can be left open, in which case the amplifier will run whenever power is applied. If you do want to use either or both of these control inputs, simply pull that pin to ground to activate the associated feature. Remember that both pins normally sit near V_{CC}, so if you want to drive them with a micro and it's running off a different supply, then you will need to drive these pins using NPN transistors.

Be sure to use shielded cable with the signal input(s), especially for the *Pre-Champion* as its inputs are very sensitive and will otherwise pick up noise and possibly also mains hum. If using the *Pre-Champion* separately, you will also need to apply power to CON1 and then run the output from

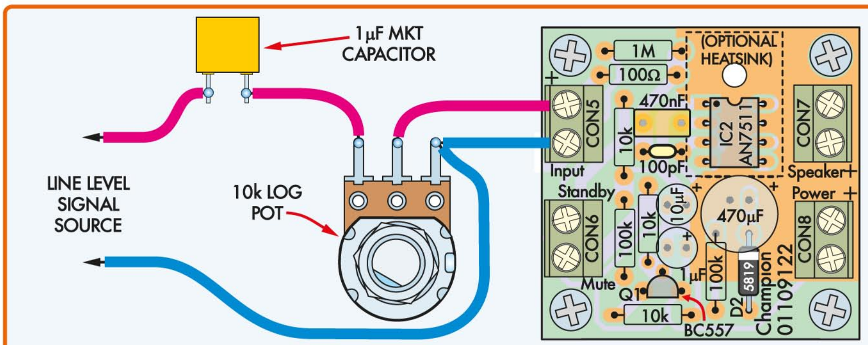
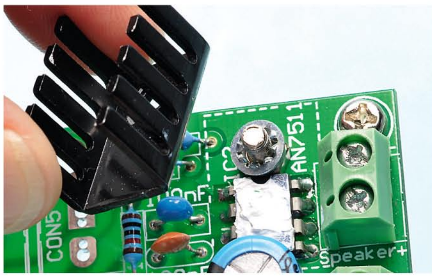


Fig.6: for higher level signals (eg, line level), the *Champion* can be used on its own. In this case, you will normally still need a volume control, wired as shown here. Even if the volume will be fixed, you will still usually need a pot, because otherwise higher level signals will overload the input.



Smear thermal grease over the top of the audio amplifier IC (or use a TO-220 thermal pad) before fitting the heatsink. Make sure the heatsink sits flat against the IC when the mounting nut is tightened (see text).

CON4 to the *Champion's* input, again using shielded cable.

Note that if you're using only one input on the *Pre-Champion*, it's a good idea to short the other one out with a wire link or low-value resistor, as this reduces the output noise.

If the gain of the *Pre-Champion* is too high, it can be lowered by reducing the two 22kΩ feedback resistors. The gain is calculated as R ÷ 1kΩ + 1 (where R is the feedback resistor value). So, if you use 2.2kΩ resistors, then you get a gain of 2.2kΩ ÷ 1kΩ + 1 = 3.2.

Microphone bias current

The *Pre-Champion* is a relatively simple design and doesn't have on-board support for balanced microphones, electret bias current and so on. However, most mics have a built-in power supply or require no bias, in which case you can just connect them straight to one of the inputs

If you do want to use an electret, you could wire a 10kΩ resistor between the regulator's +5V output pin and terminal 1 (the upper terminal) of either CON2 or CON3.

TechnoTalk

Mark Nelson

Boost for burglars, bad for health?

The well-known law of unintended consequences means technical innovations can sometimes have unwelcome by-products. Smart Meters are a prime example – they help us manage energy consumption better but also act as beacons to housebreakers looking to relieve us of our property. Mark Nelson spotlights this electronic vulnerability.

ONE of the surest ways is to exploit an unfortunate side effect of automated meter reading (AMR), which has taken off big-time in the United States. AMR is the name given to techniques used for collecting consumption, diagnostic and status information from water, gas and electricity meters, and transferring this to the utility companies for billing, troubleshooting and analysing. Many of the first systems transmitted this data by wireless (radio) means. Typically, the meters in people's homes transmit readings every 30 seconds for the benefit of meter readers who may be walking the streets or driving slowly by. The range of these transmissions is generally 300m or so.

According to Ishtiaq Rouf, early adopters are paying the price of using unsophisticated technology. His research team at University of South Carolina captured transmissions from AMR meters and reverse-engineered these to analyse the readings, using $1,000 worth of open-source radio equipment. Crucially, because energy usage normally drops significantly when a house is empty, abnormally low readings can identify which and when residents are not at home.

Klaus Kursawe, a security researcher at Radboud University (Nijmegen) in the Netherlands, who was not involved in the work, told *New Scientist* magazine: 'I consider it an embarrassment that this kind of technology is deployed with no protection whatsoever. It is well known by now how to properly and economically secure communication for such a device.'

Coming your way too

Some of the more advanced implementations of smart metering use power line communications (over the electricity mains), telephone lines, broadband connections or cellular radio to eliminate this vulnerability – but not all. The UK government aims for all homes and small businesses to have smart meters by 2020. Energy suppliers will be required to install more than 53 million new gas and electricity meters that will enable consumers to see how much energy they are using and what it will cost. This, the government says, will give us more control over our energy use and help us save energy and money.

At the heart of the smart metering solution being installed in Britain is a wireless home area network (HAN) operating in the 2.4GHz ISM band. This employs the ZigBee transmission protocol (**www.zigbee.org**), a global open standard developed specifically to address the unique needs of low-cost, low-power wireless machine-to-machine (M2M) networking. Unfortunately, the security of ZigBee is only as good as the specific implementation; just enter 'hacking zigbee' into Google to discover many exploits and technical presentations). If you next type 'hacking smart meters' you will discover Termineter, an open-source tool designed to assess the security of smart meters along with numerous forecasts of dire consequences.

However, the risk of burglary may be the least of your worries. 'From the viewpoint of a cyber attacker – whether a hostile government agency, a terrorist organisation or even a militant environmental group – the ideal attack on a target country is to interrupt its citizens' electricity supply, warns Cambridge University's Professor Ross Anderson, a leading expert on cyber-security. 'This is the cyber equivalent of a nuclear strike; when electricity stops, then pretty soon everything else does too. Until now, the only plausible way to do that involved attacks on critical generation, transmission and distribution assets, which are increasingly well defended. Smart meters change the game.'

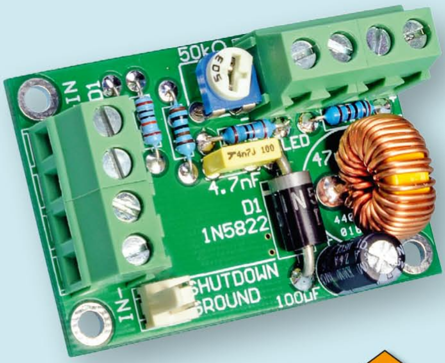
Choose to refuse?

You are under no obligation to have a smart meter installed in your home. And if you do decide to accept one, under OFGEM codes published July 2013, you can dictate how much data your energy supplier can retrieve from your smart meter and whether your supplier can share that data with third parties. You can also decide whether or not your supplier can use that information for marketing purposes. The Stop Smart Meters pressure group (**http://stopsmartmeters.org.uk**) aims to raise awareness about smart meters so that people can become informed about smart meters and take necessary and appropriate action to resist them.

Worryingly, there is also a health risk associated with the home area networks associated with smart metering, although the same could be said for any domestic Wi-Fi system. 'The Smart Meter is #1 in terms of devastation to our nervous system; [the radiation] permanently destroys and alters the manufacture of brain proteins... meaning that it completely changes the human organism – permanently', states USA-based physician Dr Dietrich Klinghardt, MD PhD. His fears are shared by other medical authorities on the SSM website, which claims: 'Smart meters emit pulsed microwaves constantly – 24 hours a day, seven days a week – and a single smart meter, pulsing up to 190,000 times a day, can expose the human body to 800 times as much radiation as a cellphone. And you do not have the ability to switch smart meters off.'

Claim and counterclaim

Numerous websites claim that in 2011 the World Health Organization (WHO) officially recognised that wireless radiation, such as that emitted by smart meters, is a possible carcinogen. Even if correct, the word 'possible' does not mean definite. Official information from Public Health England (part of the UK Department of Health) states there is no convincing evidence to suggest exposure to the radio waves produced by smart meters poses any health risk. Furthermore, David Higgins, professor of radiation biophysics at the Center for Radiological Research, Columbia University Medical Center in the US, told *New Statesman* magazine that while it's always hard to prove something is 'safe', 'Wireless smart power meters result in significantly less radiofrequency radiation exposure than produced by cellphones, so it is very unlikely they would be associated with adverse health effects.' So should we be worried?



The *MiniSwitcher* gives a regulated output from 1.2-20V at currents up to 1.5A and doesn't require a heatsink.

Simple 1.5A Switching Regulator

By NICHOLAS VINEN

This tiny regulator board outputs 1.2-20V from a higher voltage DC supply at currents up to 1.5A. It's small, efficient and cheap to build, with many handy features such as a very low drop-out voltage, little heat generation and electronic shut-down.

IN THE SEPTEMBER 2013 issue, we presented the *MiniReg*, an adjustable linear regulator. This has been a very popular kit because it's cheap, simple and can be adjusted to suit whatever voltage you need.

But while an LM317 regulator circuit might appeal to old dudes and codgers, it's so '1980s'! For anyone in their thirties or younger, it's just plain boring. In fact, the LM317 was designed in 1970 by two engineers working for National Semiconductor. That's over 40 years ago, well before I was born! And while linear regulators are still in use in many applications (yeah, yeah, still boring), these days, just about every computer, monitor and TV (and a lot of other gear) uses switch-mode regulation.

The benefit of switch-mode regulators is much higher efficiency. This means lower power consumption, less heat and cheaper components (eg, smaller transformers and heatsinks). Small size, light weight and low power consumption are particularly important for portable electronic gear.

In short, for a large range of applications, why would you bother with linear regulation? Linear regulators only have to be used if you need very low noise and ripple and for EMI-sensitive applications like radios. For just about everything else, switch-mode is the way to go.

Just look at the photo towards the end of this article – it shows how large a heatsink you need to get the rated current of 1.5A from the MiniReg with a 14.4V input and a 5V output (ie, when the power source is a lead-acid battery). That is no longer a small or cheap regulator!

Then there's the fact that a lot of linear regulators have quite a large 'dropout voltage'. This is the minimum difference between input and output voltage. For example, to get a regulated 12V, you generally need at least a 15V input (unless you are using a low-dropout regulator – an 'LDO'). Sometimes, a high drop-out voltage is a serious inconvenience (and it increases the dissipation as well, because the supply voltage is higher than it would otherwise need to be).

Main features

- Wide operating voltage range
- Very low drop-out voltage
- High efficiency
- No heatsinking necessary
- Electronic shutdown
- Thermal, overload and short circuit protection
- Soft start
- Provision for power switch / LED

Enter the MiniSwitcher

With only a modest increase in size and complexity, this design overcomes all those limitations. Like the elderly LM317, the chip we use here (the AP5002) has an adjustable output voltage, can deliver around 1.5A and it also has over-temperature and over-current protection. But unlike the LM317, it has a very low dropout voltage (about 0.1V) and doesn't need a heatsink, even with maximum input voltage and at the full load current of 1.5A.

Because it dissipates a lot less heat, that also means that less of the input supply power is wasted. Plus it has an electronic shut-down feature, allowing a micro or other logic circuit to turn it off if necessary. In this 'sleep' mode, it draws very little current.

The only real disadvantage of a switch-mode regulator (besides the extra complexity) is the high-frequency ripple on the output due to the switching action. But since the AP5002 operates at such a high frequency (typically 500kHz), the ripple has a low amplitude and sub-harmonics are not audible. It can be reduced even further by an external LC filter, to suit a particular application.

Regulation

So why do you need a regulator anyway? Well, there are a number of important reasons.

If you have a device which must run at a particular voltage (eg, 5V ± 0.5V or 4.5-5.5V), then you could just use a regulated plugpack or bench supply.

However, depending on the length and thickness of the supply leads and the unit's current consumption, there will be a voltage drop before the power reaches the device.

Even if the supply is putting out exactly 5V, it's possible that it may be below the minimum (in this case, 4.5V) by the time it reaches the unit. What's worse, as the unit's current draw changes, so will the voltage it receives, due to the cable drop and the output impedance of the power supply itself.

Local regulation solves this problem. By placing a regulator board in close proximity to the device being powered and feeding a higher voltage to it, changes in the power supply's output voltage become irrelevant.

Also, there are times when (for various reasons) you want to use a linear power supply, eg, a mains transformer with its output rectified and filtered. Not only can the output voltage of this type of supply vary quite a bit with load, but there is also 50/100Hz voltage ripple, due to the fact that the filter capacitor(s) charge and discharge over each mains cycle. This can cause hum in audio equipment and various other problems.

An efficient switch-mode regulator can turn this rather variable output into a nice, stable supply with a minimum of energy being wasted as heat.

Switch-mode basics

Before going further, let's take a look at how a step-down (or 'buck') switch-mode regulator works. Fig.1 shows the basic circuit. It uses a switch (in practice, a switching transistor or a MOSFET) to rapidly connect and disconnect the incoming power supply to the input end of inductor L1. The other end of the inductor connects to filter capacitor C1 (which acts as an energy storage device) and the load.

As shown by the blue line labelled 'PATH 1', when the switch is closed, current flows through the inductor and then the load. The rate of current flow ramps up linearly as the inductor's magnetic field strength builds.

Then, when the switch opens, the current flow from the input supply is interrupted and the inductor's magnetic field begins to collapse. This continues driving current into the output but at a diminishing rate. While the switch is open, the output current is sourced from ground, via diode D1 (the red line shown as 'PATH 2').

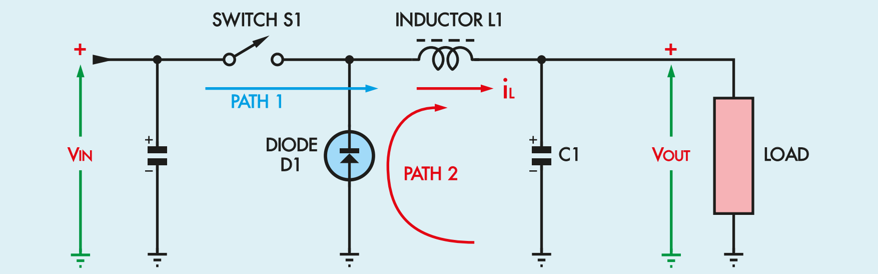


Fig.1: basic scheme for a switch-mode buck converter. Voltage regulation is achieved by rapidly switching S1 and varying its duty cycle. The current flows via path 1 when S1 is closed and path 2 when it is open. In a practical circuit, S1 is replaced by a switching transistor or a MOSFET.

In practice, because this current then flows to ground after passing through the load, it actually travels in a loop, through D1, L1, the load and then around again until either the inductor's magnetic field is fully discharged or switch S1 closes again.

By varying the switch on/off ratio, the average current through the inductor can be controlled and this, in combination with the load characteristics, determines the output voltage. The ratio of the switch on-time to the switching period (on-time plus off-time) is known as the duty cycle. However, because the inductor and load properties can vary, for a constant output voltage we can't use a fixed duty cycle.

Instead, the output voltage is monitored and if it is too low, the duty cycle is increased. Conversely, if the output voltage is too high, the duty cycle is decreased. This negative feedback provides the required regulation.

There's a bit more to it than that, but in practical circuits, most of the details are taken care of by a switch-mode IC.

Circuit description

We decided to use an AP5002 after surveying the range of switch-mode regulator ICs available. This device has a good range of features and is low in cost.

Fig.2 shows the circuit details. It's based on the data sheet, but with several important changes.

As well as the switch-mode regulator (IC1), you should recognise inductor L1 and Schottky diode D1 from the explanatory diagram (Fig.1). While the recommended inductor value is 10-22µH, we found that 47µH provides better duty cycle stability over a range of input and output voltages and load currents. It's also a more common value and it provides better ripple filtering than a lower value inductor.

Both the input and output lines are filtered using low-value (100nF) and high value (22µF) ceramic capacitors in parallel. This results in a very low ESR (equivalent series resistance) across a wide range of frequencies, reducing the current spikes in the input and output wiring. Note that the 100nF

Specifications

Input voltage	3.6 to 20V (absolute maximum 22V)
Output voltage	1.2-20V (must be below input voltage)
Dropout voltage	typically 0.1V at 1A
Output current	at least 1.5A
Efficiency	can exceed 90%, typically over 85%
Switching frequency	approximately 500kHz
Quiescent current	3mA (10µA when shut down)
Load regulation	~1%, 1.5A step
Line regulation	~2%, 4-20V
Output ripple	<5mV RMS at 1.5A (see Fig.2)
Transient response	~250mV overshoot, ~100mV undershoot, 1A step

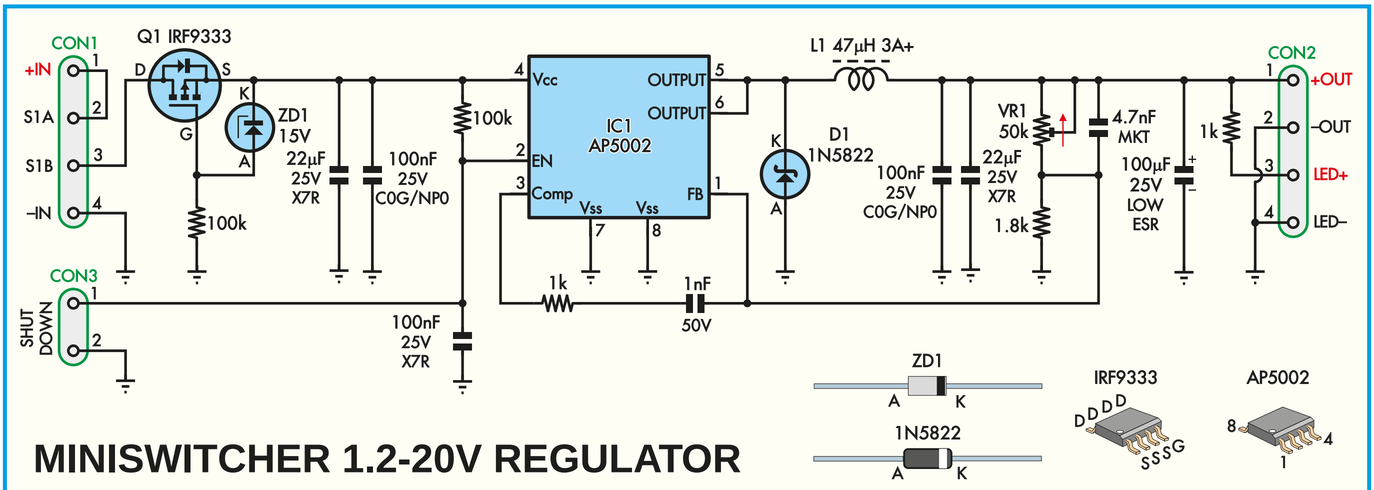


Fig.2: the complete switching regulator circuit. MOSFET Q1 provides input reverse polarity protection, while IC1 does the switching and regulation via negative feedback. Inductor L1 filters the output in combination with three capacitors across the ouput rail, while trimpot VR1 provides output voltage adjustment.

capacitors are specified with a ceramic C0G dielectric, as this provides the best performance over the widest range of frequencies and temperatures.

Trimpot VR1 allows the output voltage to be adjusted. It forms part of a resistive voltage divider which is in the feedback path from the output to IC1's FB (feedback) input at pin 1. IC1's negative feedback keeps its FB pin at around 0.8V. This means that in order to get a 5V output (for example), VR1 is set to around 9.45kΩ. In practice, you just turn VR1 until the desired output voltage is achieved.

VR1 is in the upper half of the feedback divider, with a 1.8kΩ resistor in the lower half, as this provides a more linear and progressive adjustment. However, there are advantages to using the opposite configuration (ie, with VR1 between FB and ground), the primary one being that if VR1 goes open circuit, the output voltage goes down rather than up. But then it's trickier to set the desired voltage.

The 4.7nF capacitor across VR1 is a 'feed-forward' capacitor, which reduces the gain of the feedback system to unity at high frequencies. This improves the circuit's stability, like the capacitor across the feedback resistor often seen in op amp circuits.

The 1nF capacitor and 1kΩ resistor in series between pins 1 (FB) and 3 (Comp) of IC1 also work to improve the loop stability of the regulator. These components provide frequency compensation, hence the labelling of pin 3. Pin 1 connects to the input of IC1's internal error amplifier, while pin 3 connects to the output, and so these components are in the feedback loop and limit the slew rate of the error amplifier output.

Pin 2 of IC1, labelled 'EN', is the enable input. If this is pulled low, the regulator shuts down – its internal switch turns off, the output pins go high impedance and its quiescent current drops to 10µA. A 100kΩ pull-up resistor to Vcc enables the regulator by default, while a 100nF capacitor filters the voltage at this pin to prevent the EN pin from rapidly toggling due to EMI (electromagnetic interference).

EN can be driven low for shut-down and simply pulled high (via a resistor) for normal operation. Alternatively, it can be actively driven high and low. However, if actively driven high (not used here), the high voltage must be below Vcc. It's also a good idea to drive the EN pin via a series resistor of about 2.2kΩ, to protect IC1.

The input supply is normally connected to terminals 1 (positive) and 4 (negative) of CON1. A power switch can then be connected between terminals 2 and 3. If you don't want a power switch, you can simply connect a short piece of wire (eg, 1mm tinned copper wire) between terminals 2 and 3. Alternatively, the positive input supply can be connected directly to terminal 3.

P-channel MOSFET Q1 (a surface-mount type) protects IC1 against accidental reversal of the supply voltage polarity. This is a logic-level device with a very low on-resistance, so it can operate down to the minimum supply voltage for IC1 (3.6V), In addition, during normal operation, very little power is lost in Q1. Its on-threshold is typically 1.8V (maximum 2.4V), so by 3.6V its channel resistance is already quite low – around 33mΩ at 4.5V and 20mΩ at 10V and above.

If the input supply voltage has the correct polarity, Q1's gate is pulled below its source, which is initially no more than one diode drop below its drain. This is connected to the positive supply lead (clamped by the parasitic body diode). Since Q1 is a P-channel type, this turns it on. Its maximum gate-source voltage rating is 20V, so Zener diode ZD1 limits this to around 15V (for higher supply voltages).

However, if the supply voltage is reversed, Q1's gate is instead pulled above its source and so Q1 is off. The parasitic body diode is now reverse-biased, so no current can flow into the circuit. ZD1 clamps the gate to no more than one diode drop above the source, with some current flowing through the 100kΩ resistor (up to a maximum of 0.22mA at 22V).

With a correctly polarised supply voltage above 15V, ZD1 conducts and a small amount of the supply current passes through Q1's 100kΩ gate resistor. This is no more than about 70µA at the maximum allowable supply voltage (22V). Below 15V, Q1's gate has a very high resistance and so once its gate capacitance has charged up and Q1 is on, only a tiny current flows.

The output voltage is available from terminals 1 and 2 of CON2. An LED can be connected between terminals 3 and 4, to indicate when the regulator

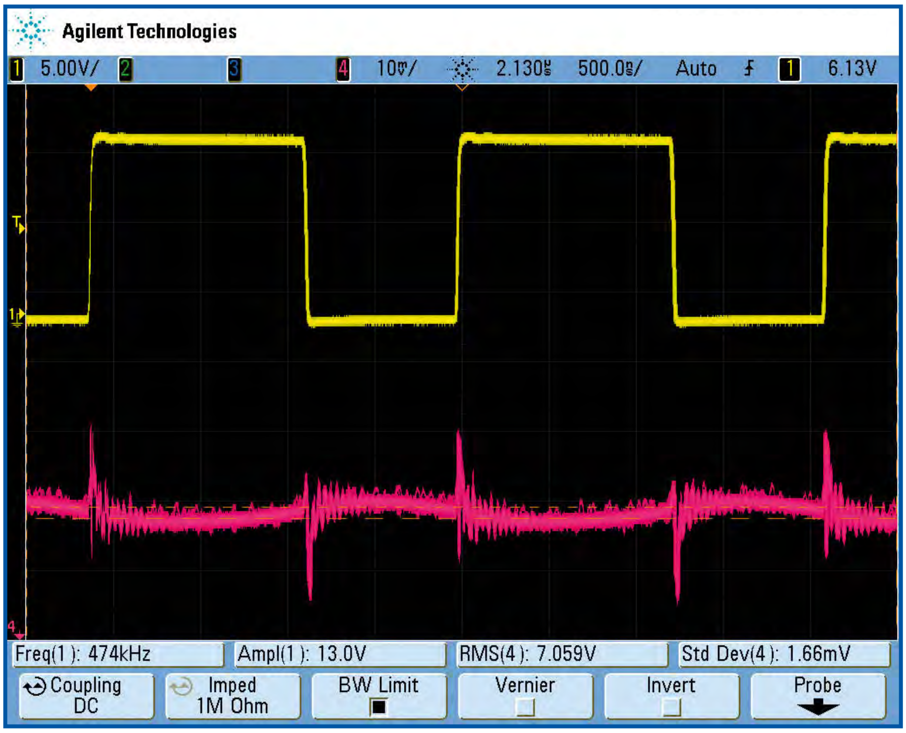


Fig.3: this shows the operation of the unit with 13V in and 7V out at 1.5A. The yellow trace is the voltage at the output pins of IC1, while the mauve trace shows the voltage across the load. The spikes in the latter trace corresponding with the output transitions are due to inductance in the scope probe ground lead. If you ignore that, there's only a few millivolts of ripple at the regulator output.

is operating. The specified 1kΩ current-limiting resistor will suit some combinations of output voltage with some standard LEDs, but may need to be reduced for other combinations (ie, lower output voltages and/or blue or white LEDs).

Transient response

The 100µF electrolytic capacitor in parallel with the output filter has been added to improve transient response. If the regulator's load suddenly drops (ie, its impedance increases), the output isn't immediately reduced to compensate. This is partly due to energy stored in the inductor and partly due to the frequency compensation scheme required for stable operation.

The result is a temporary spike in the output voltage. By increasing the output capacitance, we reduce the amplitude of this spike.

With the circuit as shown, we measured an overshoot of around 0.25V with a step of over 1A. The undershoot when the load impedance suddenly drops (ie, current demand increases) is much lower, at less than 0.1V. These figures should be acceptable in most applications and will be reduced further by any input load capacitance associated with the load – typically several hundred microfarads.

Note that we have specified a low-ESR type for the 100µF filter capacitor so that it has sufficient ripple current capability. These are also usually rated for 105°C operation. Capacitors this small are usually only rated for around 500mA ripple current, but in this regulator, the ripple is quite low and so heating isn't a problem. In operation, the electrolytic capacitor is normally only heated to about 10°C above ambient (tested at 1.5A).

Construction

The *MiniSwitcher* is built on a PCB, available from the *EPE PCB Service,* coded 18102121 and measuring 49.5mm × 34mm. This has been designed as a double-sided PCB with some plated-through holes and the top layer acting as a ground plane to reduce electro-magnetic interference (EMI).

Fig.4 shows where the various parts go. Begin the assembly by installing IC1 on the underside of the PCB. This is in a surface-mount 8-pin SOIC package and its pins are sufficiently spaced for it to be soldered with a regular iron.

Parts list

1 PCB, available from the *EPE PCB Service,* code, 18102121, size, 49.5mm × 34mm
1 47µH 3A inductor (L1)
1 50kΩ mini horizontal trimpot
4 2-way terminal blocks, 5mm or 5.08mm pitch (CON1, CON2)
1 2-way polarised header (CON3)
3 M3 × 6mm machine screws
3 M3 × 12mm tapped spacers

Semiconductors
1 AP5002SG-13 switch-mode regulator [SOIC-8] (IC1) (Element14 1825351)
1 IRF9333 P-channel MOSFET [SOIC-8] (Q1) (Element14 1831077)
1 1N5822 3A Schottky diode (D1)
1 15V 400mW/1W Zener diode (ZD1)

Capacitors
1 100µF 25V low-ESR electrolytic
2 22µF 25V X7R ceramic [4832/1812] (Element14 1843167)
3 100nF 25V NP0/C0G ceramic [3216/1206] (Element14 8820210)
1 4.7nF MKT
1 1nF 50V NP0/C0G ceramic [3216/1206] (Element14 1414710)

Resistors (0.25W, 1%)
2 100kΩ 1 1.8kΩ
2 1kΩ

First, check that it is oriented correctly, with its pin 1 towards the bottom edge of the board. That done, line its pins up with the pads and solder them in place. If your IC doesn't have a dot to indicate pin 1, check to see whether it has a bevelled edge, as shown on Fig.4.

Because its output and ground pins connect directly to its internal MOSFET switch, these are soldered to two large pads for better heat dissipation. The other four pins connect to individual pads as usual. Use fresh solder and ensure it has been heated enough to flow properly.

If you don't do this, it's possible for solder to adhere to one of the pins but

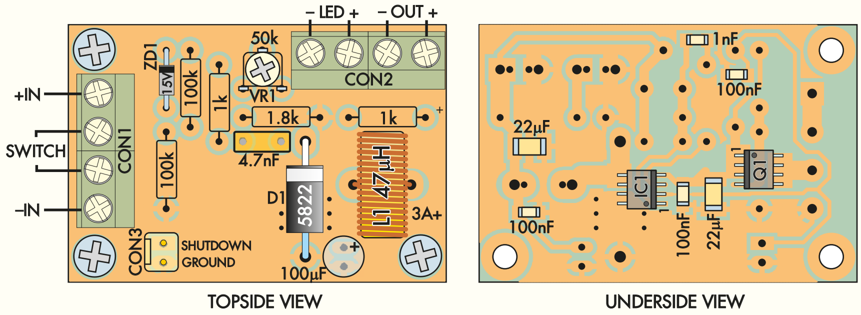
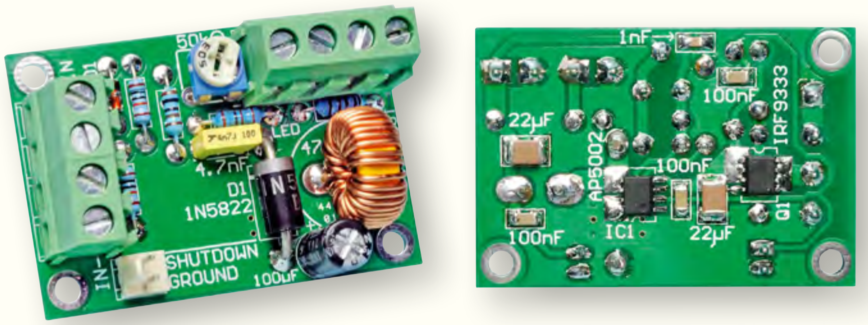


Fig.4: the regulator is built on a small double-sided board and utilises both surface-mount and through-hole components. The top layer is a ground plane, minimising the current loops and thus keeping electromagnetic radiation outside the board to a low level.



These top and bottom same-size views show the fully-assembled PCB. You will need a soldering iron with a fine conical tip to solder the surface-mount parts. Unwanted solder bridges can be removed using solder wick.

not actually flow under the pin and onto the associated pad.

Install MOSFET Q1 next, using the same technique. It too has large pads for its multiple drain and source pins. Be careful, because **its orientation is opposite to IC1, ie, its pin 1 goes towards the top of the board.**

Now check IC1 and Q1 for any unwanted solder bridges between adjacent pins (ie, ignore those between pins that solder to the same pad). If you do find any, they can be easily removed using solder wick (or de-soldering braid).

The 100nF and 1nF ceramic capacitors in the 3216/1206 packages are next on the list. The easiest way to install these is to first melt some solder onto one of the pads. You then hold the capacitor alongside this pad using tweezers, reheat the solder and slide the capacitor into place.

If you don't get it perfectly positioned on the first attempt, just reheat the solder and adjust it slightly. That done, solder the other pad, then go back to the first one and apply a little fresh solder, to reflow it and form a proper joint. The two larger 22µF ceramic capacitors can then be installed using the same procedure.

Through-hole parts

You can now proceed to install the through-hole parts, starting with the resistors. Check the values with a DMM before installing them, then fit diode D1 and Zener diode ZD1, taking care to orient them correctly.

Follow with trimpot VR1, the 4.7nF MKT capacitor and then the terminal blocks. Be sure to dovetail the 2-way terminal blocks together (to make 4-way blocks) before pushing them down fully onto the PCB and soldering their pins. Make sure that their wire entry holes face towards the adjacent edge of the PCB.

Note that there is provision on the board for the load and/or LED to be connected via a polarised header instead of a terminal block. This could be useful for loads drawing under 1A, such as computer fans. If you decide to install polarised headers instead, check the polarity of the fan plug and orient them accordingly. You can mix and match 2-way terminal blocks and polarised headers if you like.

The polarised header for the shutdown feature can then be fitted at bottom left. Orient it as shown on the overlay diagram (Fig.4). The 100µF electrolytic capacitor can then be installed, followed by inductor L1 (47µH).

The assembly can now be completed by fitting three M3 × 12mm tapped spacers to the corner mounting holes.

Setting up and testing

The first step is to turn VR1 fully anticlockwise, then back it off a little. That done, connect a power supply between terminals 3 and 4 of CON1 (eg, a 12V plugpack or a bench supply). The positive lead should go to terminal 3. It's also a good idea to connect a DMM set to measure current in series with the supply, if possible.

You may also want to connect an LED across terminals 3 and 4 of CON2, with the anode (longer lead) to terminal 3. Depending on the output voltage and LED colour, it will be driven at 1-20mA. If the LED is too dim (eg, at low output voltages), use a lower value resistor and if it is too bright, increase the value. For output voltages of 5V and below it's probably a good idea to change this resistor to 300-470Ω, while for output voltages above 12V you may want to increase it to, say, 2.2kΩ.

Note, however, that the LED will not light if the regulator's output voltage is lower than the LED's forward voltage (1.8V for a red LED and 3.3V for a blue LED).

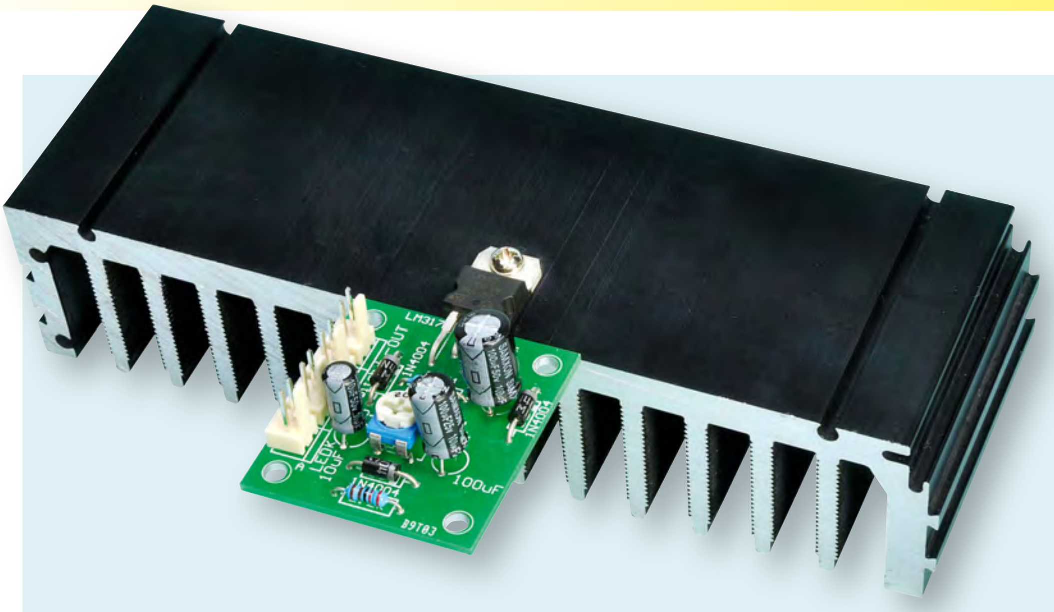
If you want to use a 12V LED (ie, one with a built-in resistor) and the output voltage is no more than say 15V, replace the 1kΩ resistor with a wire link. Alternatively, the LED can simply be connected across the output terminals, in parallel with the load.

Now apply power and check that the current quickly drops to just a few milliamps. Assuming it does, check the voltage at the output, ie, between pins 1 and 2 of CON2. This should be around 1V, depending on the exact position of VR1. If this is correct, turn VR1 and check that this adjusts the output voltage.

Note that you may hear some whine from the inductor if you set it below 1.2V, as this typically results in some sub-harmonic oscillation.

Assuming all is well, adjust VR1 to give the desired output voltage. It's a good idea to make the final adjustment later, with the power supply you will be using in your application (assuming it's different from the one you're using for the set-up).

If you have a low-value, high-power resistor (eg, 4-10Ω 10W), connect it across the output terminals and check



This photo of the *MiniReg* linear regulator (September 2013) shows just how inefficient it is compared to the *MiniSwitcher*. This is the size of heatsink it requires in order to handle a current of 1A if there is a large voltage differential between input and output (eg, 14.4V input and 5V output). By contrast, the *MiniSwitcher* can handle currents up to 1.5A and doesn't require a heatsink at all, regardless of the input-to-output difference.

that the set voltage is maintained. This assumes that with your set voltage, the current draw will be within the permissible range (up to 1.5A) and that your test supply can deliver enough power to the regulator.

Troubleshooting

If the board isn't working, switch off and check the solder joints with a magnifying glass. In particular, check IC1 and Q1 carefully, as it isn't always obvious when the solder has adhered to a pin and not to the pad.

Assuming there are no soldering problems, the other likely cause of a fault is an incorrectly oriented component or a part in the wrong location.

If all is well, install the regulator board into the chassis you want to use it in and monitor the output voltage while making the final adjustment to VR1. You can then use a dab of silicone sealant or hot-melt glue to prevent it from being changed accidentally.

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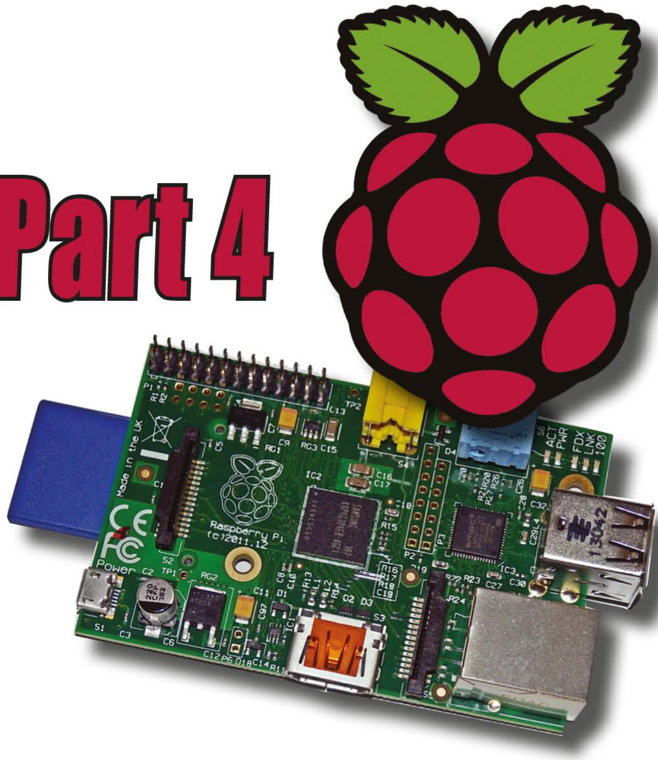
Teach-In 2014 Raspberry Pi – Part 4

by Mike and Richard Tooley



Welcome to *Teach-In 2014* with Raspberry Pi. This exciting new series has been designed for electronics enthusiasts wanting to get to grips with the immensely popular Raspberry Pi, as well as computer buffs eager to explore hardware and interfacing. So, whether you are considering what to do with your Pi, or maybe have an idea for a project but don't know how to turn it into reality, our *Teach-In* series will provide you with a one-stop source of ideas and practical information.

The Raspberry Pi offers you a remarkably effective platform for developing a huge variety of projects; from operating a few lights to remotely controlling a robotic vehicle through the Internet. *Teach-In 2014* is based around a series of practical exercises with plenty of information for you to customise each project to meet your own requirements.

The Raspberry Pi is no mean performer; it can offer you very similar performance to that which you might expect from a larger and much more expensive computer system, so don't be fooled by the relatively small price tag. By shopping around you can build a very effective computer system based on a Raspberry Pi for less than £100. However, if you are looking for something more modest and just want to take advantage of the Raspberry Pi as a single-board computer for a particular control application then you can be up and running for a very reasonable outlay.

This series will teach you about:

- **Programming** – introducing you to the powerful Python programming language and allowing you to develop your programming skills
- **Hardware** – learning about the components and circuits that are used to interface microcomputers to the real world
- **Computers** – letting you get to grips with computer hardware and software and helping you understand how they work together
- **Communications** – showing you how to connect your Raspberry Pi to a network and control a remote device using Wi-Fi and the Internet.

So, what's coming up? Regular features of *Teach-In 2014* with Raspberry Pi will include:

- **Pi Project** – the main topic for each part will be a project that explores a particular use or application of the Raspberry Pi in the real word. Projects will include shopping for your Pi, set up, environmental monitoring, data logging, automation and remote control.
- **Pi Class** – each of our Pi Projects will be linked to one or more specific learning aims. Examples will include methods of representing and handling data, serial versus parallel data transmission and architecture of a microprocessor system.
- **Python Quickstart** – a short feature devoted to specific programming topics, such as data types and structures, processing user input, creating graphical dialogues and buttons and importing Python modules. We will help you get up and running with Python in the shortest time!
- **Pi World** – this is where we take a look at a wide range of Raspberry Pi accessories, including breadboards, prototype cards, bus extenders and Wi-Fi adapters. We will also help you build your Raspberry Pi bookshelf with a selection of recommended books and other publications.
- **Home baking –** suggested follow-up and extension activities such as 'check this out', a simple quiz, things to try and websites to visit.
- **Special features –** an occasional 'special feature'. For example, how to laser cut your own mounting plate – with additional downloadable resources such as templates and diagrams.

What will I need?

To get the best out of our series you will, of course, need access to a Raspberry Pi. If you don't already have one, don't worry – we will be explaining what you need and why you need it (we will also be showing you how you can emulate a Raspberry Pi using a Windows PC).

This month

In this month's *Teach-In 2014* we will be entering the analogue world. Our *Pi Project* deals with the construction of a simple eight-channel analogue input board based on the Humble Pi. We will also be taking a first look at the serial (SPI) interface and how to make effective use of it. *Python Quickstart* will provide you with an introduction to ways of giving your programs a more professional finish with the aid of the Tk graphical user interface (GUI) that comes bundled with Python.

Python Quickstart

This month we will be looking at ways of giving your Python programs a more attractive graphical user interface (GUI). If you've entered any of the example Python code that we've provided thus far, you will have noticed that the user interface is rather limited and the output only consists of text printed in a console window. This can be quite acceptable for simple one-off applications but can become tedious and frustrating when programs are more complex in terms of user input and output. Fortunately, there's a solution to this problem in the form of the GUI extensions available from within the powerful and versatile tkinter package.

What is tkinter?

Tkinter is the standard Python interface to the Tk graphical user interface (GUI) toolkit. Tk and tkinter (or Tkinter) are available on most Unix platforms, as well as on Windows and Macintosh systems, so this can help to make your code portable between different operating systems. The Tk interface is provided by a binary extension module (`_tkinter`), which constitutes the operating system-specific, low-level interface to Tk.

Using tkinter

To use `tkinter` (in Python 3.x onwards) all you need to do is to import the `tkinter` module using the following line of code:

```
import tkinter
```

Thereafter, you will need to prefix every `Tk` class name you use with `tkinter`, for example:

```
import tkinter
root = tkinter.Tk()
w = tkinter.Label(root, text="Here is some text")
```

To simplify matters you can use:

```
import tkinter as tk
```

If you use this form of the import command you will only need to use the prefix `tk` in your subsequent code. This renames `tkinter` as `tk` within your namespace and thus saves typing, as in:

```
import tkinter as tk
root = tk.Tk()
w = tk.Label(root, text="Here is some more text")
```

One further possibility is that of importing all of the tkinter objects into your namespace using the * wildcard. The required code is:

```
from tkinter import *
```

This imports every object in tkinter into your current namespace, see next example.

A simple example

To show how easy it is to start using `tkinter`, let's work through a simple example that just produces some text in a window (see Fig.4.1). First we must import tkinter into our namespace using:

```
from tkinter import *
```

Notice how we have used the wildcard in order to save typing. Next, we need to create a `Tk` root 'widget'. This is an ordinary window, with a title bar and other features provided by your window manager. Only *one* root widget should be created in a program, and it needs to be created *before* any other widgets are added:

```
root = Tk()
```

Now we can add a Label widget as a child to the root window:

```
w = Label(root, text="Teach-In with Raspberry Pi")
```

A Label widget can display either text or an icon or another image supplied in an appropriate file format (eg, a GIF file). In this case, we are only using the text option.

Next, we use the pack method on this widget. This simply tells the window to size itself in order to fit the text that we want to display:

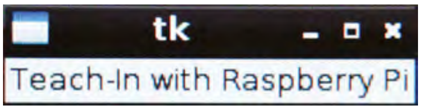
```
w.pack()
```

Finally, and in order to make the window appear, we need to create an event loop. This requires the following line of code:

```
root.mainloop()
```

The program will stay in the event loop until we close the window

Fig.4.1. Using tkinter's Label widget



(just click on the close button at the top right-hand corner of the window). Note that, not only does the event loop handle events from the user (such as the mouse click to close the window) but it also handles redraw messages allowing, for example, the window to be dragged, resized, minimised and maximised. Here's the complete example with just five lines of code:

```
from tkinter import *
root = Tk()
w = Label(root, text="Teach-In with
Raspberry Pi")
w.pack()
root.mainloop()
```

Now for another simple example that makes use of `tkinter`. This time, we will use the Message widget to produce a window that contains the current date and time (see Fig.4.2). Once again, we must start by importing tkinter but, for this application, we will also need to gain access to the time library using:

```
from tkinter import *
import time
```

Next, we can give our message a title by using the following line of code:

```
title = "Time Box".title()
```

The information that we need to display in our window is an ASCII string comprising the date, time and year. The next line of code defines the message that we are going to display:

```
msg = Message(text= "%s" % time.asctime())
```

Next, and to make the message display a little more attractive, we will configure the message so that it appears in 16 point bold Times Roman font:

```
msg.config(bg='yellow', font=('times', 16,
'bold'))
```

Finally, we need to use the pack method to size the message box before ending the program:

```
msg.pack()
mainloop()
```

The full code for the date/time application is as follows:

```
from tkinter import *
import time
title = "Time Box".title()
msg = Message(text= "%s" % time.asctime())
msg.config(bg='yellow', font=('times', 16,
'bold'))
msg.pack()
mainloop
```

Fig.4.2. Using tkinter's Message widget

There are many more widgets for you to play with, including button, check button, entry, frame, listbox and menu widgets. There's not enough space to describe any of these this month, but at least this brief introduction should have given you some idea of what you can do with `tkinter` and how it can be used to make your programs visually attractive and also easy to use. Later in this instalment of *Teach-In* you will find a complete example of a practical `tkinter` application in the form of a digital voltmeter for use with this month's *Pi Project*.

Pi Project

Last month in *Pi Project* we described the construction of an eight-channel output driver. This month, we'll be entering the analogue world and our project involves the design and construction of an eight-channel analogue input port, which is ideal for a number of applications including temperature sensing (see next month).

MCP3008 ADC

The simplified block schematic of our eight-channel analogue input board is shown in Fig.4.3. The circuit is based on a single MCP3008 eight-channel analogue-to-digital converter. This handy chip from Microchip Technology uses a serial (rather than parallel) interface for connection to a host computer or microprocessor-based system. The pin connections for an MCP3008 are shown in Fig.4.4. Note that there are two ground connections; one for analogue ground and one for digital ground.

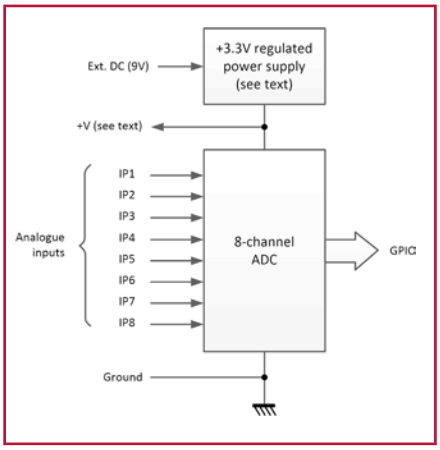


Fig.4.3. Simplified block diagram of the eight-channel analogue input board

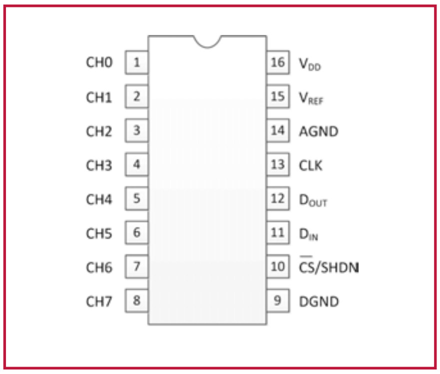


Fig.4.4. Pin connections for an MCP3008 (viewed from the top)

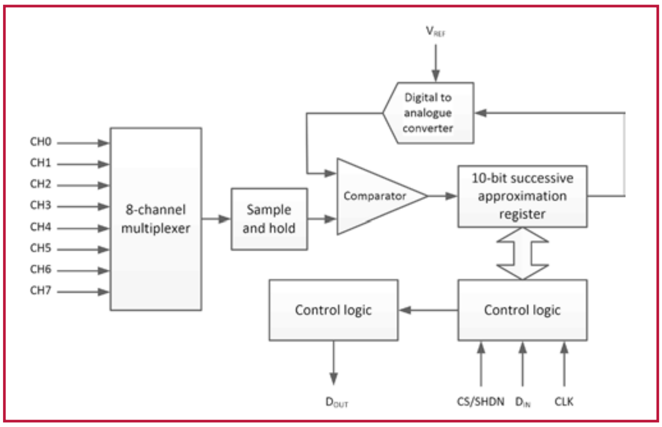


Fig.4.5. Simplified internal block schematic of MCP3008

The MCP3008 is a 10-bit analogue-to-digital converter (ADC) with on-board sample-and-hold circuitry. The chip is programmable to provide either four pseudo-differential input pairs or eight single-ended inputs. Communication with the device is accomplished using a simple serial interface compatible with the SPI protocol (see boxed feature on page 44). The chip is capable of conversion rates of up to 200,000 samples per second and it requires a supply of between 2.7V and 5.5V. Low-current design permits operation with typical standby currents of only 5nA and typical active currents of 320µA.

The range of analogue voltages that can be converted by the MCP3008 is determined by the voltage that appears at the reference voltage present at pin-15 of the device. Note that, as the reference input is reduced, the least-significant bit (LSB) size is reduced. The size of the least significant bit can be calculated from:

$$LSB = V_{REF} / 1024$$

The theoretical digital output code produced by the A/D converter is a function of the analogue input signal and the reference input, as shown below.

$$\text{Digital output code} = 1024 \times V_{IN} / V_{REF}$$

Where V_{IN} is the analogue input voltage and V_{REF} is the reference voltage.

As an example, let's suppose that the analogue input voltage is 660mV and the reference voltage is 3.3V. In this case, the digital output code will be given by:

$$\text{Digital output code} = 1024 \times 0.22 / 3.3 = 205$$

This code will be sent via the SPI interface to the Raspberry Pi when the MCP3008's chip select line is taken low. The simplified internal block schematic of the MCP3008 is shown in Fig.4.5.

Eight-channel analogue input board

The complete circuit of the eight-channel analogue board is shown in Fig.4.6. The reference voltage is derived from the 3.3V supply rail (pins 14 and 15 on IC1 are linked together) while the analogue and digital ground connections (AGND and DGND) are connected to the common 0V/ground rail. The 3.3V supply comes from low-dropout voltage regulator, IC2. Note that, when ordering a power supply kit for this particular application, it is essential

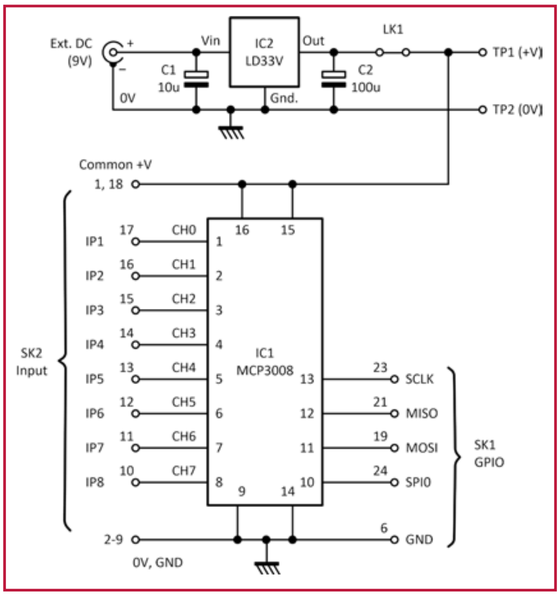


Fig.4.6. Complete circuit of the eight-channel analogue input board

to use a 3.3V regulator (such as an LD33V or equivalent) *not* a 5V device. The four additional power supply components can be quickly and easily fitted to the Humble Pi prototype board (see Fig.4.6, 4.7 and Fig.4.8).

The eight analogue inputs to IC1 are taken to an 18-way connector (P2). Two of the pins on this connector are connected to the 3.3V positive supply and eight pins are taken to the 0V/ground rail. The pin connections for P2 are shown in Fig.4.7

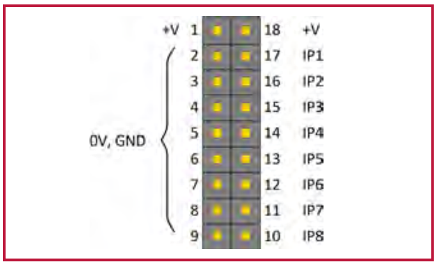


Fig.4.7. Pin connections for P2

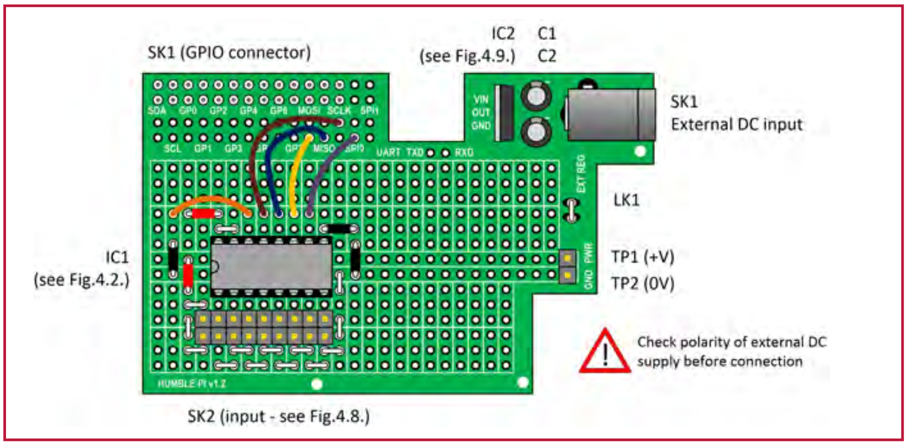


Fig.4.8. Wiring diagram for the eight-channel analogue input board

Table 4.1: Pin assignments for input connector P2

P2 pin number	MCP3008 signal	Input pin identifier
17	CH0	IP1
16	CH1	IP2
15	CH2	IP3
14	CH3	IP4
13	CH4	IP5
12	CH5	IP6
11	CH6	IP7
10	CH7	IP8
1, 18	VDD	+V
2 to 9	AGND	0V

and the individual pin assignments are given in Table 4.1.

Construction

We built our eight-channel input board using a Humble Pi prototyping board, as described in last month's *Teach-In*. The Humble Pi can be fitted with the 26-way connector (supplied with the board) so that the finished eight-channel analogue board sits piggy-back style immediately above the Raspberry Pi. The result is an extremely neat and compact layout. The wiring diagram for the eight-channel analogue input board is shown in Fig.4.8.

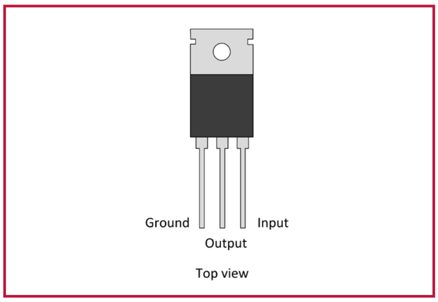


Fig.4.9. Pin connections for the LD33V voltage regulator, IC2

Testing

The eight-channel analogue input board should be tested before use. The prototype can be tested using a potentiometer to provide a variable input voltage, as shown in Fig.4.11. Depending on the setting of the slider of VR1, this arrangement will produce an input voltage in the range 0V to 3.3V (which should correspond to digital codes in the range 0 to 1023). Note that the allowable range of input voltage for the circuit shown in Fig.4.6 is 0V (minimum) to 3.3V (maximum). To avoid the risk of damage to the MCP3008 it is essential that the input voltages present on IP1 to IP7 do not stray outside this range. You will find details of a simple input protection circuit (based on Zener diodes) later in *Home Baking*.

You will need to enter your code (see *Home Baking* below) using an editor (or an IDE such as IDLE) before saving it to the folder in which you are currently storing your Python files (we created a folder called `Work_files` on the desktop for storing our files, but you can save them in any other convenient location). To test the code you can then start LXTerminal (or an equivalent terminal utility) and enter the appropriate command (using `sudo` to gain root privileges, as explained last month).

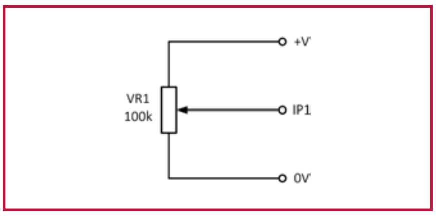


Fig.4.11. Using a potentiometer to test the eight-channel analogue input board

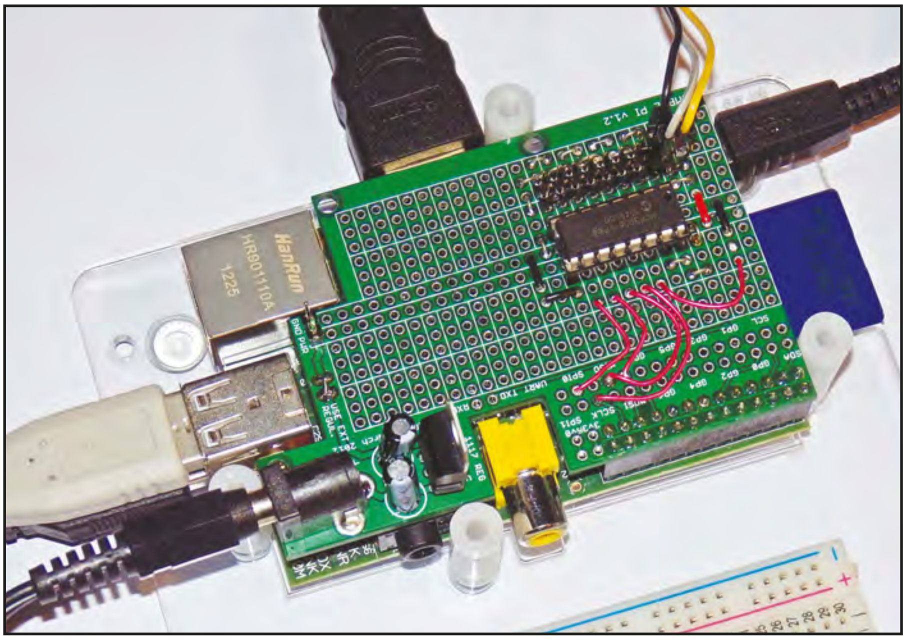


Fig.4.10. The finished prototype for the eight-channel analogue input board under test (as with last month's project, note how the Humble Pi board fits neatly over the Raspberry Pi)

Home Baking

In this month's *Home Baking* we will be looking at how the GPIO SPI ADC library module will allow you access to the features of the MCP3008 ADC chip when connected through the SPIO port. The Python code is (not surprisingly) a little more complicated than when using the GPIO as a basic parallel port. As usual, we need to begin by importing the necessary library modules before we can configure the GPIO port lines and set up the SPI port. The following Python code (or something equivalent) will be required:

```
import time
import os
import RPi.GPIO as GPIO
from gpiospiadc import *

GPIO.setmode(GPIO.BOARD)
DEBUG = 1

#  Define  pins  on  the  GPIO
connector
SPICLK = 23
SPIMISO = 21
SPIMOSI = 19
SPICS = 24

# Set up the SPI
GPIO.setup(SPIMOSI, GPIO.OUT)
GPIO.setup(SPIMISO, GPIO.IN)
GPIO.setup(SPICLK, GPIO.OUT)
GPIO.setup(SPICS, GPIO.OUT)
```

Note that the tricky job of handling the MCP3008's SPI interface to the Pi is covered by the `gpiospiadc` library module, which can be downloaded from the *EPE* website at: **www.epemag.com**

Next, we need to specify the required input channel before entering a loop that will read the digital code from the selected ADC, convert this to a corresponding voltage string, and then print the results on the screen. The code that will do this can be written along the following lines:

```
sensor_adc = 0

while True:
    sensor_value = readadc(sensor_adc, SPICLK, SPIMOSI, SPIMISO, 
SPICS)
     sensor_voltage = (sensor_value * 3.3)/1024
    print("Analogue input voltage = %5.3f V" % (sensor_voltage))
     time.sleep(0.5)
```

There are a few important things to note here. First, it is important to indent the code that forms the body of the loop, which in this case, will repeat indefinitely (you can easily break out of a loop by pressing the `Ctrl` and `C` keys at the same time). Second, the `readadc()` function is part of the `gpiospiadc` library module that we imported at the start of the code. If you forget to import modules (such as this one) the program will not run and you will be presented with a message warning you that the module cannot be found. Third, notice how we have to perform a little mathematics in order to convert the code returned from the ADC into a voltage. Fourth, because the `sensor_voltage` string can be rather long, we have used some of Python's powerful string formatting features in order to produce a reading with just three decimal places (this is the function of the `%5.3f` in the penultimate line of code). Last, we need to update the display on a regular basis just in case the input voltage has changed. To do this we have used one of the `time` module's functions – ie, `time.sleep(0.5)`. The complete code for testing IP1 (the other channels can be tested by changing the value of `sensor_adc`) of the eight-channel analogue interface is as follows:

```
#!/usr/bin/env python
import time
import os
import RPi.GPIO as GPIO
from gpiospiadc import *

GPIO.setmode(GPIO.BOARD)
DEBUG = 1

# Define pins on the GPIO connector
SPICLK = 23
SPIMISO = 21
SPIMOSI = 19
SPICS = 24

# Set up the SPI
GPIO.setup(SPIMOSI, GPIO.OUT)
GPIO.setup(SPIMISO, GPIO.IN)
GPIO.setup(SPICLK, GPIO.OUT)
GPIO.setup(SPICS, GPIO.OUT)

sensor_adc = 0

while True:
     sensor_value = readadc(sensor_adc, SPICLK, SPIMOSI, SPIMISO, 
SPICS)
     sensor_voltage = (sensor_value * 3.3)/1024
     print("Analogue input voltage = %5.3f V" % (sensor_voltage))
     time.sleep(0.5)
```

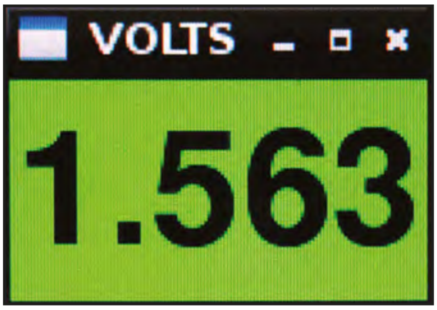


Fig.4.12. Digital voltmeter display

Finally, don't forget that you will need to run this code as a super-user (SUDO will give you access to the root privileges that are needed in order to make use of the GPIO library module). If in doubt, take a look back at last month's *Teach-In*.

A real-world application

Now, to put everything that we've just learned into practice, let's look at a simple (but nevertheless useful) real-world application in the form of a simple digital voltmeter based on the eight-channel analogue input board. In addition to the Humble Pi board, all we need is a few lines of Python code using `tkinter` as a means of providing a friendly graphical user interface.

At the start of the code we need to import the required library modules (in this case we need access to five of them, including `tkinter`). Next, we've defined a root window (every GUI program must have one of these) and given it a title (`VOLTS`). This makes it look a bit more impressive than just the default (`tk`). Within the root window, and so that our voltmeter display is easily readable, we've increased the font size to 36 and used Arial font (in black) against a green background, as shown in Fig.4.12.

In the main loop of the program we've used a UDF (see last month) called `measure()`. This reads the value returned from Channel 0 (IP1) of the ADC and then converts it to a corresponding voltage (`sensor_voltage`). It then converts the sensor voltage into a format that will produce a sensible display using

The SPI bus

The 'serial peripheral interface' (SPI) is a communication bus that is used to interface one or more peripheral devices (known as 'slaves') to a computer, microprocessor or microcontroller (referred to as the 'master'). A large number of SPI devices are available, including analogue-to-digital converters (ADC), digital-to-analogue converters (DAC), general purpose input/output (GPIO) expansion chips, temperature sensors and accelerometers. The bus is capable of operating at high speed (faster than the I^2C) but it normally requires a four-wire connection with one additional wire for each peripheral chip.

The SPI bus (sometimes also known as 'synchronous serial interface' or SSI) is a synchronous serially-clocked bus capable of supporting data transfer in both directions, master to slave and slave to master) at the same time (this is referred to as 'full duplex' operation). The Raspberry Pi's SPI implementation uses four signal wires (plus ground). The signals are referred to as:

`SCLK`	serial clock output from master
`MOSI`	master output/slave input
`MISO`	master input/slave output
`CSn`	chip select output from master

The Raspberry Pi's two active-low chip select signals (CS0 and CS1) allow it to control up to two slave devices (the SPI bus is capable of supporting more than two devices, but it requires a chip select line for each device). This should be contrasted with the Raspberry Pi's I^2C interface that permits up to 127 devices to be connected using a two-wire (plus ground) interface. Finally, it is important to note that there is some variation in the naming of the SPI bus signals. In particular, the Humble Pi prototyping board shows the two chip select lines, CS0 and CS1, as SPI0 and SPI1 respectively.

the meter.config() function. The entire loop is repeated every 200ms until the user closes the display window (at which point the program terminates). The code is shown below:

```
#!/usr/bin/env python
from tkinter import *
import time
import os
import RPi.GPIO as GPIO
from gpiospiadc import *

root = Tk()
root.title(“VOLTS”)
voltage1 = ‘’
meter = Label(root, font=(‘arial’, 36, ‘bold’), bg=’green’)
meter.pack(fill=BOTH, expand=1)

GPIO.setmode(GPIO.BOARD)
DEBUG = 1

# Define pins on the GPIO connector
SPICLK = 23
SPIMISO = 21
SPIMOSI = 19
SPICS = 24

# Set up the SPI
GPIO.setup(SPIMOSI, GPIO.OUT)
GPIO.setup(SPIMISO, GPIO.IN)
GPIO.setup(SPICLK, GPIO.OUT)
GPIO.setup(SPICS, GPIO.OUT)

sensor_adc = 0

def measure():
    global voltage1
    # get the current voltage from the SPI device
   sensor_value = readadc(sensor_adc, SPICLK, SPIMOSI, SPIMISO,
SPICS)
    sensor_voltage = (sensor_value * 3.3)/1024
    voltage2 = sensor_voltage
    sv = ‘%.3f’ % sensor_voltage
    # if the voltage has changed, update it
    if voltage2 != voltage1:
        voltage1 = voltage2
        meter.config(text=sv)
    # update the display every 200ms
    meter.after(200, measure)

measure()
root.mainloop()
```

The simple digital voltmeter caters for input voltages ranging from a few tens of millivolts up to about 3.3V – but, where necessary, a simple potential divider can be used at the input in order to extend the range. It might also be sensible to provide some protection at the input of the ADC by connecting an anti-parallel pair of Zener diodes (each rated at 3.3V) across the input, as shown in Fig.4.13.

This example should have given you some idea of what can be easily achieved with a very simple interface and just a few lines of Python code. Next month, we will be looking at some other applications for the analogue interface, including temperature, light and resistance measurement, but for the time being, there's plenty of scope for further development so please do let us know what you've achieved. 'Share and share alike' is very much the ethos of the Raspberry Pi community, as well, of course, many *EPE* readers.

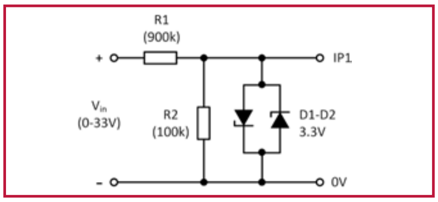


Fig.4.13. Potential divider and input protection for simple digital voltmeter

Pi Class

Remote access

There are many instances when you might like to be able to take control of your Raspberry Pi remotely. This could be to remotely start applications/processes or to transfer files when you can't be physically in front of the device. Many Pi applications are or eventually become 'headless' and in operation do not have a display or input devices attached during normal use. Alternatively, it could just be that you don't want to have to invest in another set of peripherals for your Pi and/or you don't want to have to keep swapping over leads or fork out for a KVM switch. Whatever your need for remote control, this section will help you to get access to your Pi from another device (with or without a display or input peripherals connected).

Secure shell

The first method of remote access we'll look at is 'secure shell' or SSH. If you've used Unix/Linux systems before, and in particular embedded systems, chances are that you'll be familiar with using SSH. Essentially, SSH allows you to make a secure remote terminal connection to your Pi from which you can then issue any commands, just as you would if running a terminal session directly on the device. To start with you'll need to get an SSH client that will run on the operating system of the computer which you wish to use for remote access. There's a large number to choose from, but a popular and recommended option is PuTTY.

PuTTY is a free open-source terminal client and available for various different operating systems including Windows and Mac. What's more, it's smaller that 500Kb and is a single executable file that runs with no installation required; ideal for running from a memory stick

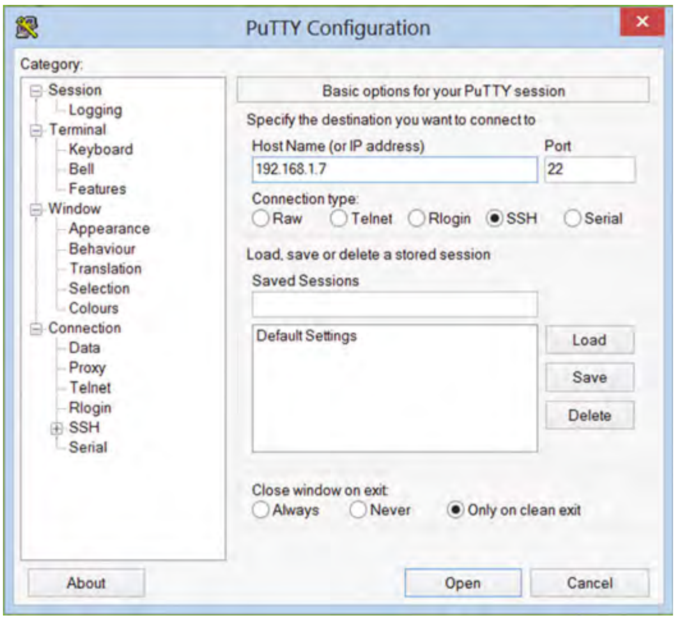


Fig.4.14. The PuTTY login screen

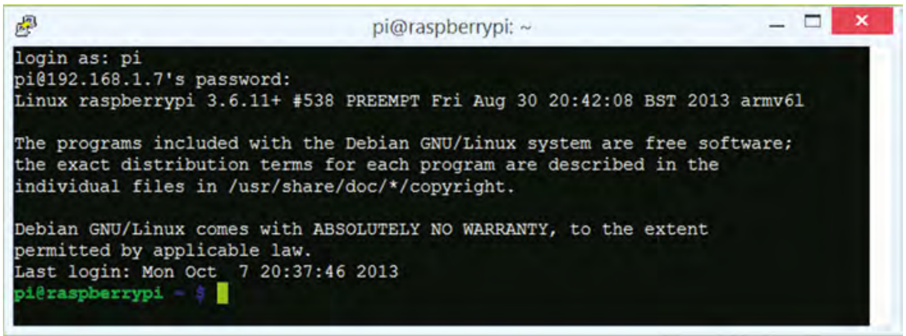


Fig.4.15. SSH command prompt

for example. You can download a copy from **www.putty.org**

To make a connection to your Pi you'll need to know its IP address. Check out our box feature on finding your IP address to see how it's done. Enter your Pi's IP address into the 'Host Name (or IP address)' field and ensure that the 'SSH' radio button is selected and the 'Port' is set to 22. To begin your session, click 'Open'. You may then receive a security warning; click 'Yes' to continue. You will then be presented with a familiar command line window where you'll then be prompted to login into your Pi. If you have left these as the default, the username will be 'pi' and the password 'raspberry'. If you've changed these then you should use those credentials instead. Note that when typing your Pi password, it is not locally echoed – ie, it's not displayed as you type, so it can appear that nothing is actually being typed. If all goes well you should then be presented with the standard command prompt from where you can carry out any operations, just as if you were sitting in front of the unit!

On most Pi distributions, SSH telnet is enabled by default. However, if you find that you're unable to connect it might just be that it's not enabled. To enable SSH simply jump back on to your Pi, start up a terminal window and run:

```
sudo raspi-config
```

Select option 8 'Advanced Options' then 'ssh' from the second screen before enabling SSH on the next screen. You will receive a confirmation stating that the SSH server has been enabled. Note that if you have a different (earlier) OS version you might have a different menu selection screen and, if this is the case, you should select 'ssh' and then 'Enable or disable ssh server' before moving to the next screen (see Fig.1.14 on page 46 of October 2013's *EPE*).

Virtual network computing (VNC)

Whereas SSH is a quick and easy way of issuing commands and remote management, there may be times when you want to work on the Pi using the full graphical environment. To achieve this, we'll use VNC (virtual network computing). This is an open-source system for remotely viewing and controlling computers over a network. It's hugely popular for remote control of different types of computer system, and there are numerous derivative software projects that are based on it. If you're a self-confessed computer nerd like us, then most likely you'll have heard of it, or used it before.

There are a few steps required to get VNC setup, but once you've done the hard work connecting will be really quick. The process requires that we download and install a VNC server then set it up to run automatically when the Pi boots.

We'll be using x11vnc server. To install x11vnc, start a terminal window and run the following commands:

```
sudo apt-get update
sudo apt-get install x11vnc
```

The first line ensures that the software catalogue is up to date and the second instructs your Pi to download and install the latest version of the x11vnc software, as shown in Fig.4.16.

We now need to ensure that the VNC server starts when the Pi boots so that we can get remote access without having to connect up keyboard, mouse and monitor each time to initiate the server.

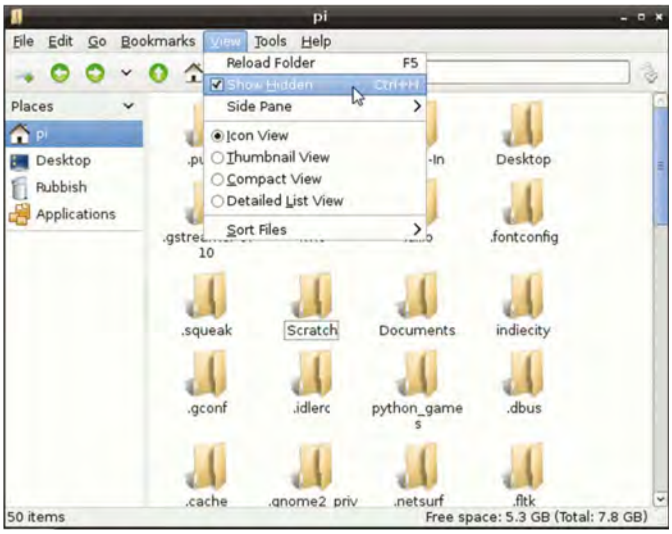


Fig.4.17. Using File Manager to show hidden files

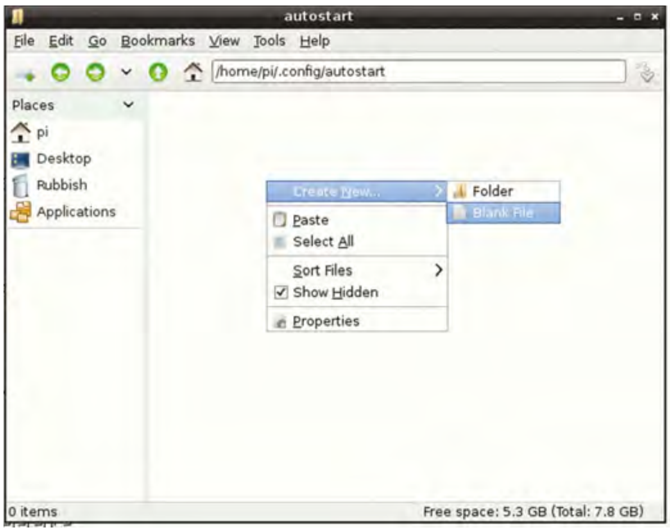


Fig.4.18. Creating a new (blank) file

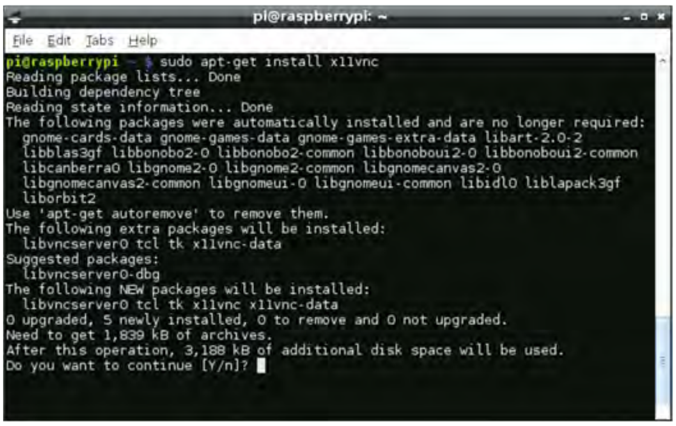


Fig.4.16. Installing x11vnc

Fig.4.19. Naming the new x11vnc desktop file

Fig.4.21. The autostart file

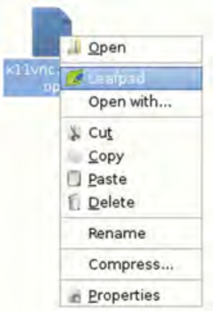


Fig.4.20. Editing the new x11vnc file

To achieve this we need to create an autostart file. Open File Manager and navigate to: **/home/pi**. Some system files/folders are 'hidden', including those where we need to create our autostart file. By default, hidden files/folders are not visible in File Manager. Click 'View' on the top menu and check 'Show Hidden' or use the shortcut Ctrl+H (see Fig.4.17).

Now navigate to the .config and then the autostart folder (if either do not exist then simply create folders with those names; File>Create New…>Folder). Once inside the autostart folder, either right-click or click File then Create New…>Blank File (Fig.4.18). Name the blank file **x11vnc.desktop** (Fig.4.19). Now right-click the new file that you've created and select 'Leafpad' from the context menu. Edit the file in Leafpad (Fig.4.20) to read as follows:

```
[Desktop Entry]
Encoding=UTF-8
Type=Application
Name=X11VNC
Exec=x11vnc -forever -passwd
epe2013 -display :0 -ultrafilexfer
StartupNotify=false
Hidden=false
```

Fig.4.21. The autostart file

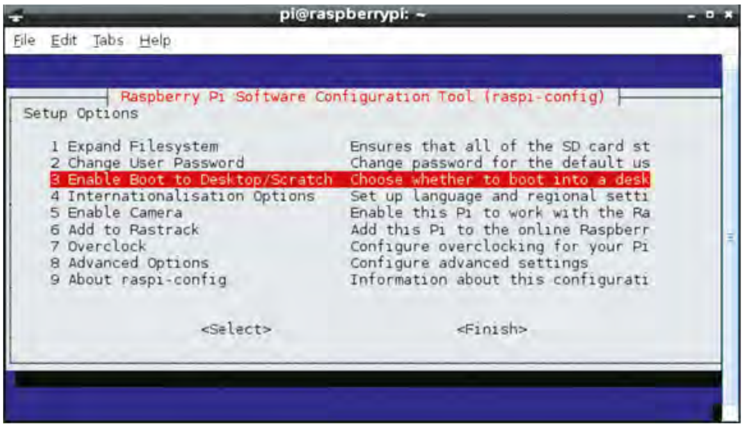


Fig.4.22. Enabling boot to desktop using raspi-config

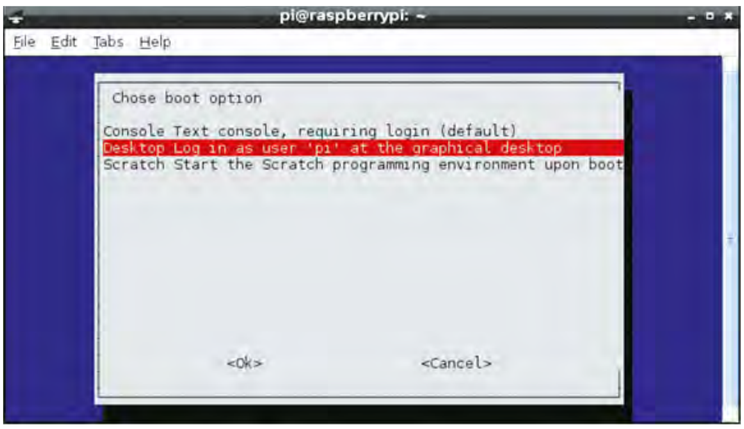


Fig.4.23. Setting the boot option in raspi-config

The file instructs the Pi to start x11vnc when the desktop environment boots. The line that starts `Exec` is the most notable; it's the command line that's actually executed. If you're an advanced user you can edit this line to initialise x11vnc with different settings. You can find out more about the various options at: **www.karlrunge.com/x11vnc**. In our example, we have set the server to launch and remain running with the password `epe2013`. You can change this to a password of your choice. It's important to note that anyone who has local access could potentially locate this file and read the password. If this constitutes a security concern to your application there are more secure password options; refer to the x11vnc website. The `-display` argument refers to the 'display number' which corresponds to the port that x11vnc operates over. This number is added to 5900 to give the port number. In our case a display number of 0 means that communications will be carried out via port 5900 (this may be useful to know if you are an advanced user and need to open or forward ports through a router/firewall). Now save your file and exit Leafpad.

Now we have the VNC server set to start when xWindows loads. If you haven't already got it set to do so you'll also need to set your Pi to boot into xWindows automatically (if you're running your Pi headless then you won't be able to type `startx` to initiate the desktop environment). To do this, open a terminal windows and run:

```
sudo raspi-config
```

Select option 3, 'Boot to Desktop/Scratch' then on the following screen select 'Desktop Log in as user 'pi' at the graphical desktop'.

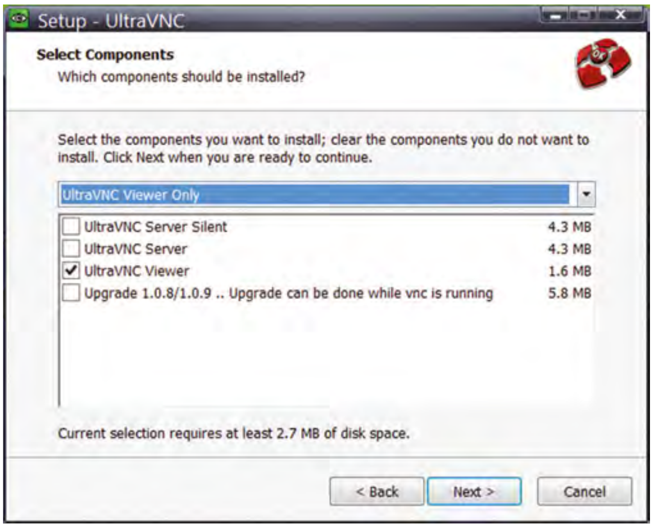


Fig.4.24. Installing the UltraVNC viewer

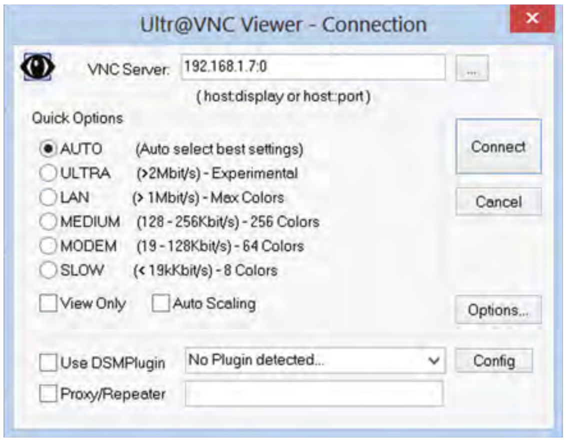


Fig.4.25. Setting up an UltraVNC connection

You're now ready to reboot your Pi and have a go at connecting remotely for the first time. You can reboot your Pi using the following command:

```
sudo reboot
```

It is worth noting that the menu selection screen for the raspi-config utility may appear differently with different OS versions. For example, you may need to select 'boot_behaviour' from the list of options and then 'Start desktop on boot?' in order to run the desktop whenever the Pi starts up (see Fig,1.14 on page 46 of October 2013's *EPE*).

To connect to the VNC server we'll need to use a viewer application that's suitable for the operating system on the computer that we wish to access from. There are many different viewers available. If you are using a PC we'd recommend UltraVNC viewer. It's a free and stable viewer that works well with x11vnc. It is also available as a portable app, runnable from a memory stick without install. You can download the latest version of UltraVNC viewer from **www.uvnc.com**. Note that you do not need to install the UltraVNC server, only the viewer application. When running the installation wizard, select 'UltraVNC Viewer Only' on the 'Select Components' page (FigureX).

Having installed UltraVNC viewer, we are ready to connect for the first time. Launch the viewer and enter the IP address of the your Raspberry Pi into the host box, followed by a semicolon and the display number. For example, in our case, the IP address was **192.168.1.7** and the display number (as set out in the desktop autostart file earlier) was 0. Therefore we would enter:

```
192.168.1.7:0
```

There are also various connection settings we can tweak here. Notably we can change the quality of the image to influence the bandwidth usage. This can be handy if we are accessing through a slow speed connection – eg, over the Internet – and we want to reduce bandwidth in favour of clarity. If you are

Fig.4.27. The Ultra VNC menu bar

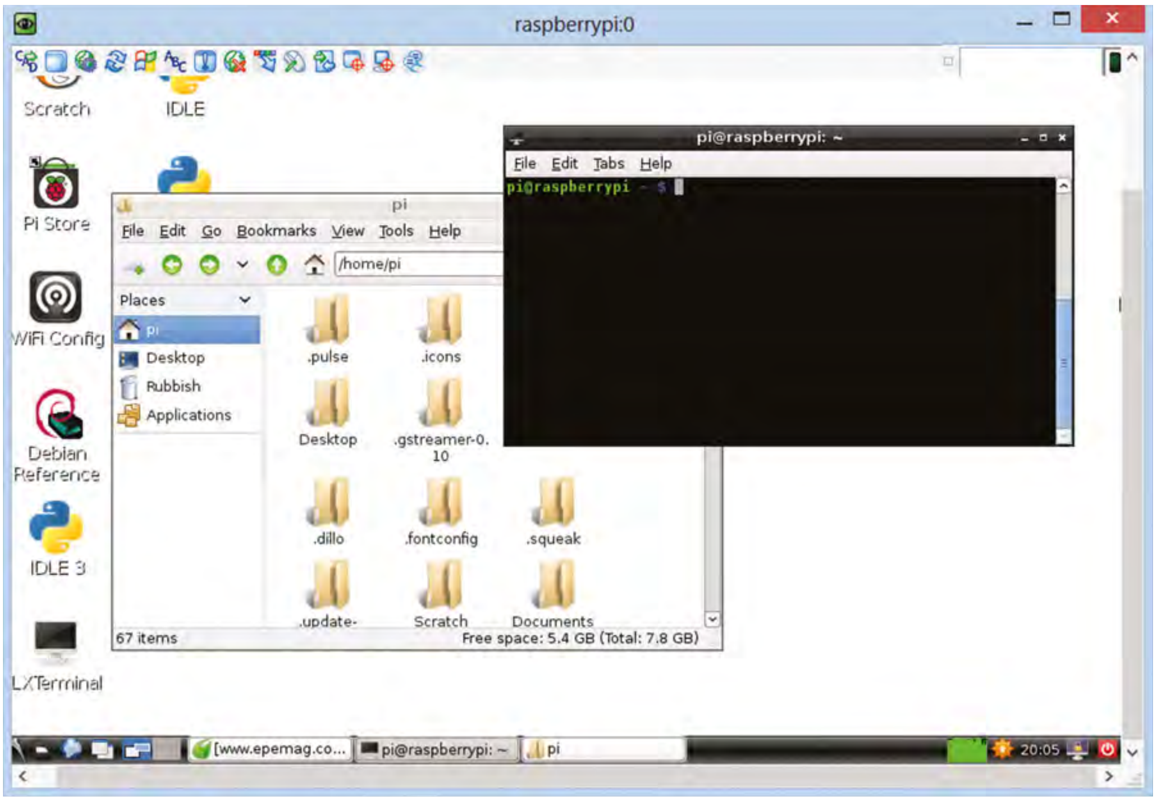


Fig.4.26. An UltraVNC session

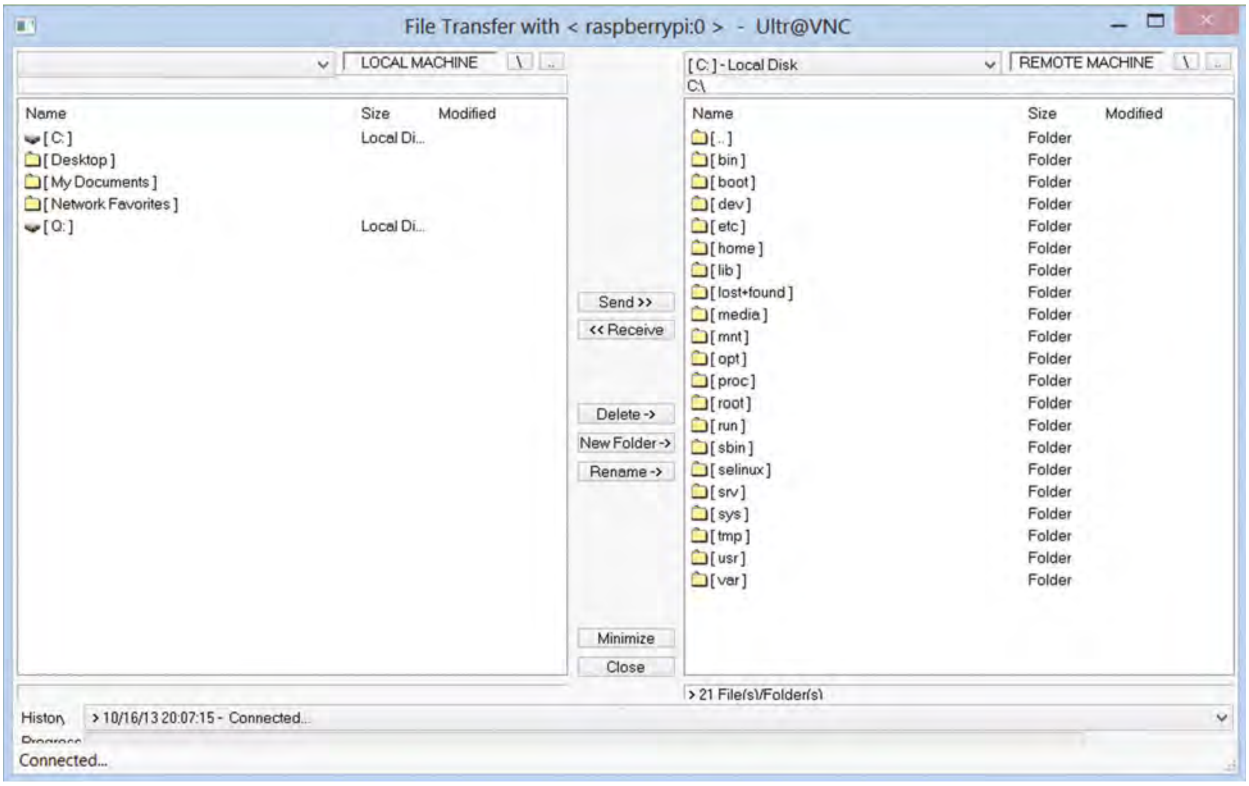


Fig.4.28. Using UltraVNC for transferring files

accessing through your home network 'AUTO' or 'LAN' are most likely the best option. When you're ready, click on 'Connect'. You will then be asked to enter a password; enter the password that you setup in your desktop autostart file earlier (in our case `epe2013`).

If all has gone well a window will appear and you should now be presented with your Raspberry Pi desktop mirroring the output on your Pi display. You are now remote controlling your Pi and can operate the system just as you would if you were physically connected.

As well as the ability to mimic physical control of the device there are also some other useful features of UltraVNC. At the top of the UltraVNC window you'll see a toolbar from which you can access some of these features (you can also access these from a context menu by right-clicking the UltraVNC window title bar). The menu bar is shown in Fig.4.27, and we'll let you experiment with this yourself. However, a particularly useful feature worth noting here is File Transfer. This allows you to easily transfer files between your local and remote computer. UltraVNC also supports 'remote clipboard', which allows you to copy and paste text from local to remote device, or vice-versa, which can prove extremely useful.

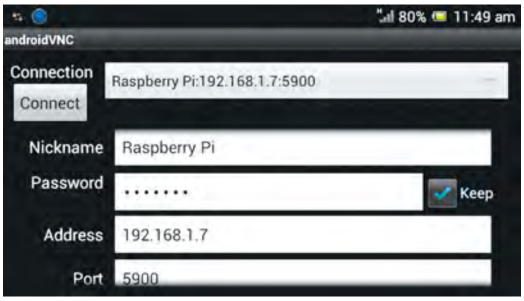


Fig.4.29. Setting up Android VNC on a tablet computer

There is also a number of VNC viewer applications available for other platforms, including Apple iOS, Android and Windows Phone 8. This means that you can use your smart phone or tablet device to remotely control your Pi too. We tested the 'Android VNC' app (a free download from Google Play) and found it to work reliably on both Android based smartphone and tablet platforms.

A note about VNC server software for the Pi

There are numerous tutorials on the Internet describing installing VNC on the Raspberry Pi. Most of these tutorials utilise TightVNC server rather than x11vnc. Using TightVNC works nicely. However, the drawback with TightVNC is that when connecting it starts a new instance of the xWindows environment that operates separately from the local instance of xWindows – ie, it is not a mirror of what's seen on a connected display.

In next month's Teach-In with Raspberry Pi

Next month, in *Teach-In 2014*, our Pi Project will be covering temperature sensing, light level and resistance measurement using the Humble Pi analogue input board that we've described this month. Python Quickstart will provide you with an introduction to 'pickling' (a quick way of saving Python objects to a file for later use). We will also be looking at data logging and showing you how you can remote control your Raspberry Pi from anywhere in the world.

Problem corner

When attempting to run programs that need access to the low-level operating system routines, for example, if you attempt to run Python code from IDLE with only limited system privileges you will be unable to access the hardware level control offered by the GPIO library. In this event, you will be presented with an error message and your program will refuse to run. To overcome this problem you will need to ensure that you have the privilege level of a 'super user'. You can do this by simply using `sudo` before the program name. For example, `sudo idle` when running a program from within IDLE or `sudo python control.py` when running a Python program from a terminal window. Also, don't forget that there are compatibility problems with different versions of Python and IDLE. However, if you do run into problems, plenty of help is available from various on-line forums. Finally, it's very important to remember that the Debian operating system (as well as Linux in general) is case sensitive, thus Debian will treat `IDLE` and `idle` as totally different commands.

What's your Raspberry Pi's IP address?

Every device that connects to a network has a unique number assigned to it known as an 'Internet protocol' or IP address. A standard IP address consist of four eight-bit numbers (ie, 0-255) separated by dots – for example, **192.168.1.2**. The IP address is used to direct the packets of information that are travelling around the network to/from one device to another.

On most home networks your router will automatically assign the next available IP address to any device that you connect to it. This is called 'dynamic host configuration protocol' or DHCP. DHCP is great because it allows you to quickly connect new devices without having to worry about setting up and network configuration. However, this does mean that there's no guarantee that any particular device will always be given the same IP address when it's connected to your network. In order to access your device remotely you'll need to know the current IP address of your Raspberry Pi. There are several potential solutions for this; we've described five ways to identify your Pi's IP address below.

1. Set up your Pi to always have the same IP address by changing its network settings to a static IP address that you specify. This is a little more advanced and we will not cover this here, although there are many tutorials available for this on the Internet.

2. Many home broadband routers will display a table of current IP address allocations via their web-based admin console. You should consult your router documentation to find out how to log into your specific device. Normally, to log in you would visit the address of your router (eg, **http://192.168.1.1**) in a web browser, where you would be asked to log in and access the router settings. You might need to enter an 'advanced' setting area for this. Please do take care here, as you could cause all sorts of network or Internet problems by accidentally changing settings.

3. Some home routers will allow you to specify that you wish for particular network items to always have the same IP address. Generally, this involves logging into the web-based admin page for your router and creating an IP address reservation. Again, you should refer to the user guide for your router or consult their website for advice on your specific model.

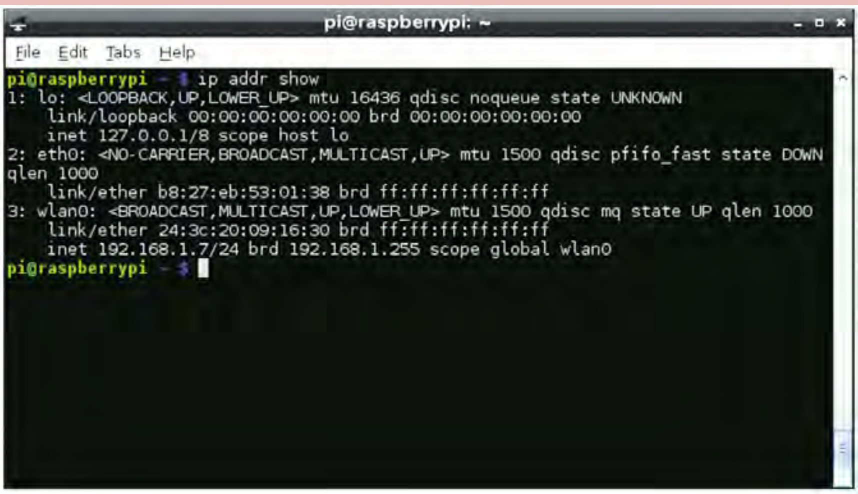
4. If you are able to access your Pi directly you can find out its current IP address by running a simple command in a terminal window:

```
ip addr show
```

As you can see from our example in Fig.4.30, you will be presented with a list of network devices and their particulars including their IP address. In our case, we have three network devices connected. The first is a virtual 'local loopback' adapter. 'eth0' is our on-board wired Ethernet adapter (currently not connected) and 'wlan0' is our Wi-Fi adapter. Listed under 'wlan0' you'll see our IP address just after 'inet' of **192.168.1.7**.

Additionally, if you are connecting to your Pi using Wi-Fi, then you can find out your IP address by running 'WiFi Config'.

5. If you can't get on to your Pi directly, for example if you are running your Pi headless, then you'll need to do a little investigative work from another remote computer on your network. There are various software network tools that will 'scan' your network and identify the IP addresses and hostnames of the connected devices. One type of such software is known as an IP scanner. An IP scanner checks each IP address one-by-one and looks to see if it's currently in use. Typically, you would enter the range of IP addresses to scan; the most common of these for home router-based networks are **192.168.0.1** to **192.168.0.255** and **192.168.1.1** to **192.168.1.255**. Your Pi will be identified with the default hostname of 'raspberrypi'. Note that in order to identify the hostnames of the devices, certain network facilities must be active and this may or may not be the case depending on your router/network infrastructure.



```
pi@raspberrypi: ~
File Edit Tabs Help
pi@raspberrypi ~ $ ip addr show
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 16436 qdisc noqueue state UNKNOWN
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
2: eth0: <NO-CARRIER,BROADCAST,MULTICAST,UP> mtu 1500 qdisc pfifo_fast state DOWN
qlen 1000
    link/ether b8:27:eb:53:01:38 brd ff:ff:ff:ff:ff:ff
3: wlan0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc mq state UP qlen 1000
    link/ether 24:3c:20:09:16:30 brd ff:ff:ff:ff:ff:ff
    inet 192.168.1.7/24 brd 192.168.1.255 scope global wlan0
pi@raspberrypi ~ $
```

Fig.4.30. Using ip addr show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PIC n' Mix

Mike Hibbett

Our periodic column for PIC programming enlightenment

Custom-made development board

THE time has come to commit our minimalist micro-controller circuit to its own custom- made PCB. Building micro-controller circuits on a prototyping board might be cost efficient and flexible, but the circuit won't be physically robust (ours fell on the floor, spewing hook-up wires everywhere!) and the repetition of wiring up decoupling capacitors, programming interfaces etc for each new project becomes tedious. When we have an idea for an interesting project we want a micro-controller circuit available to take code immediately, not after several evenings of electronic knitting!

Our main issue this month, however, is exactly what to place on the board. Do we add loads of 'bells and whistles' that *may* be useful in the future, or nothing more that the processor and a crystal? Or something in between?

Our original guidelines for the design, as you may remember, were:

- Very low cost
- Very low power
- Easy to construct
- Maximise flexibility

The low-cost point being important if a board will end up inside a project. Low power is desirable to open up the use of the board with portable, battery-powered designs. Ease of construction is of course important for us hobbyists, although there is nothing wrong with pushing the limits occasionally and learning new skills.

Maximising the flexibility of the design is about not forcing general-purpose or multi-function pins into one specific function or other. Microchip have gone to great lengths to make their devices as flexible as possible; it would be a little narrow minded to reduce that flexibility. We have indulged ourselves with a single example of fixing the use of an I/O pin by adding an LED to PORTB.5. Our justification is that an LED is simply so useful, not only for your application but also for initial and on-going development debugging. Flashing an LED is the first evidence that your hardware is working (or that the batteries have juice in them!) Naturally you do not need to actually fit the LED if you do not want to; the I/O pin is still routed to a header pin.

Continuing with the flexibility theme, the main oscillator components are marked as optional. The on-chip high speed RC (resistor-capacitor) oscillator should be good enough for most needs. Not fitting these parts reduces the cost, and frees up two pins for use as general purpose I/O. There are only three components involved, and fitting them on the board is easy, so they have been left on.

The only I/O pins not brought out to a header pin are the two used by the watch crystal oscillator. The oscillator circuit inside the chip that drives these pins is a very low power design, and will not work if the pins are 'load-

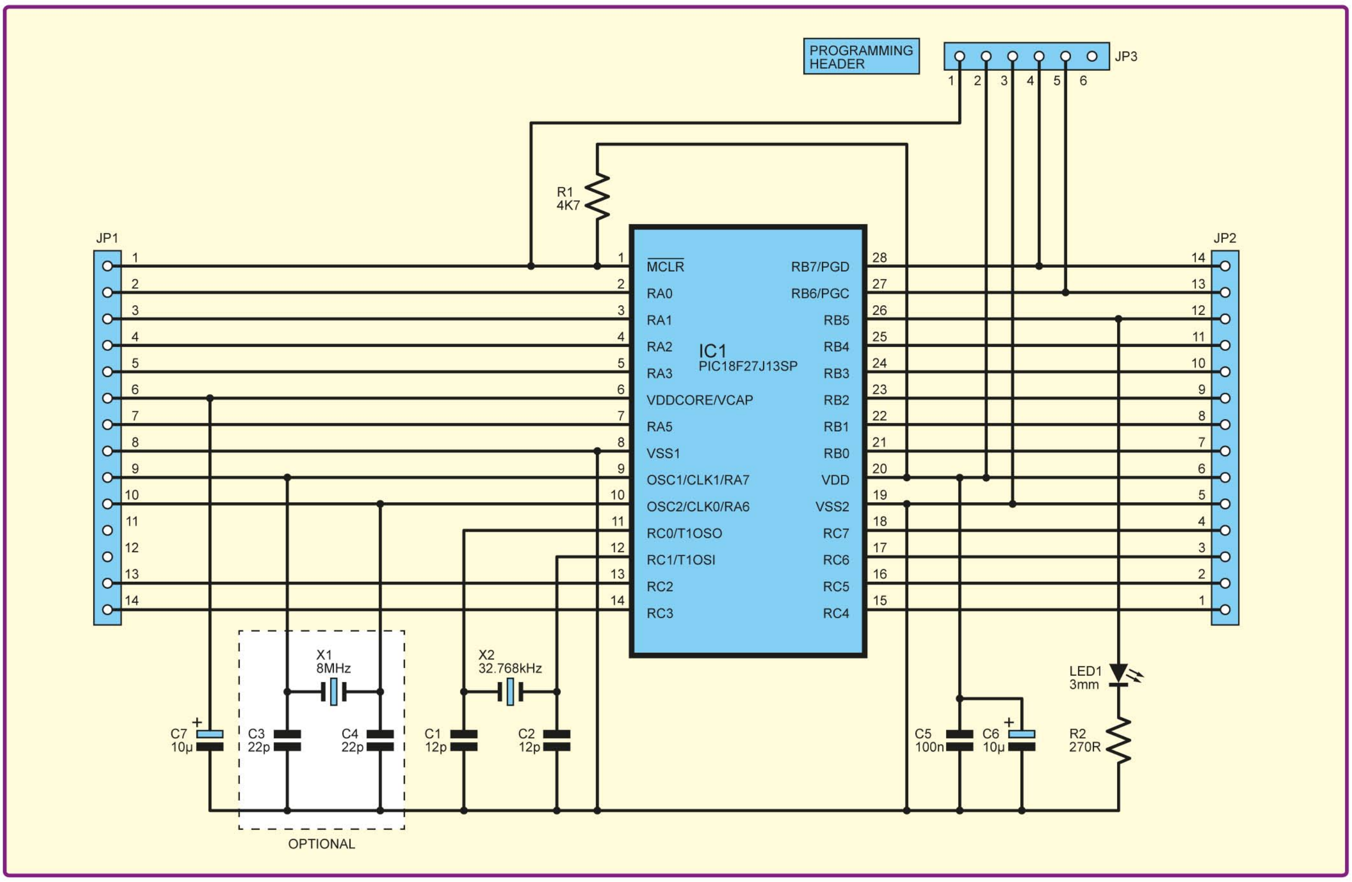


Fig. 1. Schematic of the PIC development board

ed' with any other components. Even short lengths of wire or PCB traces can be a problem, as these act like antenna picking up noise from the rest of the circuit. The final schematic is shown in Fig.1

Maximising flexibility results in this design being a physically small, minimal system. It would be nice to try a more 'maximal' system one day, but the question of where to stop then becomes somewhat more difficult, and we would all have different ideas of what would be needed.

Mechanical aspects

The specification for the components is fairly flexible, with the most critical part being the SIL header strip – it's important to choose one that fits into a standard prototyping board. We have provided example part numbers from Farnell in a zip file that accompanies this month's article on the *EPE* website (**www.epemag.com**) (in file bom.txt) along with a pdf file of the board copper image, for printout at a scale of 1:1 (copper.pdf). Farnell would not be the only supplier, nor necessarily the cheapest; these components can be sourced from many different sources. Note that the use of electrolytic rather than tantalum capacitors for C6 and C7 is acceptable, and a lot cheaper. You may use either.

We have opted for a single-sided PCB layout, fabricated using a standard 1.6mm photo-resist PCB readily available from Maplins, Farnell etc. The figures show a board manufactured from thin PCB, available through RS Components. Although more expensive than the thicker board, this is much easier to cut – you can cut it cleanly with tin snips. Cutting 1.6mm PCB material is much more difficult and, if using a saw rather than a PCB guillotine, the dust is very toxic. We purchased a cheap water-lubricated tile saw from the local DIY store, which cuts these boards easily, although it is messier.

The single-sided board design does require one jumper wire to complete the circuit routing. It might have been possible to avoid this using thinner tracks, but we wanted to keep the design as simple to manufacture as possible.

Board etching

As with other projects intended to be hand etched, the solder-side image shown in Fig.2. should be printed out on a transparent sheet at a 1:1 scale, the dimensions checked, and the **printed** side placed against the PCB for etching. The image is produced this way to reduce the light from the UV development lamp 'undercutting' the image.

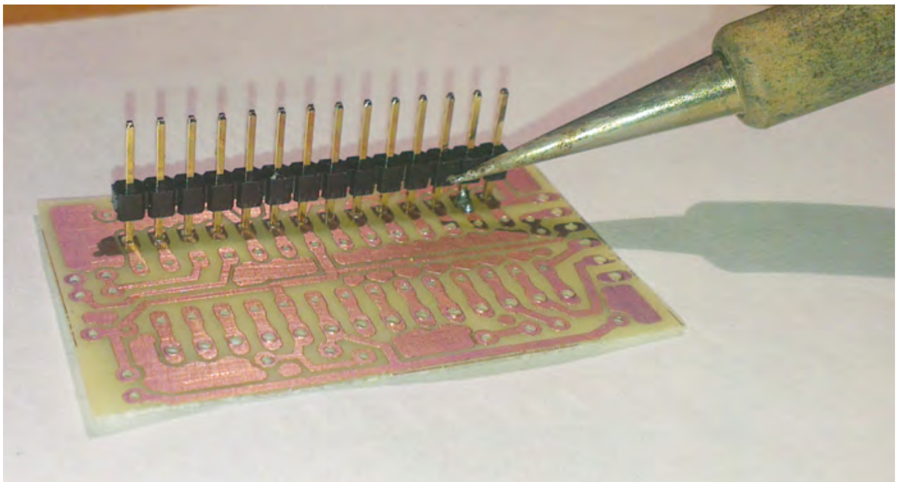


Fig.3. Soldering the connector

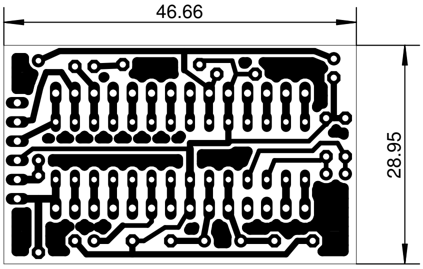


Fig.2. Board Image, solder side

While we used photo-resist PCBs for our boards, the board can be made with normal copper-clad boards and the 'Press And Peel' system, available from Maplins and other electronics suppliers. We are not great fans of Press And Peel; each A4 sheet costs about £4, and it can take several attempts to do a good transfer. Ultimately, it's down to personal preference as to which system you use. Press And Peel involves the use of one less toxic chemical, and doesn't require the use of photo-resist boards (which have a shelf life of only a year.)

Assembly guidelines

Once etched and cleaned, the holes should be drilled. You may want to use a small spotting drill to get the centres correctly aligned, particularly on the SIL headers, as they are difficult to fit if the holes are miss-aligned. A 'small' drill in this context does mean 0.5mm to 0.8mm diameter, so great care needs to be taken not to tilt the drill while making the holes. These thin drills are not very forgiving, and snap easily!

The hardest part of assembling the board is soldering the header strips, as these need to be soldered on the *underside* of the header, as seen in Fig.3. It's best to do this first, before soldering the other components. Solder the two end pins first on a header strip, then inspect to ensure it is straight and at a right-angle to the board. If it is not simply reheat the solder joints and move into the correct position. When you are happy with the alignment, solder the remaining pins. Fit the remaining components, starting with the IC socket. Fig.4. shows the positioning of the various components.

We recommend a socket for the IC, even if you do not plan to swap it out for another project at a later date. The chips last for decades, and it's surprising just how often we have recycled old projects and re-used their processors. The choice of IC socket is not important, and using the cheap, non-turned pin variant is perfectly acceptable, as the processor is unlikely

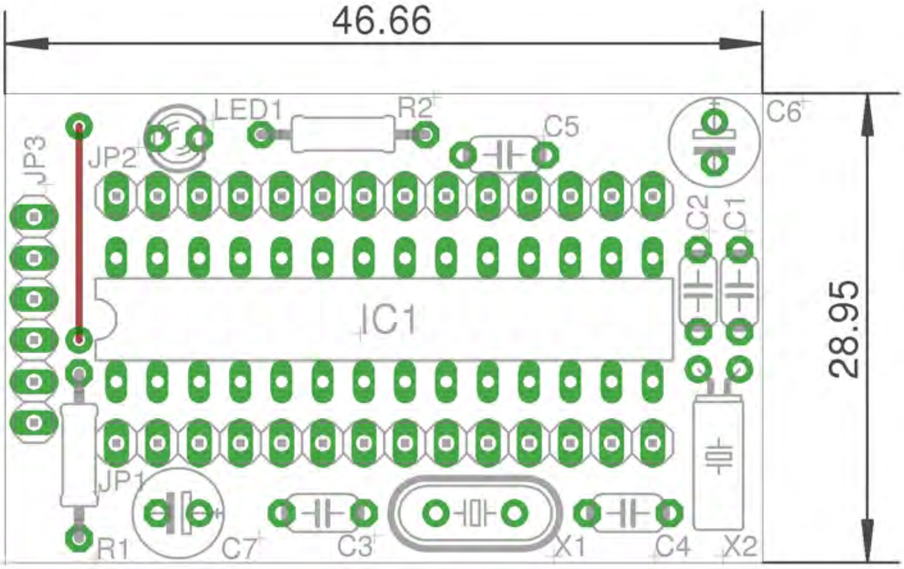


Fig.4. Board image, top side (not to scale)

to be removed and reinserted many times. An example of a completed PCB connected to a prototyping board is shown in Fig.5.

The circuit and software for a kitchen timer was created using this platform before the software was transferred to a 'header-less' board, and wired directly into a box. There were so few additional components in this example that an additional circuit board was not deemed necessary, and the parts were secured with hot melt glue.

Next month

We will create and explain the workings of the template source files for the board, and show how to create the kitchen timer mentioned this month.

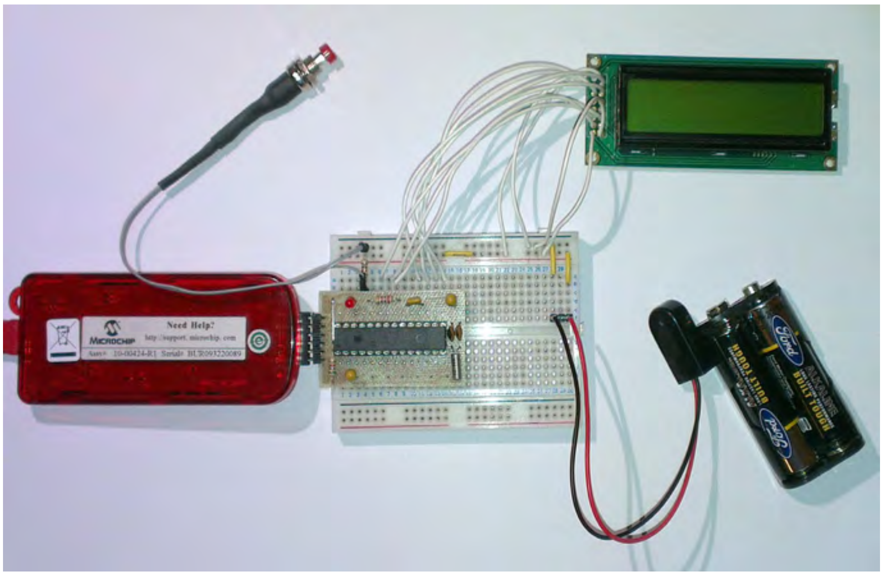


Fig. 5. In use, on a prototyping board

Practically Speaking

Robert Penfold looks at the Techniques of Actually Doing it!

Capacitor overview

NORMAL capacitors are a good candidate for the rank of the simplest type of electronic component in common use today. A capacitor is essentially just two pieces of metal separated by an insulating material. The latter is called the 'dielectric'. If the metal plates are connected to a DC voltage source the capacitor will charge to a potential virtually equal to that of the voltage source. The speed at which the charge voltage rises depends on the rate at which current flows into the component, and its value.

The basic unit of capacitance is the 'farad', and a charge current of one amp for one second will produce a charge potential of one volt on a one-farad capacitor. In theory, a capacitor will hold its charge voltage indefinitely or until the component is discharged into some form of load such as a resistor. Of course, in practice there is some leakage through the insulating layer and real-world capacitors gradually lose any charge left on them.

Little and large

The farad is a very large unit, and components having values of a farad or more are not used in electronic circuits, apart from a few 'specials' that are used as an alternative to back-up batteries! I have never used a capacitor having a value as high as a thousandth of a farad. Most of the components used in everyday electronic circuits have values of a few millionths of a farad or less. In some cases much less, at a thousand millionth or lower.

The values of large capacitors are expressed in microfarads, and the metric system uses 'micro' as a prefix that means 'a millionth of'. Therefore, one microfarad is equal to a millionth of a farad, and (say) a 220 microfarad capacitor has a value of 0.00022 farads. The Greek letter mu (µ) is used as the abbreviation for micro, but a lower case letter 'u' is often used instead. A 47-microfarad capacitor would therefore have its value given in the form '47µF' or '47uF'. The 'F' is often omitted because the values of capacitors are always given in farads. Also, as is normal practice in electronics, the unit of measurement can be used to indicate the decimal point. A value of 4.7 microfarads would therefore be given in the form '4µ7' or '4u7'.

Small and middle-value capacitors usually have their values expressed in nanofarads or picofarads. A nanofarad is one thousandth of a microfarad, and a picofarad is one thousandth of a nanofarad. A picofarad is therefore equal to just one millionth of a microfarad, or one trillionth of a farad! Capacitors having values of a few picofarads are perhaps not used that much in modern electronics, but they do have their uses and are quite common in high frequency equipment.

As with the micro prefix, nano, and pico are the standard metric prefixes, and can be used to respectively indicate a thousand-millionth, and a trillionth of any basic unit. The lower case letters 'n' and 'p' are used as the abbreviations for nanofarads and picofarads. Therefore, values of 3.3 picofarads and 2.7 nanofarads would normally be written as '3p3' and '2n7'.

On a roll

The main problem with manufacturing real-world capacitors is that it is difficult to produce components that have sufficiently high capacitance to be of any real worth in practical electronic circuits. As pointed out previously, some circuits do require capacitors that have extremely low values, but very low value components seem to be used much less than they were in the past. Most of the capacitors used in modern electronics have values of a few nanofarads or more. Capacitors having values of this order are potentially huge, and the manufacturers have to achieve something more than the proverbial 'quart into a pint pot' in order to produce capacitors of useable sizes.

The difficulty in producing high value components is that it requires metal plates that have quite large areas, together with a very thin layer of insulation to separate them. The thinner the insulation, the smaller the plates need to be for a given value. However, having a very thin layer of insulation tends to give a lack of durability, and it requires the material used to be a really good insulator so that leakage currents are kept to insignificant levels. The insulating layer also has to be of high quality so that it does not break down altogether when anything more than a low voltage is applied to the component.

The normal solution to reducing the size of capacitors is to have two strips of metal foil interleaved with two strips of plastic foil. The four strips are then rolled into a cylindrical shape to produce an axial lead component. More often these days the strips are folded to produce the familiar box-shaped printed circuit mounting (PCM) capacitors (Fig.1). There are variations on this scheme of things, such as having a film of plastic deposited on one side

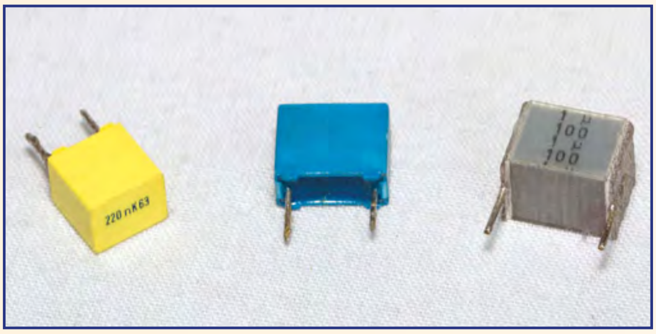


Fig.1. These PCM (printed circuit mounting) capacitors use essentially the same method of construction as axial lead types. Four layers of foil (two metal and two dielectric) are rolled or folded around

of each metal strip rather than having separate strips of insulation. In a similar vein, the strips of plastic foil can have metal deposited on one side. Although the insulating material is usually some form of plastic, other materials such as mica and ceramics can be used. The basic scheme of things remains the same though, with the metal and dielectric strips being rolled or folded in order to produce a component that has small physical size.

In electronic components catalogues, capacitors are grouped into types such as mylar, polyester, polystyrene, and ceramic. In other words, they are grouped according to the material used for the dielectric. There are important differences between the various types, with some offering better temperature stability than others, and some perhaps offering something as basic as extreme physical toughness. Where a components list specifies a particular type of capacitor it is definitely not a good idea to use anything other than that particular type. In many cases though, the exact characteristics of the component are not critical, and practically any capacitor of the right value will work. There are a few important points to bear in mind though:

Cheap ceramics

Some ceramic capacitors work very well at high frequencies, but are far from perfect in other respects. In particular, their initial accuracy is not very good, and the value tends to drift over time and with changes in temperature. They are only intended for non-critical applications such as high frequency coupling and decoupling, and are not intended for general use.

Tolerance

Like resistors, capacitors have a tolerance rating that indicates the maximum error between the marked and actual values. It is acceptable to use a component that has a better tolerance rating than that called for in a components list, but not one that has a worse rating. For instance, a 5% component can be used in place of a 10% type, but a substitution the other way around would not be a good idea.

Fig.2. This was a polyester capacitor! It has been cut open to reveal the numerous layers of foil needed to get a value of 100nf into a small volume (it is about 8mm wide)

Voltage

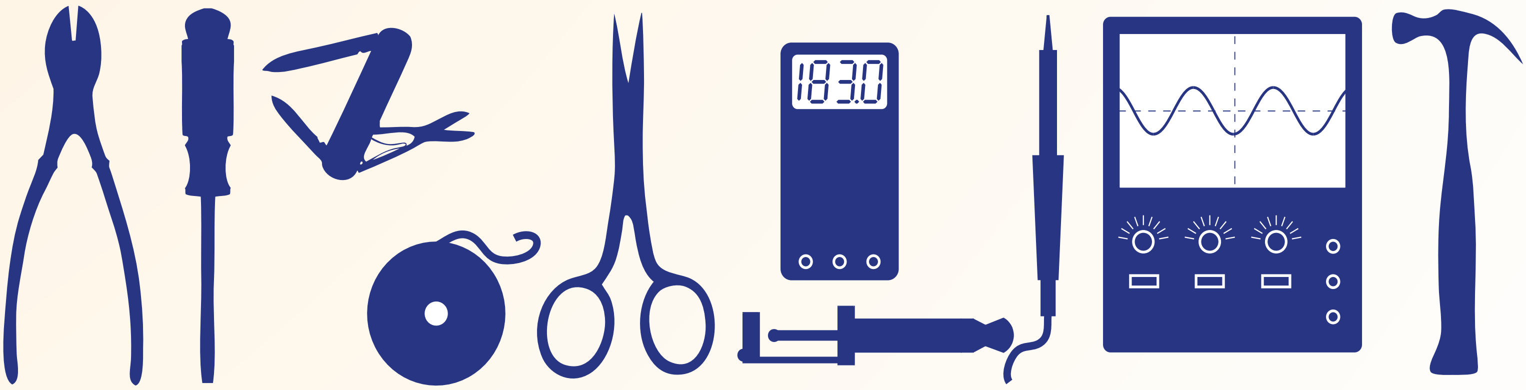
The thinness of the dielectric means that the maximum voltage that can be applied to a capacitor might not be very high. Exceeding the maximum rated voltage can cause the dielectric to break down, which will often result in the component exploding with a loud 'crack'. Ordinary capacitors mostly have maximum voltage ratings of about 50V or higher, and a rating of 400V or more is quite common. With most circuits these days operating on supplies of just a few volts, the voltage rating is often of no practical consequence. However, where appropriate, make sure that a component having an adequate voltage rating is used, especially with electrolytics.

Size matters

With modern electronic projects it is usually the size and shape of a capacitor that is of prime importance, rather than factors such as the type of dielectric and operating voltage. If the printed circuit is designed to accept a PCM capacitor having the pins on a pitch of 5mm, fitting a non-PCM type or one having a pitch of 10mm would be difficult or impossible. Bear in mind that there can be substantial differences in the physical size of capacitors that have the same value and lead spacing. An 'outsize' capacitor having the correct pin spacing will not necessarily fit into a given printed circuit layout. Using capacitors that fit the printed circuit board correctly will make construction easier, give a neater finished product, and provide better reliability.

Electrolytic capacitors

While it is possible to produce capacitors having values of more than about one microfarad using conventional methods, capacitors of this ilk tend to be relatively large and expensive. A solution of sorts is available in the form of electrolytic capacitors, which have essentially the same type of construction as conventional capacitors. The



difference is that the normal dielectric is replaced with one that consists of a porous material that contains a liquid or jelly electrolyte. On the plus side, this enables extremely high value but physically small capacitors to be produced. The downside is that electrolytic capacitors have some major shortcomings.

The most significant of these is that a normal electrolytic capacitor can only work properly while it is supplied with a voltage of the correct polarity. There are actually some special electrolytic capacitors that do not require a polarising voltage, but these are only used very rarely. Since a suitable polarising voltage will be present in most circuits where a very high value capacitor is needed, I suppose the need for one is not a major drawback. From a practical standpoint it means that, unlike ordinary capacitors, the electrolytic variety have to be connected the right way round.

Out with a bang

Connecting an electrolytic capacitor the wrong way round could produce large leakage currents that will almost certainly prevent the circuit from working. In the case of something like a smoothing capacitor it could be dangerous. Like supplying an excessive voltage to a capacitor, getting the polarity wrong can cause a high current to flow, and destruction of the component. Even with a battery powered circuit this could result in the capacitor going out with a loud bang! With the larger electrolytic capacitors, and especially with those that operate at relatively high voltages, getting the polarity wrong is potentially very dangerous.

The polarity of a capacitor is normally marked with '+' and (or) '–' signs on the body of the component. These days it seems to be the norm for only the '–' sign to be included, especially with components of the PCM variety (Fig.3 – left). Axial electrolytic capacitors have the positive (+) leadout wire indicated by an indentation around the body at the appropriate end of the component (Fig.3 – right), which makes it possible to see the polarity of the component without having to look at it closely. The normal polarity markings should also be included, and with modern components might be the only method used to indicate the polarity.

Although PCM electrolytic capacitors usually have an indentation at the bottom end of the body, it seems to be of no practical significance, and it is presumably just part of the manufacturing process. With some PCM electrolytic capacitors the markings are perhaps a bit over elaborate and not quite as clear as they might be. The negative (–) lead is usually shorter than the positive (+) one, and this might help to clarify matters.

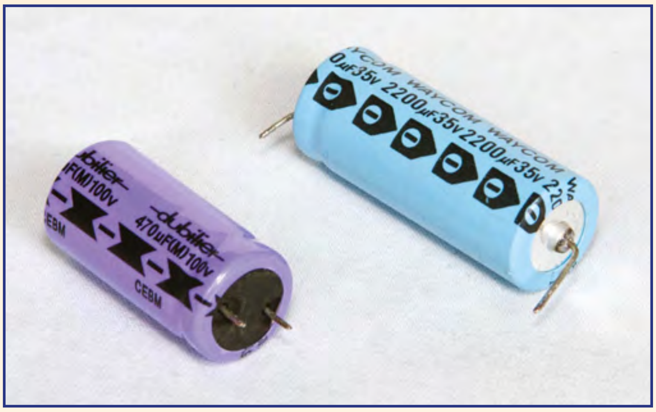


Fig.3. The PCM electrolytic on the left has the negative (–) lead clearly marked, as does the radial lead capacitor on the right. The latter also has an indentation around the body near the positive (+) lead

The maximum operating voltages of electrolytic capacitors are generally much lower than those of ordinary capacitors, and can be as low as a few volts. An adequate voltage rating is therefore something that you cannot simply take for granted, and you have to be careful to order components that are satisfactory in this respect. Because electrolytic capacitors are generally rather low specification devices, and because they require a suitable polarising voltage, they should not be used in applications where an ordinary capacitor is specified.

High quality electrolytic capacitors that offer better accuracy, lower leakage levels, etc. are available, and there are other polarised capacitors that provide improved performance, such as the tantalum type. Again, an ordinary electrolytic capacitor should not be used if one of these higher quality components is specified in a components list. At best, the circuit will work badly, and it may simply fail to work at all.

Variable capacitors

Variable capacitors were much used in the heyday of radio construction, but seem to be little used and difficult to obtain these days. The basic scheme of things is to have a set of fixed metal plates and a set of moveable plates on a shaft. The degree of overlap between the two sets of plates, and thus the component's capacitance, can be varied by rotating the shaft. With air-spaced components the two sets of plates are carefully set up so that there is always a gap between them and they never touch. Solid dielectric variable capacitors use the alternative approach of having thin pieces of plastic to ensure that the two sets of plates remain separated. This makes them smaller than air-spaced equivalents, but in other respects they are generally considered to be inferior.

Preset capacitors are available, and they are sometimes called 'trimmers'. They can be much like miniature versions of variable capacitors, but the compression type is much more common. These have a solid dielectric and both sets of plates are made from a springy material. By adjusting a screw it is possible to press the plates closer together or move them further apart, which respectively gives increased and reduced capacitance. The maximum values of preset and variable capacitors are very low, and range from a few picofarads to no more than about 500 picofarads.

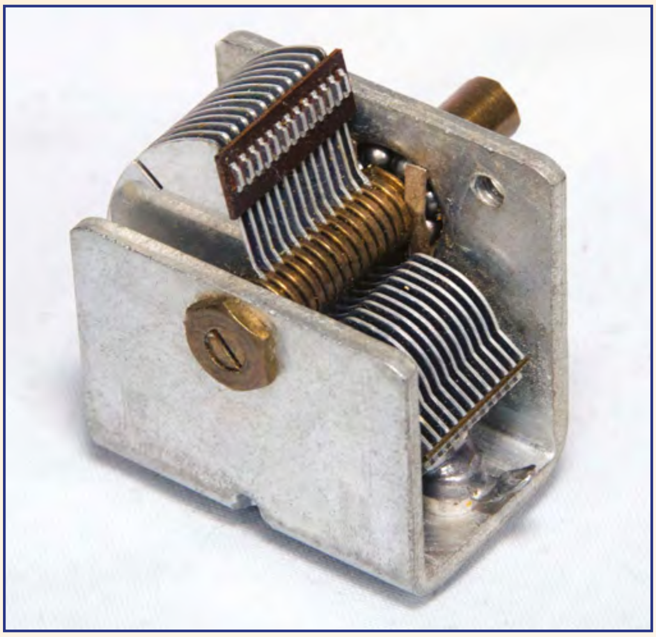


Fig.4. This is an air-spaced variable capacitor. It is accurately manufactured and set up to ensure that the two sets of metal plates do not come into physical and electrical contact

Circuit Surgery

Regular Clinic

by Ian Bell

Counter subtleties

This month, we will look at a problem with a digital counter circuit posted by ***perro*** on the *EPE Chat Zone*. His circuit is shown in Fig.1 and the resulting simulation waveform in Fig.2.

I've run into a problem with a simulated circuit, which I don't think should arise, but I can't tell if it's the circuit design or the simulator that's causing it. I've been trying to make the sample decade counter to work in Circuit Wizard, *from* Teach-In 2011, Part 6 *(Fig, 6.37) [April 2011]. Basically, this is a ripple counter made of daisy-chained JK bistables, with their outputs going to a decoder/driver for a single 7-segment display. SW1 advances the count.*

The circuit works fine until it comes to reset back to 0. Instead of returning to 0, the output resets to 4 (ie, IC2a output high). Reset occurs via NAND gate IC4b, when outputs from IC1b and IC2b are high (ie, value 0x0A, 10 or 0b0101).

As far as I can tell, the reset happens when it should, but it seems that as IC1b goes from high to low, it's causing IC2a to go high (generating an output value of 4). However, that doesn't happen if I use the manual reset button, SW2 (that works OK – even if I change the circuit so it is allowed to stay at 10, to allow me to accurately simulate what should be happening).

So, my question is: is there a problem with the CW simulation OR do I need to add some components to hold reset for longer?

As you can see [In the waveform plot], when channel 1 goes high (to match channel 3), it causes the output of NAND IC4b to go low, and thereby resets all bistables. This should instantly(ish) set bistable outputs to 0. But (and this seems to be the problem) because channel 2 transitions from high to low, channel 3 goes high.

There was some discussion following perro's post, with various other *Circuit Wizard* simulations posted, including attempts to stretch the reset pulse. In one response, ***istedman*** correctly pointed out that there may be a race condition occurring in the circuit, which is something we will look at in this article. I have not used *Circuit Wizard* so I cannot comment on any specific issues there might be with this simulator. However, as we will see, this circuit can be shown to exhibit this problem in other simulators. Indeed, ***istedman*** reported that a simulation he ran using ADI Multisim produced a similar result. For details on ADI Multisim, see: **www.analog.com/en/amplifier-linear-tools/multisim/topic.html**

It is possible that perro's use of a 4011B NAND gate instead of the 74LS00 from the original *Teach-In* circuit may produce a different simulation result from the original, but without *Circuit Wizard* I have not checked this.

In this article we will look in detail at what is happening in the circuit in Fig.1 in terms of circuit timing – how variation of the switching delays of individual gates in a circuit can influence its overall behaviour. We will also see how the way components are modelled in the simulation can affect the results. Such issues are not restricted to ***perro's*** circuit – the relationship between component delay and overall circuit functionality is a very important topic in commercial digital design.

Use will be made of simulations employing Questa Sim from Mentor Graphics (**www.mentor.com/products/fv/questa/**). For this, the circuits were coded using the VHDL hardware description language (a computer language which can be used to describe both the behaviour and structure of digital circuits and systems). We will

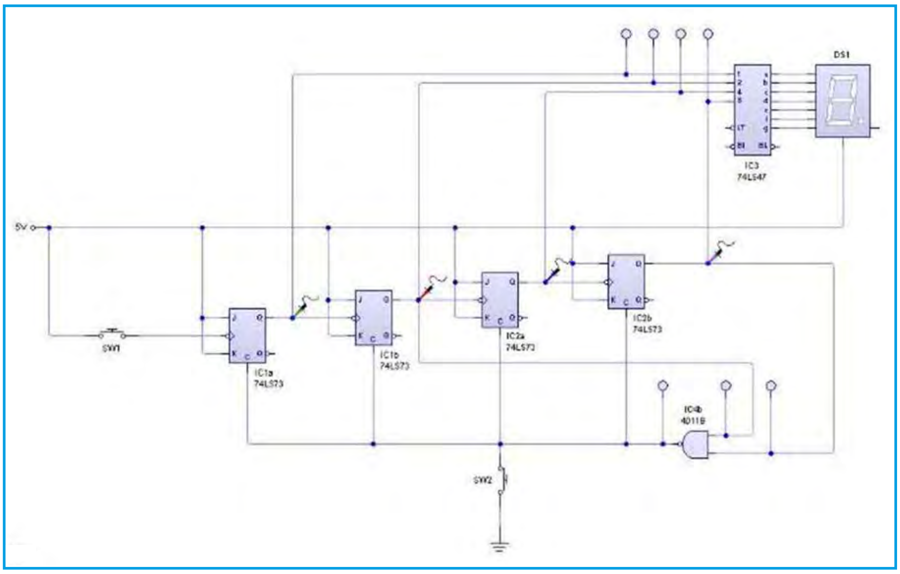


Fig.1. Perro's counter circuit

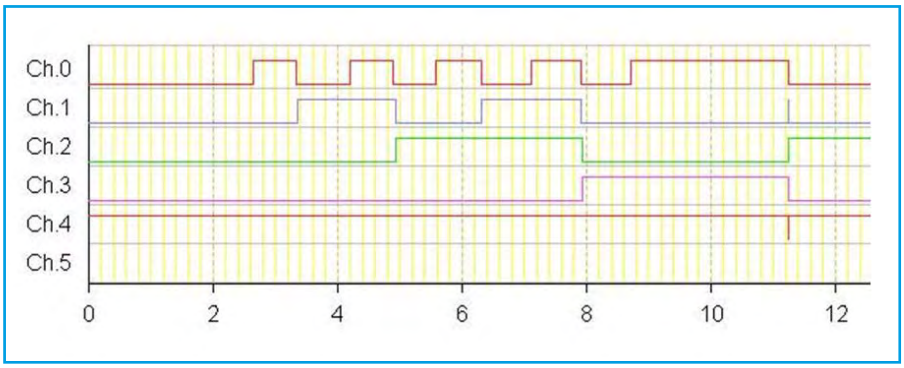


Fig.2. Perro's simulation result

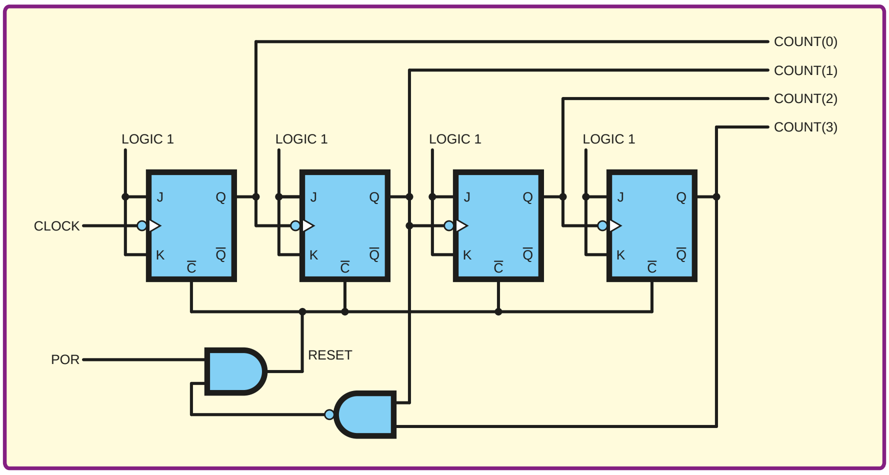


Fig.3. Counter circuit used in simulations in this article

not go into full details of the code due to lack of space. This is a departure from the usual use of simulations in *Circuit Surgery* which are straightforward for readers to reproduce. However, in this case it was useful to be able to control the behaviour of components in the simulation to illustrate some of the points made. The fact that a couple of suitable and adaptable JK flip-flop models happened to be available too, made this the best choice on this occasion.

The counter simulated for this article is shown in Fig.3; the signal labels correspond with the waveforms shown later. This is fundamentally the same as ***perro's*** circuit, but without the display, which we do not need for investigating the timing of the reset logic. The reset circuit has been modified slightly to provide a power-on reset (POR) input in addition to the reset signal from the NAND gate. The POR AND gate is only employed during circuit initialisation, effectively has no delay, and will be ignored in the rest of our discussion. The circuit in Fig.3 uses generic components rather than models for specific devices such as the 74LS73.

First simulation

Our first simulation uses a very simple model for the behaviour of the JK flip-flops. The follow pseudocode represents the way the JK flip-flop is modelled.

```
if (C is 0)
  {the flip flop stores 0}
else if (there is a falling edge on the clock)
  {use J and K to determine the stored value}
else
  {no change, continue storing the current value}
```

Any change to the stored value appears on the Q and $\overline{Q}$ outputs after a delay set elsewhere in the code. This code 'executes' in the simulation each time an input to the flip-flop changes to determine if the output value should be updated. A key point for the following discussion is that in this model the clear ($\overline{C}$ = 0) immediately overrides all other inputs.

The results from simulating this circuit using the above flip-flop behaviour are shown in Fig.4. The top trace shows the count value in binary. The next four traces are the individual bits, with the most significant bit (count(3), the binary 8's digit) at the top. The bottom three traces are the clock and reset signals which control the circuit. The clock period is 1000ns (1µs), but the absolute value is not particularly important as this simulation is of a generic circuit, not a specific technology.

In Fig.4 we see that the circuit is initially reset by application of the POR signal. It then starts counting in binary, in response to the clock, until it reaches 1001 (decimal 9), at which point it resets to 0000. This is the desired operation of this circuit, which perro's circuit failed to exhibit. A careful look at the simulation will show that not all the transitions between count value look clean (eg, 0111 to 1000). Fig.5 shows a zoom-in of this part of the waveform. On counting up from 0111 (decimal 7) the counter temporarily outputs three incorrect values (0110, 0100 and 0000) before settling down to the correct 1000 (decimal 8).

The reason for this behaviour is the asynchronous nature of the counter. One flip-flop clocks the next, so changes ripple through the circuit from one flip-flop to the next. The circuit in Fig.3 is called a ripple counter for this reason. For this circuit, the more

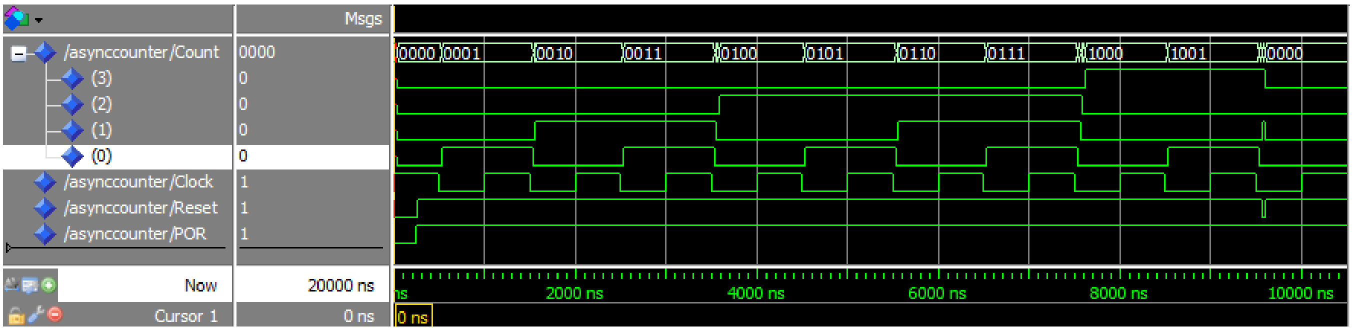


Fig.4. Simulation of the circuit in Fig.3 using a simple JK flip-flop model

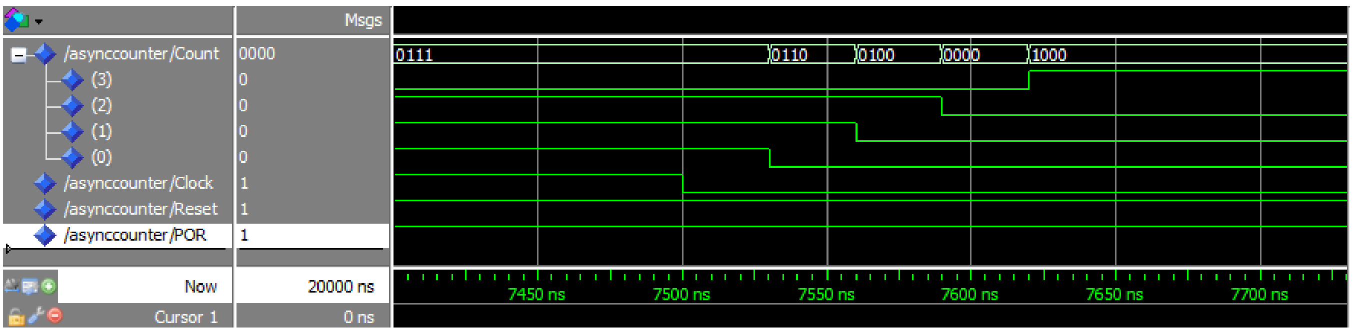


Fig.5. Zoom in on the 0111 to 1000 change from Fig.4

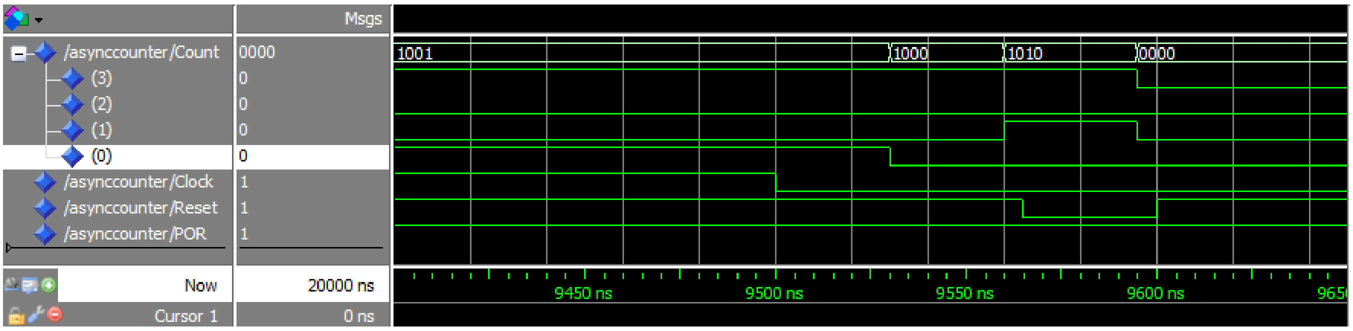


Fig.6. Zoom-in on the reset from the NAND gate from Fig.4

0 to 1 changes there are in a row the longer the counter takes to settle. For a larger counter this problem would be worse. The intermediate output values can cause problems if we connect gates (such as the reset NAND gate in Fig.3) to detect specific count values. If we had wired gates detect one of the count values 0110, 0100 or 0000, the circuit would have falsely triggered during the count change from 7 to 8.

The problem with perro's circuit is not directly related to intermediate count values because the reset NAND gate does not happen to get triggered in this way. However, it was worth mentioning this in passing as it is a common pitfall when using asynchronous ripple counters. An alternative approach is to use a synchronous counter, in which all the flip-flop clocks are connected together, so all the flip-flops update together and intermediate values are avoided.

Reset action

Fig.6 shows a zoom-in of the reset action from Fig.4. The counter starts at 1001 (decimal 9). When the negative edge occurs on Clock, the Count(0) flip-flop toggles to 0. This causes an intermediate count output of 1000 until the Count(1) flip-flop has responded, in turn, to its clock, to give the next true count value of 1010 (decimal 10). The bit pattern of 1010 is detected by the NAND gate (just the two 1's), so the next event is the Reset signal going low (at around 9565ns, after the 5ns delay due to the NAND gate).

All the flip-flops respond to the applied reset after a delay of 30ns, causing the two flip-flops which were holding Q=1 to reset to 0. One of these, the Count(1) output, is connected to the clock of the next flip-flop, so the negative edge due to the reset could potentially clock the Count(2) flip-flop. However, looking at the waveform in Fig.6 we see that the reset is active when this clock edge occurs and the pseudocode above determines that the flip-flop's clear overrides the clock under any circumstance. Therefore, the circuit resets correctly to 0000 as shown in the waveform. The reset is removed when the counter returns to 0000 after the 5ns delay due to the NAND gate.

The simple model of the JK flip-flop used for the simulation in Fig.4 to Fig.6 may be insufficient to model all the behaviour of a real flip-flop. We can develop a more detailed flip-flop model if we know something of its structure and operation. Fig.7 shows a typical edge-triggered master-slave JK flip-flop, with Clear (C̄), build using a couple of set-reset latches. We discussed a similar circuit in the July 2013 issue of *EPE*. We can create a JK flip-flop model based on this for simulation. The gates are modelled using Boolean functions with delay, and the SR latches are modelled using code of a similar form to the basic JK pseudo code listed above.

Simulation results

Fig.8 shows simulation results for the circuit in Fig.3 in which the flip-flops models are based on Fig.7 (as described above). This is a zoom in on the reset action around the 1010 count value and, covering a similar time range to Fig.6.

Initially, the waveform follows the same pattern as in Fig.6. The negative clock edge toggles the first flip-flop, producing the 1000 intermediate count value. This happens very slightly faster than the 30ns for the simple model, but it is not significantly different. Again, as before, the first flip-flop clocks the second and a count value of 1010 is achieved. This in turn switches the NAND gate (after 5ns, as above – this gate has not changed) and the count

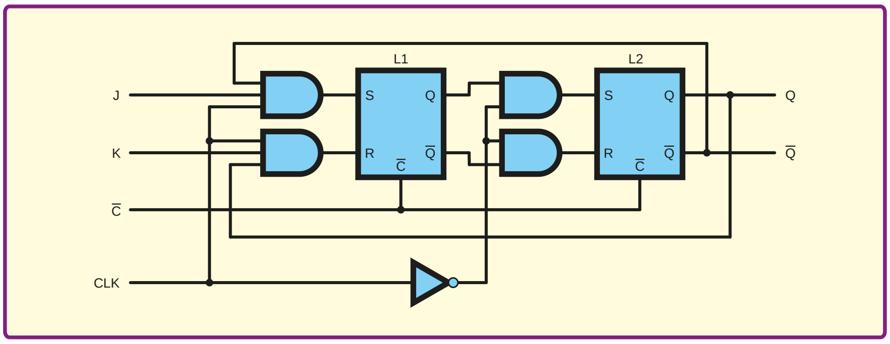


Fig.7. Structure of an edge-triggered master slave flip-flop

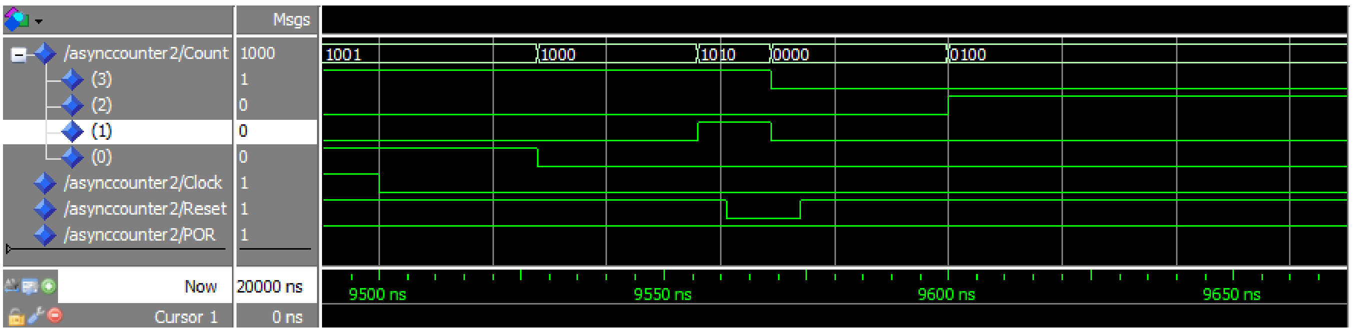


Fig.8. Zoom-in on the reset from the NAND gate from Fig.4. This simulation uses a more detailed JK flip-flop model and a fast NAND gate. The reset fails

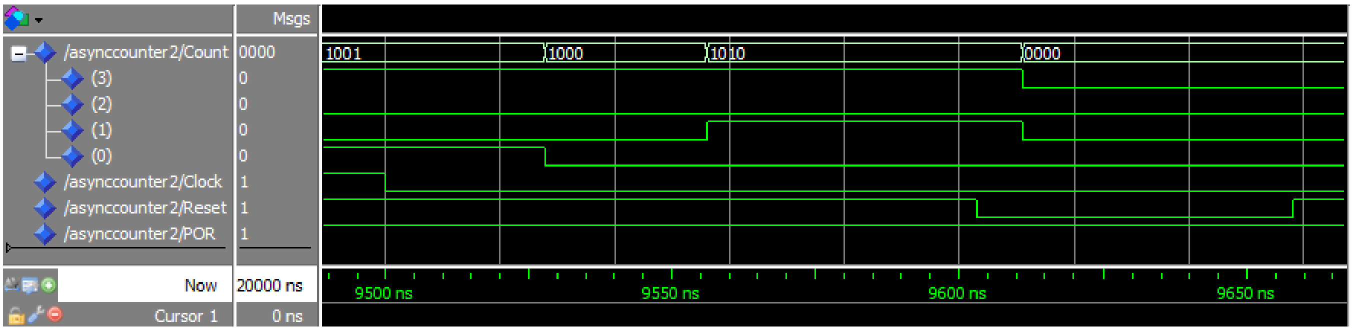


Fig.9. Zoom-in on the reset from the NAND gate from Fig.4. This simulation uses a more detailed JK flip-flop model and a slow NAND gate. The reset is successful

value returns to 0000. Unfortunately, the sequence of events does not stop there because the negative edge on Count(1) clocks the Count(2) flip-flop, which toggles to 1. The final count value after this reset action is 0100, not 0000. This is exactly the problem that ***perro*** reported in his *Chat Zone* post.

In the *Chat Zone* discussion it was proposed that stretching the reset pulse may get round the problem, with capacitors and pulse-stretching circuits suggested to achieve this. In the simulation we are using here it was easy to achieve something similar by simply increasing the delay of the NAND gate driving the reset (a minor change in one line of code). Resimulating the circuit, still with the detailed JK model, but with a NAND delay of 47ns rather than 5ns produces the result shown in Fig.9. The counter resets to 0000 as required.

Failure cause

What is causing the reset failure and why does increasing the NAND gate delay remove the problem? The negative edge on Count(1) resulting from the reset applied via the NAND gate has two effects. It removes the reset from the JK flip-flops, because the NAND gate output returns to 1, and it produces an active clock (negative edge) to the Count(2) flip-flop. In both cases a signal starts from the Count(1) flip-flop Q output and travels through the circuit to the SR latches inside the Count(2) flip-flop. Although the start and end points are the same in both cases, the routes through the circuit are different, as illustrated in Fig.10. This is an example of a race condition. The outcome depends on which signal gets to the SR latch first.

If the path from Count(1) to the SR latches' S and R inputs (blue in Fig.10) is faster than the path to the latches' clear ($\overline{C}$) inputs (red in Fig.10) the reset condition will not have been removed by the time the S and R inputs are activated. The active clock action will have no effect and the flip-flop will remain in reset. The counter will reset correctly. For this to happen, the NAND gate delay (red) must be longer than the total delay of the gates on the clock path inside the flip-flop (blue). This is why the simulation with the longer NAND gate delay shows correct reset operation.

If the path from Count(1) to the SR latches' S and R inputs (blue in Fig.10) is slower than the path to the latches' clear inputs (red in Fig.10) the reset condition will have been removed by the time the S and R inputs are activated. The JK flip-flop will respond to its clock. In this case, because J and K are both 1, it will toggle from 0 to 1. The counter will therefore fail to reset correctly. For this to happen, the NAND gate delay (red) must be shorter than the total delay of the gates on the clock path inside the flip-flop (blue). This is why the simulation with the faster NAND gate shows failure of the reset operation.

Ambiguities

Perro asks if there is anything wrong with the *Circuit Wizard* simulation. The answer, as we have seen, is that it is certainly possible for the circuit to behave in the way he observed in his simulation. Whether the simulation is correct or not depends on what a real version of the circuit would do – has its behaviour been correctly predicted? However, this is not quite as simple as it may seem at first sight.

Individual components vary in their characteristics, so it is possible that different versions of the same circuit could behave differently. For example, the NAND gates in several different copies of a real circuit may have quite different delay values, potentially meaning that some copies reset correctly, while others do not. In this situation it may better if the simulator indicates failure – thus highlighting a potential reliability problem, but it should not be excessively pessimistic. Digital circuits may be simulated under different conditions (eg, expected 'fastest' and 'slowest' conditions) to check that functionality is maintained. Advanced digital design software includes timing analyser tools which help identify situations where variations in delay may cause ambiguities in circuit operation.

Ad hoc asynchronous logic, such as the circuit discussed here, is generally very susceptible to timing problems and is often best avoided. This is despite the potential advantages of lower power consumption and component count than synchronous versions. In commercial system design, formal, structured, asynchronous digital circuits (eg, using handshaking protocols) avoid the timing ambiguities seen here and can provide potentially significant advantages (faster and lower power) when used for large digital designs. Such asynchronous design has not been used as widely as might have been expected due to lack of suitably experienced designers and appropriate design software.

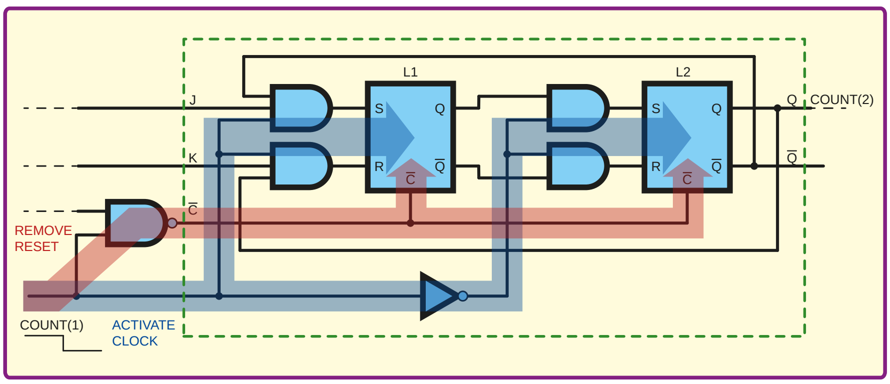


Fig.10. The 1010 to 0000 change during reset creates a negative edge which races to both remove the reset (red path) and clock the flip-flop (blue path). The final result depends on whether the reset has gone by the time the clock arrives

Max's Cool Beans

By Max The Magnificent

Consolidating around Arduino

I typically have a number of hobby projects 'on the go' at any one time. Many of these projects require one or more microcontrollers to do 'stuff.' Until recently, I've been flitting back and forth between different platforms, but now it appears as though I'm committed to the Arduino (**www.arduino.cc**). But before I explain my current interest in the Arduino, let's first make sure we're all marching to the same drumbeat...

Arduino hardware

The term Arduino refers to an open-source microcontroller-based platform that's based on easy-to-use hardware and software. These platforms come in all sorts of shapes and sizes. A very common system is called an Arduino Uno. This features an 8-bit microcontroller, which can be powered by a USB cable, a battery, or an external power supply (there are much more powerful Arduino devices with 32-bit processors available). You can pick up an Arduino Uno from **amazon.co.uk** for around £19, or from **amazon.com** in the US for around $14 (note that you will also need to purchase a USB-A to USB-B cable to connect the Arduino to your host computer so you can program it; also, I would recommend using an external power supply).

One of the key things about the Arduino is that it sports two 16-pin connectors on either side of the board. These provide inputs and outputs that allow the Arduino to 'talk' to the outside world – accepting signals from sensors (temperature, pressure, light, sound...) and generating signals to control things like LEDs and motors. Daughter boards – called 'shields' – can plug into the connectors on the main Arduino board. In many cases it's possible to stack multiple shields on top of each other. You can purchase off-the-shelf shields for things like Ethernet, Wi-Fi, wireless, motor controllers, and so forth. You can also purchase special prototyping shields that make it easier for you to build your own projects.

Arduino software

There are several programming environments one can use with the Arduino. If you are a beginner, perhaps the best option is to use the official Arduino IDE (integrated development environment), which you can download for free from the main Arduino website. There are Windows, Mac OS X, and Linux versions of this IDE available. Just follow the instructions on the Arduino website.

A program written for the Arduino using the Arduino IDE is called a 'sketch.' As always, there are many nuances to everything. For our purposes here, however, the simplest way to think of things is that the Arduino programming language is a simplified version of the C and C++ programming languages.

Learning resources

There are a bunch of useful tutorials and other resources available for free on the main Arduino website. If you are an absolute newcomer to C/C++, then one book that I would personally recommend is *Programming Arduino: Getting Started with Sketches* by Simon Monk, which is available for a very reasonable £9.89 from **amazon.co.uk**. Another book I find very useful is *Arduino Workshop: A Hands-On Introduction with 65 Projects* by John Boxall (£14.34 from **amazon.co.uk**). There are also a couple of very useful starter kits available from Amazon should you wish to avail yourself of them. These typically include an Arduino Uno, a USB cable, a breadboard and wires (no soldering required), a bunch of sensors and actuators, and a book of projects.

LED cubes

So, why am I so enthused with learning the Arduino? Well, this all started with a local 'Hamfest' I attended a month or so ago. Now, if you show me a flashing LED, I will show you a man entranced. Thus, you can imagine my surprise and delight when I passed a booth selling 3D tri-color LED cubes (4 × 4 × 4 = 64 LEDs) in the form of a do-it-yourself kit powered by an Arduino-compatible controller.

I've always wanted to experiment with one of these little scamps. I've got all sorts of ideas, such as using it to display the actions of a small Turing machine and presenting a simple 3D Game-of-Life, along with a variety of other visualisations. As an aside, this involved more than 400 soldered joints, and it worked the first time I powered it up – ha! It's now sitting on my desk displaying a variety of mesmerising patterns... I'm sorry, what were we talking about?

An Arduino-driven 4×4×4 LED tri-colour cube

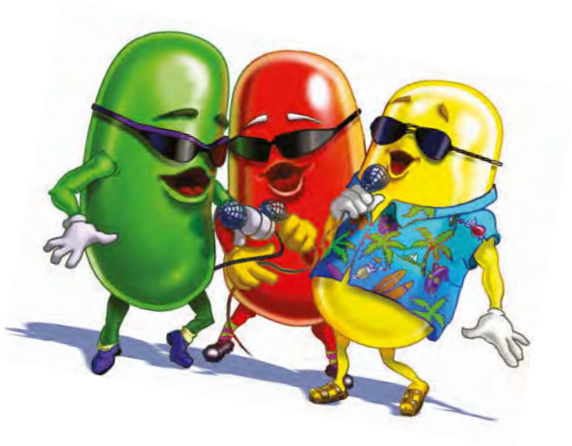
Nanocopters, and robots

The strange thing is, almost immediately after I'd started work on my cube, I started seeing all sorts of Arduino-related 'things.' First, I ran across a Kickstarter project for little nanocopter drones that you can control via your smartphone or tablet computer (**http://kck.st/1f65Bvi**). The controller board used in these little beauties is Arduino-compatible, so I've started thinking about using mine to control a much bigger hexacopter that I'm planning to build.

But the Kickstarter project that really grabbed me by the short-and-curlies was the one for a low-cost machine-vision sensor (**http://kck.st/1bGfhdn**). This can detect and identify objects and output information in such a way that an Arduino-controlled robot can use it. All of which explains why I am currently building an Arduino-controlled robot!

Now, some folks favour two-wheeled robot platforms (with an additional castor for balance). Others say a four-wheeled platform is the way to go. I scoff at both of these points of view. Like the French taunter said in Monty Python's *The Holy Grail*: 'Go away or I shall taunt you a second time!' (**http://bit.ly/16OxJ66**) No, as far as I'm concerned, the only sensible way to go is to have a three-wheeled platform in which three geared motors and associated wheels are mounted at 120° to each other.

'What?' I can hear you say 'Surely such a beast will only be capable of spinning on the spot.' Ha! That's where you're wrong, because I will be using omni-directional wheels from VexRobotics.com (**http://bit.ly/Hhesya**).



Omnidirectional dual-roller robotic wheels

These little beauties have a dual set of rollers mounted around the periphery of the wheel, thereby allowing the wheel to move in any direction. The really clever part is that these rollers are precisely shaped so that the overall contour of the main wheel is absolutely round.

Of course, there are so many other things to think about, such as motors and sensors and suchlike. But maybe I'm boring you. Do you want to hear more? If so, why not drop a 'Letter to the editor' telling him so, and he will communicate your wishes to yours truly. Until next time, have a good one!

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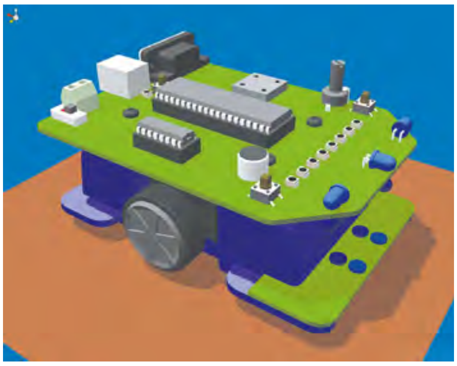

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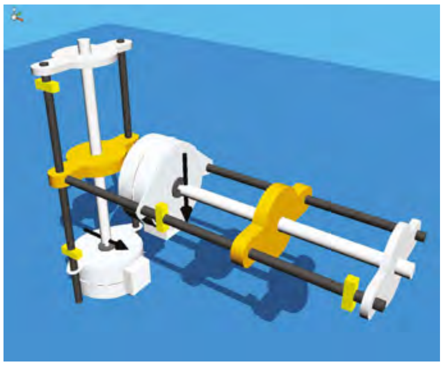

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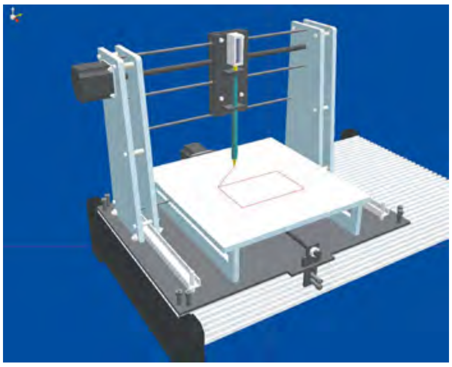

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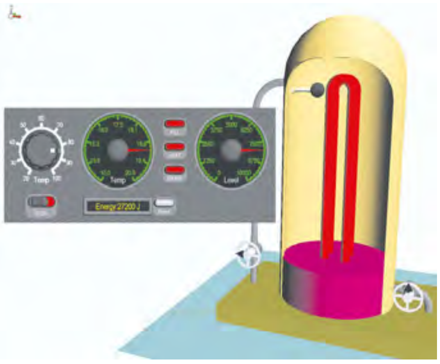

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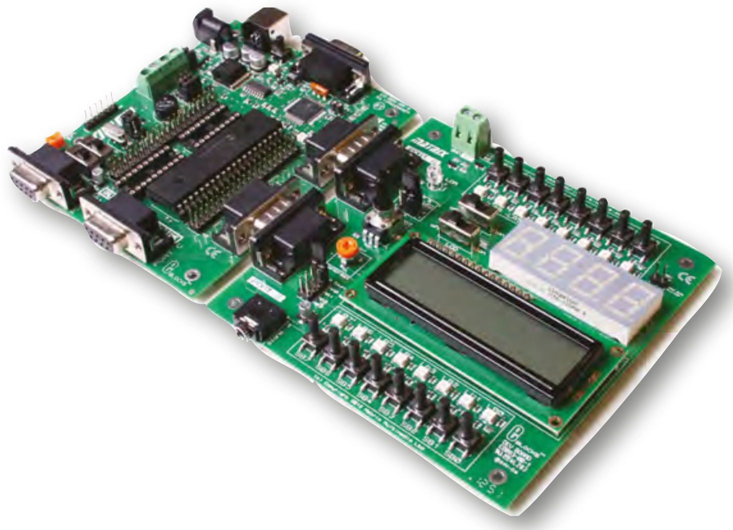

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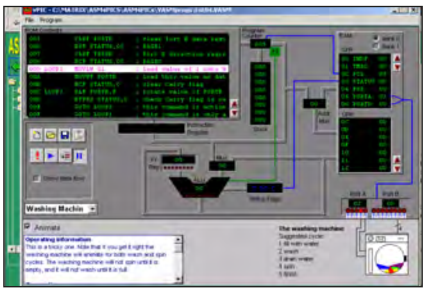

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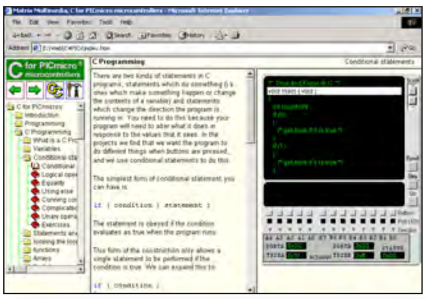

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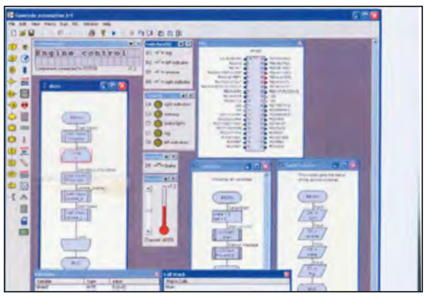

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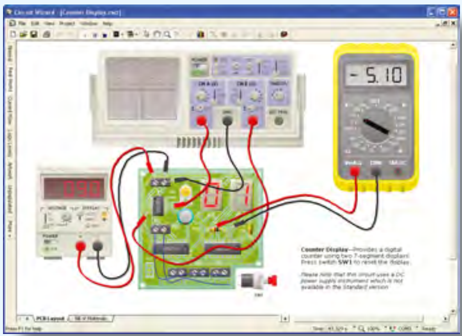

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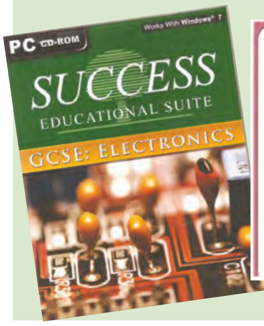

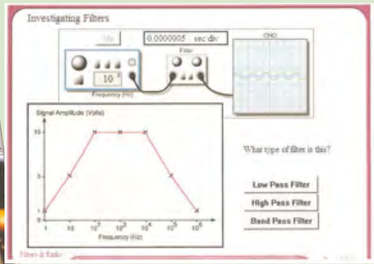

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NET WORK

by Alan Winstanley

Smarter networking

WITH my home area network already groaning under the strain, the addition of a Samsung SmartTV eventually highlighted some practical shortcomings in Wi-Fi performance that became impossible to ignore. In particular, trying to stream standard movies to the TV was a challenge, while watching HD content was nigh on impossible, which may be due to local broadband bandwidth falling at peak times.

In order to improve Wi-Fi coverage around the home I've previously highlighted the Billion 3100SN plug-in wireless range extender, a device that not even Billion could help configure to work as an 'extender' with my Billion 7800N router as I'd initially hoped. Instead, it was re-configured as a stand-alone wireless access point. Even then, some problems in Wi-Fi reliability started to emerge, so it was time to revisit the home network once again.

Homeplug

With Wi-Fi channels becoming overcrowded, if wired Ethernet isn't possible then the last resort is an option that I've tried before – Homeplug, a system that enables broadband to be distributed through the ring mains. Near the router, a Homeplug device is plugged into the mains and connected to the router with an Ethernet cable. Around the network, similar devices plug into the mains and connect to (say) a laptop or TV using another Ethernet cable.

As a final solution I opted for Develo's dLAN 500 AV Wireless+ Starter Homeplug Kit, which I figured would be reasonably future-proof. It's currently the fastest Homeplug standard available and is suitable for high-definition multimedia. Two Homeplug adaptors are supplied in this kit, a smaller adaptor with single port that connects to the router, and a bulkier unit with three-port Fast Ethernet switch, allowing up to three devices to be cabled up to the network. 300Mbps Wi-Fi is incorporated in the main body, which effectively turns your mains socket into a wireless access point. It's best to get as direct a connection to the mains as possible, preferably by plugging directly into a wall socket and avoiding the use of mains leads or extension sockets for Homeplug connections.

I last discussed mains-borne networking technology in *Net Work*, June 2011 when Homeplug (IEEE 1901 standard) and rival Homegrid (G.hn standard) systems were outlined. Manufacturers have aligned themselves behind either standard, but it was hoped that the two different standards would converge so that devices could be used interchangeably. More details of both systems will be found on the corresponding consortia websites at **https://www.homeplug.org/home** and **www.homegridforum.org**

My own advice is to stick with one brand from the outset, watching for the use of authentic Homeplug or Homegrid logos on equipment. It's highly important to confirm that all electrical equipment is on the same phase. For residential property this isn't normally a problem, but industrial premises often have all three phases running around the site, which may be problematic for Homeplugs (hence there is a clue in the name 'Homeplugs'!).

Devolo dLAN 500AV Wireless+ Homeplug adaptor has three fast Ethernet ports and wireless-N. (Amazon)

Interference

Mains-borne interference can sometimes be an issue too, which is why direct connection to a wall socket is preferable. Ideally, the same supply should not be powering industrial equipment, motors and the like as power spikes can interfere with the network. The dLAN 500AV Wireless + Starter Kit has some added benefits: each adaptor has a pass-through mains socket so you don't lose the use of a mains outlet, and it has built-in mains filtering to combat electrical noise. Their vertical design allows use on mains sockets that are low down at skirting board level.

Homeplugs are as near to plug-and-play as one can get. The three-port adaptor was tried on a powerstrip initially and sure enough its LED indicator glowed red to signify a low-speed connection. After plugging it directly into the mains wall socket, the signal turned green to indicate maximum performance. The TV had no problem finding the network straight away. Last, as mentioned, the Devolo AV Wireless+ acts as a wireless-N access point to connect a phone or tablet to the network. Some Devolo models offer gigabit Ethernet ports, so check the spec sheets very closely if that appeals to you.

Devolo's dLAN Cockpit software for Windows, Mac and Linux gives a simple bird's-eye view of any connected Devolo devices. The likely maximum speed is indicated on-screen (85-105Mbps in my case), the devices can be renamed in plain English and after setting up the LED indicators can be disabled in the software should they prove distracting (which they definitely did).

Elsewhere around the home, smaller single-port Devolo adaptors may be adequate. Having used Devolo Homeplugs in the past to connect a temperamental W98 machine to a network, I cannot think of a more effortless way of connecting devices to a network or creating wireless access points around the home. The mains pass-through sockets are great (with a hefty 16A rating) but I would recommend that such a system is tested immediately after purchase so that it can be returned in the unlikely event that it doesn't work for you.

With the dLAN 500AV Wireless + Starter Kit installed, I could at last enjoy HD programs, catch-up TV and streaming video and so far I have had none of the interruptions that my Wi-Fi connections had been responsible for. If Wi-Fi is proving a problem for you, then a Homeplug-based network is worth serious consideration.

Help yourself!

Last month, I outlined some of the current generation apps and services offered by Google, including voice search, a speech-recognising app that usually does a creditable job of transcribing your spoken query into a context-aware search phrase. Apart from its use with Android phones, voice search is available on the Google Chrome web browser, which enables PC users to utilise their webcam's microphone instead of keying in search phrases when googling.

Everyone surfs the web from time to time in search of information, pointers and tips about a particular problem that they're grappling with. After all, in today's economy, being resourceful is the name of the game and electronics hobbyists are better equipped than most to tackle technical repair jobs themselves, thereby beating the system and saving money at the same time. Completing a challenging repair job against the odds is highly satisfying.

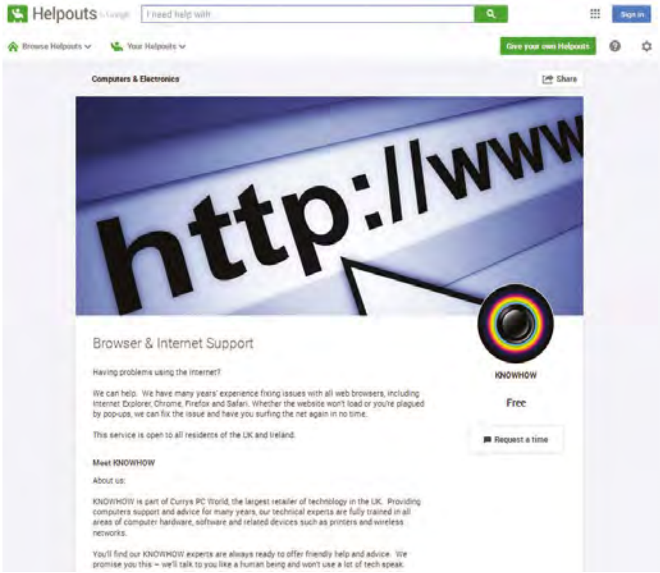
For example, right now I'm about to replace the quartz movement of a faulty watch (a new movement was sourced in Greece via eBay for £7!), in between swapping the hard drive of an iMac. The web is awash with YouTube videos and eHow articles that are occasionally helpful but sometimes of very dubious value. If you're fixing an iMac, for example, then websites such as the heroic **http://www.ifixit.com/** contain priceless information with step-by-step photos that will enable any competent technician to complete the job confidently. As a PC owner who's used to fixing my own machines I had zero experience of switching on an iMac, let alone removing the magnetically clamped glass filter of an iMac screen, and iFixit's excellent photography has aided me in repairing the hard disks of a number of these intricate machines, saving many hundreds of pounds in the process. A digital camera is very useful for recording the dismantling procedure step-by-step.

Whether it's an iPhone screen, toilet cistern or a tower PC that you need to repair, it's highly likely that you are not the first to suffer the problem and plenty of information, forums and YouTube movies are available online to help you. Quite often, a product's repair manual in PDF form may be online, or maybe you have lost the instruction book – with luck, it may be downloadable as a PDF.

Google has now turned its attention to this sector of the web and is starting to offer a real-time, personalised Help service. **Google Helpout** claims to be a 'new way to get and give help' over a live video feed. Apart from getting individuals to help each other out, Google hopes that recognised brands will climb online and lend a corporate helping hand as well. Users with a particular problem can choose a Helper based on their qualifications, ratings or availability. The Helper may charge a fee or their advice may come free, and the collaborative sessions can be recorded and screens can be shared.

Initially, Google Helpout will be a small-scale service covering just a few categories such as health, fashion and basic computing but, doubtless Helpout will grow over time, though Google has a chequered history of shutting down interesting services that no longer fit the bill. Helpout prices vary from free, to (say) $15-$25 per Helpout or a quoted rate per minute. A fee may be charged for short-notice cancellations.

There are already US and UK-based Helpouts, including the Currys/PC World (UK) electronics chain working under their 'Knowhow' brand, which promises to help sort out your



Google Helpout promises both free and paid-for support via live video feed; Currys/ PC World (UK) shown

browser and web problems for free. Don't be deterred by US$ pricing: I noticed a British GCSE and A-Level maths tutor offering help for $32 per Helpout or $0.80 a minute (say £30 an hour). This might give a new twist to getting online help with homework, or a student could book a session to buy some selective private tuition. The flip side is that Google Helpout also offers specialists in many areas an opportunity to earn revenue from selling their expertise. The prospect of giving reviews and awarding ratings will doubtless produce some interesting trends as the better Helpers rise above the poorer ones. More details are at **https://helpouts.google.com**, and a Google+ account and webcam are needed.

Christmas treats

With the Christmas season upon us, new products are clamouring for attention and now is a good time to consider investing in a new tablet or smartphone. Thanks to a vast array of apps, a smartphone or tablet can handle email or surf the web, run diagnostic apps (eg, Torque Pro uses an adaptor to display a car's OBD status in real time), educate (eg, Star Chart Infinite helps budding astronomers to identify stars) and amuse with a huge range of games.

Tablets were popularised by the alluring but expensive iPad before a wide range of more sensibly priced alternatives came to market. Retailers now recognize the power of having a presence on a customer's tablet screen, and in the UK the supermarket chain Tesco recently launched its good quality Hudl 7-inch Android tablet with some built-in functionality to appeal to Tesco shoppers. Costing £119, Hudl has been well received. The Argos chain offers My Tablet, a lower-spec. device costing £99, while Amazon's Kindle range has also had another makeover.

At the time of writing, the new 8·9-inch Kindle Fire HDX was listed at £329 (16GB) to £409 (64GB) and was destined for release on 13 December. Kindle Fire has built-in Wi-Fi and adding 3G/4G connectivity costs £70 more (noting that a basic Kindle can be had for £69 alone). Cheaper Fire tablets are also sold and you can choose standard E-Ink or 'paperwhite' displays on Amazon's cheapest models, which is all that many will need for holidays or train journeys. One Kindle Fire HDX feature already being trailed on TV is its so-called 'Mayday button'. This could be likened to a Helpout service staffed by Amazon support staff, and it provides one-touch video camera access to a Kindle Fire expert.

Google has released the latest version of its own Nexus tablet and the best way to learn about it is to visit **http://www.google.co.uk/nexus/tablets/**. The Nexus 7 is claimed to have the world's highest resolution 7-inch screen and the Nexus 10 is the 10-inch model. A Nexus 5, however, is a smartphone! Samsung's mobile devices including the Galaxy Tab 3-inch, 8-inch and 10-inch, the Galaxy Note

Amazon's Kindle Fire HDX with 'Mayday' live support button (circled)

with S Pen, and the Galaxy Gear smartwatch. Details of their models can be found on **www.samsung.com**.

There are countless other brands available in-store or online, and the choice is more bewildering than ever, so it's wise to compare the specs closely, checking mainly the memory and expansion capabilities, Wi-Fi and mobile 3G/4G availability, USB or HDMI ports, screen resolution, camera options (front and back) and battery life. Probably the best way to buy is to set a budget and get the best deal you can on the day, and then start enjoying your new tablet straight away.

Attracting the attention of early adopters are new ranges of smartwatches with LCD display which link wirelessly via Bluetooth to a smartphone. Models from Sony (the Smartwatch 2) and Samsung Galaxy Gear are already on sale and also look for the Apple-compatible Pebble and the eagerly anticipated Qualcomm Toq. An Apple smartwatch is also rumoured to be in the works and Google is said to be working on a similar device in conjunction with tech watchmaker WIMM Labs that it acquired in 2010. WIMM Labs' website alludes to an exclusivity agreement for its 'wearable technology', so my guess is that perhaps a Google Glass-compatible watch will be forthcoming.

Smartwatches can display texts, emails, messages, weather, Facebook updates and more besides, and as display technology continues to improve, a smartwatch will become more viable, but the day when it can replace a smartphone is some way away yet. Wearable technology including smartwatches will be all the rage this time next year.

Next month, I'll delve into an Android smartphone again, exploring the relatively new area of Near Field Communications (NFC), as seen on the latest phones and the Sony SmartWatch 2.

With another year tucked under our belts, it just remains for me to thank readers for your continued interest and support, and I wish you all a happy Christmas and prosperous New Year. You can email the author at **alan@epemag.demon.co.uk**.

Smartwatch 2 from Sony pairs with your Android phone, and has Bluetooth and NFC

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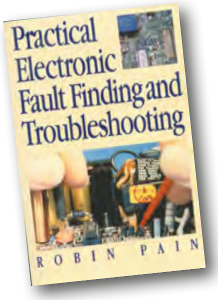

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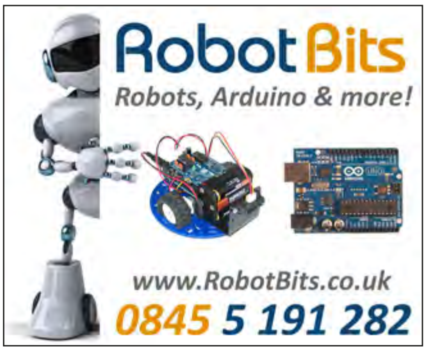

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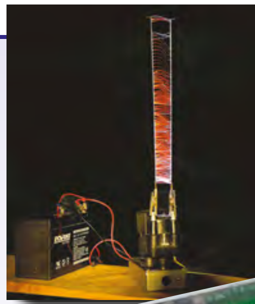
Next Month

Content may be subject to change



Jacob's Ladder

Remember those amazing spark generators in the original Frankenstein films? They are called 'Jacob's Ladders'. Our version looks and sounds spectacular and is quite easy to build. As the high voltage sparks climb up the vertical wires they snap and snarl, almost as a warning for you to keep your distance! It even smells convincing, as the purplish discharge generates ozone.

Mobile Phone Loud Ringer!

Ever missed an important call because you and your mobile were separated? You know the scene: you're working outside and the mobile is inside. Or maybe you've left it in the work vehicle while you're at a job. Either way, you pick up the phone and all you see is 'missed calls' – rats! Not any more though, here's a simple solution!

2.5GHz 12-digit frequency counter with add-on GPS accuracy – Part 2

Last month, we explained how our new 12-digit 2.5GHz counter works and gave the full circuit details. This month, we describe the construction and detail the simple set-up procedure.

Teach-In 2014: Raspberry Pi – Part 5

Next month in *Teach-In 2014*, our Pi Project will be covering temperature sensing, light level and resistance measurement using the Humble Pi analogue input board that we've described this month. *Python Quickstart* will provide you with an introduction to 'pickling' (a quick way of saving Python objects to a file for later use). We will also be looking at data logging and show you how you can remote control your Raspberry Pi from anywhere in the world.

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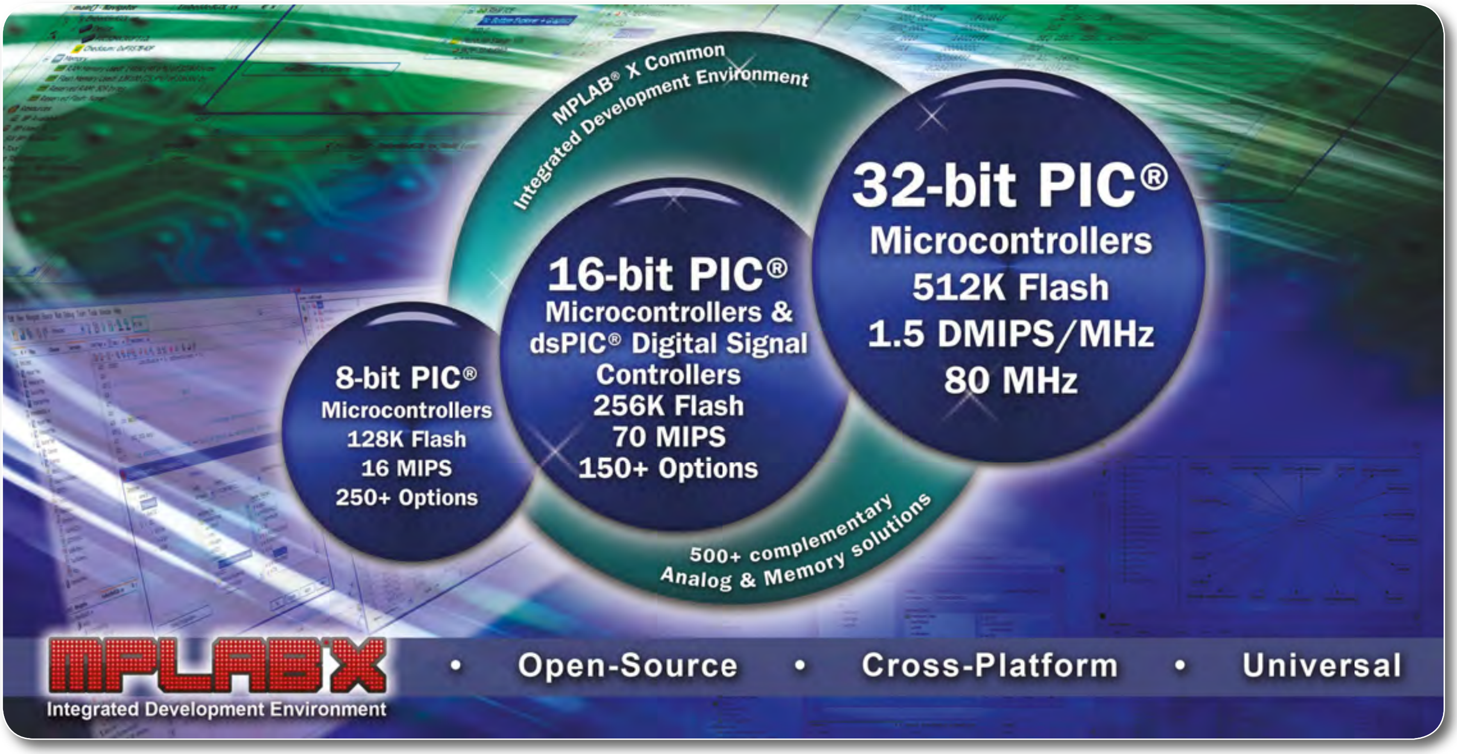

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