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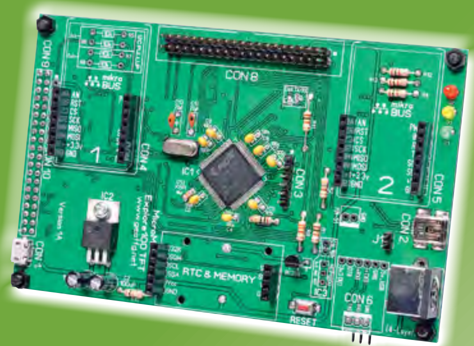

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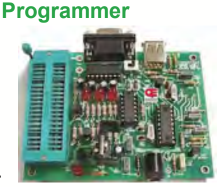

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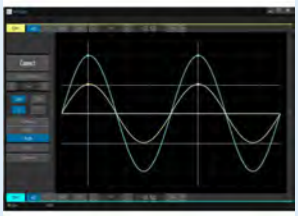

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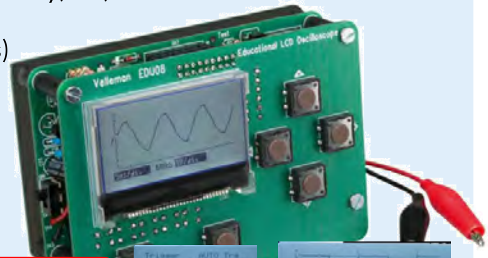

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05/17

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EVERYDAY PRACTICAL ELECTRONICS

Thank you Robert Penfold

Sadly, all good things come to an end, and Robert Penfold's columns have been very good for *EPE*. This issue's *Interface* is our last piece from Robert, who has been writing books and contributing articles to a wide range of UK magazines for nearly 50 years (his first article was an audio amplifier design for *Practical Wireless* in 1971).

Robert has been contributing to *EPE* for decades – I'm not sure exactly how many! – and for readers new to electronics, his wise words and down-to-earth approach in *Practically Speaking* and *Interface* were the perfect introduction to a fascinating, if sometimes complicated subject.

We will miss Robert, we thank him for his outstanding contribution to *EPE* and wish him a very long and comfortable retirement.

...and Ian Bell

Fortunately, *Circuit Surgery* columnist Ian Bell is not about to retire, and Alan Winstanley, his predecessor, tells me that this month Ian has been 'Mr CS' for 20 years. According to Alan, 'Mike Tooley first thought of *Circuit Surgery*, and after a few years he handed it over to me.

'Business was brisk, and readers started asking me to design bespoke circuits to order, when I already had carrier bags full of mail to take to the post office every month, on top of a busy day job.

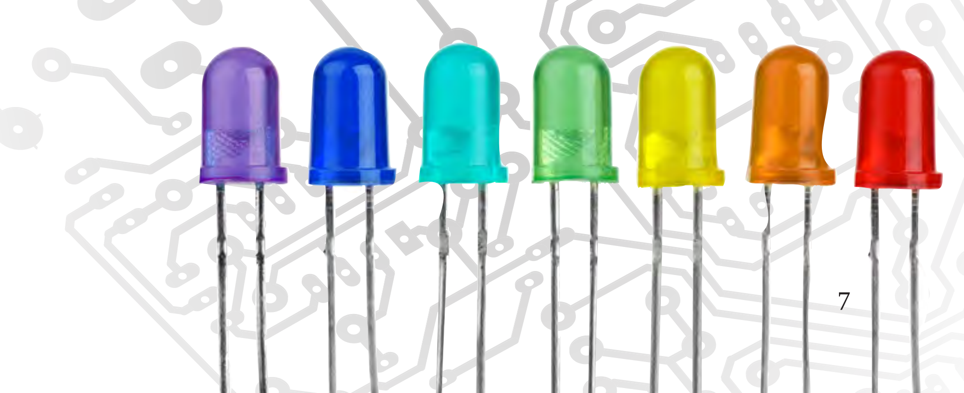
'In the late 1980s I was working at Hull Uni' on an industrial project, and at that time Ian was a post-graduate who'd been taken on as staff. I asked Ian if he wanted to help out, and eventually I handed the whole column over to him.

'Ian's first item in September 1997 was a *Bat Counter*, which used quadrature to detect and count the numbers of bats flying in and out of a roost, very clever.'

...and 20 years later Ian's still writing *Circuit Surgery*. That really is some achievement. The range and depth of Ian's articles is truly impressive; and so, from all of us here at *EPE*, 'Thank you' Ian, and we wish you a 'Happy 20th anniversary'.

Last, but certainly not least

Where would *EPE* be without Mike Tooley? Without *Teach-In* is the gloomy answer, which might just be what some of you were thinking would be the situation after this month's concluding article in *Teach-In 2017*. Well, the good news is that next month Mike dives straight into *Teach-In 2018*. It promises to be a great series that I know will be of interest to all who read and enjoy *EPE*.



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NEWS

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

The 4K juggernaut is on the move – report *by Barry Fox*

There's no escaping 4K TV, regardless of whether we want it or need it. China is 'absolutely dominating' the demand for 4K TV, and it's not just the affluent, industrial coastal areas. It's the rural villages as well. The Chinese are buying more 4K TVs than North America and Western Europe combined. This is largely due to the fact that Westerners still cling to an eight-year replacement cycle; we don't replace our TV's until they fail or become hopelessly out of date.

This was the message from Paul Gray, principal analyst, consumer devices at IHS Markit during this year's IHS Media and Technology Conference, held recently in London.

Nothing to watch

Talking about 'Moving from more pixels to compelling viewing', Paul Gray reminded that the shift to 4K and UHD is 'the other way round' from previous market shifts, such as HD, where there was plenty of content but very little hardware in homes.

'Now there is very little 4K content to play on our glorious new hardware', he said 'The market is being driven by fear of what competitors will do. So there is a "content gap".'

What do viewers actually want?

'And very little research has been done on what consumers actually think about 4K UHD, and what will make them buy sets,' Paul Gray noted. 'The only systematic research I have been able to find on what consumers, rather than geeky people like me, actually think, was done by the French consortium 4EVER. They found that resolution from more pixels has no 'wow factor' – because we don't have the eyes of Peregrine Falcons'

'But HDR was incredibly visible to viewers. They said that viewing quality went up and you get sparkle and that perception of realism. You feel you are looking through the screen; like a glass window. But you have to be careful when you keep cranking up the brightness. Some people get a feeling of visual discomfort. Let's call it the sunglasses effect. I do worry about commercials for soap powder where they turn it up to whiter than white and if you don't flinch then your wash is not white enough. So some kind of standardisation is necessary. We have gone through this in the past with audio – when a commercial came on the first thing you did was reach for the volume control.

'High Frame Rate (HFR) is quite noticeable. Consumers and viewers were able to see that. But it's quite genre specific. Hollywood content is shot at 24 frames per second and it doesn't make much sense to watch it at 120 frames per second. But for sports it's really fantastic. For example, with pole vaulting you can work out very quickly whether an athlete is going to get over that bar or not. Or when someone is reaching for a catch you can see which part of the hand will make it, or where the ball is going to hit the racquet.

'And "Deep Colour" is certainly noticeable with the right content, for instance wildlife. You add these things together and suddenly you get that feeling of enhanced realism and immersion.'

'On our timeline for Europe we see HFR as well as HDR and Deep Colour by around 2019'

Commenting on the important role being played by online services such as Amazon and Netflix in introducing these new technologies with new content, Paul Gray shared a theory. 'During the Hollywood writers' strike there were a lot of talented movie people with time on their hands, and they were snapped up. So TV started to look more like movies.'

8K issues

'The bad news is on 8K,'Gray added. 'This is where I spread the unhappiness, because 85-inches is the key size for 8K and even a 65-inch set needs to be viewed from one metre. For 8K you need a very large screen and TVs do not scale well over 65-inches. They are heavy and need big boxes for transport. And the costs begin to expand out of control. For 8K you would need to watch a 65-inch screen from a metre away.

'It's a 'numbers marketing' play. It's about numbers marketing in China and it's about panel production in China. In China '8' means happiness and wealth, but we don't expect 8K to factor in forecasts for the next five years or so. However, there are other things you can do with all those pixels and we may see the technology used for VR and 360 Video'.

Panel discussion

In a panel discussion that followed, Simon Gauntlett, director, imaging standards and technology, Dolby, 'slightly disagreed' with one of the

The 4K juggernaut is on the move – *continued*

4EVER findings, saying that Dolby believes 'colour and high dynamic range absolutely go hand in hand, and at Dolby we talk about "colour volume". The intensity of colours is an integral part'.

'One surprise that came out of World Mobile Congress,' Gauntlett (who was previously with the BBC and then the UK's Digital Television Group), continued, 'was that when HDR is used on a mobile device you would expect high power consumption and battery drain, but because HDR does not mean it is bright all the time, on a lot of content we were seeing a 15% power saving'.

Asked by a member or the audience whether there was a risk of 'messing up HDR' by having too many different systems, Simon Gauntlett acknowledged that there are 'acronyms all over the place and it's hard to cut through that.'

'Ultimately, if we as an industry want to make this work we have to make it simple for end users,' he said. 'There is work to be done. We would like to get to the stage where the proposition is clearer. I think that's why BT and Sky and others haven't launched HDR services yet, because they want to make that proposition clear.

'There is a limit to how much you can standardise or you would end up with all TVs looking exactly the same. We need enough standards to enable the market, but we also need the flexibility to differentiate'.

Later, Paul Gray gave me his own take on how things will in practice shake down. 'The chip makers will just build in all the different HDR options and formats for free and charge royalties on whichever ones the set makers enable. Royalty deals will be done between individual companies, some of which also own movie studios. So as long as no-one gets greedy and HDMI connections can recognise the different options, TV displays will just do their best with whatever HDR signal is sent to them.'

Virtual and augmented reality

The conference also looked at the emerging market for virtual and augmented reality, where one of the main selling points for headsets is that they are less likely to make users feel seasick than previous models!

Piers Harding-Rolls, IHS Markit director, games, acknowledged that despite 'a huge amount of hype, VR remains a niche market and will remain so for a good few years – even by 2021 VR is likely to account for less than 1% of the total CE market.' 'A lot of companies that have produced VR content will not have made any money' he added.

China is the most 'mature' VR market, he said, with 27,000 VR public venues by Q1 2017. Some are branded 'VR venues', some are value-added venues and some are pop-up centres where customers pay to experience VR.

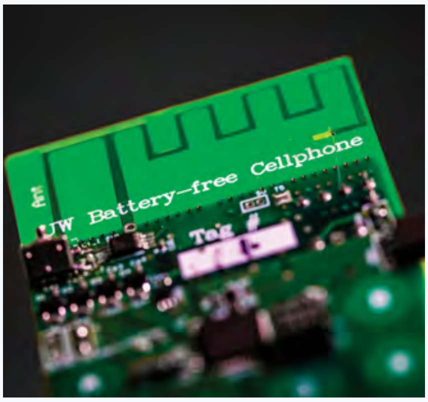
Battery-free phone harvests ambient power

University of Washington (UW) researchers have invented a mobile phone that requires no batteries. Instead, the phone harvests the few microwatts of power it requires from either ambient radio signals or light.

The UW team eliminated a power-hungry step in most modern mobile transmissions – converting analogue signals that convey sound into digital data that a phone can understand. This process consumes so much energy that it's been impossible to design a phone that can rely on ambient power sources.

Instead, the battery-free phone takes advantage of tiny vibrations in a phone's microphone or speaker that occur when a person is talking into a phone or listening to a call.

An antenna connected to those components converts the motion into changes in standard analogue radio signal emitted by a base station. This



process encodes speech patterns in reflected radio signals in a way that uses almost no power.

To transmit speech, the phone uses vibrations from the device's microphone to encode speech patterns in the reflected signals. To receive speech, it converts encoded radio signals into sound vibrations that that are picked up by the phone's speaker.

Tesla's huge battery

Last September, critical grid infrastructure was damaged by storms in the state of South Australia, causing a state-wide blackout and leaving 1.7 million residents without electricity. Further blackouts occurred in the heat of the Australian summer in early 2017. In response, the South Australian government has selected Tesla to provide a 100MW/129MWh Powerpack system.

Tesla Powerpack will charge using renewable energy from the Hornsdale wind farm and then deliver electricity during peak hours to help maintain the reliable operation of South Australia's electrical infrastructure.

Upon completion by December 2017, this system will be the largest lithium-ion battery storage project in the world and will provide enough power for more than 30,000 homes.

Au revoir ICE

Emmanuel Macron's new government has announced that France will end the sale of petrol and diesel cars by 2040. The announcement came a day after Volvo revealed it would only manufacture fully electric or hybrid cars after 2018.

The Norwegians are even more ambitious. Norway already has the highest penetration of electric cars in the world, and has now set a target of only permitting the sale of 100% electric or plug-in hybrid cars by 2025.

As the cost, capacity and charging rate of automotive batteries tumble, the French target is not just an eco pipe dream. In *The Guardian* newspaper, David Bailey, an influential automotive sector expert and professor of industry at Aston University, commented on the French announcement: 'The timescale involved here is sufficiently long term to be taken seriously. If enacted, it would send a very clear signal to manufacturers and consumers of the direction of travel and may accelerate a transition to electric cars.'

Development Tool of the Month!

PICkit™ 3 In-Circuit Debugger

Part Number
PG164130

Overview:

Microchip's PICkit™ 3 In-Circuit Debugger/Programmer uses in-circuit debugging logic incorporated into each chip with Flash memory to provide a low-cost hardware debugger and programmer, allowing debugging and programming of PIC® MCU and dsPIC® DSC microcontrollers using the powerful graphical user interface of the MPLAB® X Integrated Development Environment (IDE). The PICkit 3 is connected to the design engineer's PC using a full speed USB interface and can be connected to the target via a Microchip debug (RJ-11) connector.

Key Features:

- USB (Full speed 12 Mbits/s interface to host PC)
- Real-time execution
- Built-in over-voltage/short circuit monitor
- Supports low voltage to 2.0 volts (2.0v to 6.0v range)
- Diagnostic LEDs (power, busy, error)
- Read/write program and data memory of microcontroller
- Erase of program memory space with verification
- Freeze-peripherals at breakpoint

Order Your PICkit™ 3 In-Circuit Debugger Today at:

www.microchipdirect.com

Another potpourri

Mark Nelson

It's been a while since we had a 'pungent mixture of petals and spices', or a 'marvellous medley' (pick your preferred dictionary definition). Mark Nelson sniffs the air and reports on the weird, but useful, the strange and useless, and of course the retro but fun.

DON'T YOU HATE IT WHEN SPELL checkers auto-correct what you type? But when 'the computer says no', it means it. So what you read next remains what it says here (and not what I wrote).

Pea power

You'll probably think I'm taking the [redacted] but you can now use your own urine to power your mobile phone. Apologies if that leaves a bad taste in your mouth, but it's for real. Yes, dear reader, urine truly is the fuel of the moment, at least at the Bristol BioEnergy Centre, where MFCs (microbial fuel cells) fed with human urine are used to charge mobile phones. The microbial fuel cells work by using live microbes which feed on urine for their own growth and maintenance, giving approximately three hours of phone calls with one bathroom break (600ml).

The next step, assisted by funding from the Bill and Melinda Gates Foundation, is to develop MFCs into a mature sustainable energy technology with a direct application in everyday life that could change the way people perceive waste and energy. As well as generating electricity, the MFCs clean the urine 'fuel' to produce clean water as well as fertiliser, making this an attractive technology for assisting the more than 2.5 billion people in the world without access to safe sanitation.

Entirely natural

As the EuroNews website explains, an MFC is a system that drives electrical current by mimicking bacterial interactions found in nature. MFCs can work above ground, below ground, in hot or cold conditions and day or night. Prof Ioannis Ieropoulos, director of the Bristol BioEnergy Centre, enthuses: 'We have been putting the technology to the test, with things like recharging mobile phones; that's a very clear example of how it would work, but also integrating the microbial fuel cell in urinals, where we can collect urine and have the lights of the urinal powered directly by those microbial fuel cells. [This creates] a standalone, self-powered urinal which can go in refugee camps; it can go in slums, it can go in informal settlements, anywhere where there's no infrastructure, no national grid.'

It would never happen to me

Do you have a smartphone? And have you installed anti-virus software? No? Well, think on this. According to UK comms regulator OFCOM, the smartphone has now overtaken laptops as the most popular way of getting online. At the same time, a study conducted by market research firm Opinium on behalf of Virgin Media has revealed that only a third of consumers have installed anti-virus software on their mobile phone, despite 94% accepting the importance of data security. Although almost 24 million Britons use their mobile to shop, and nearly 23 million use Internet banking services, only 34% protect their phone with software. Even among those who consider themselves to take data security seriously, seven per cent admit to using public Wi-Fi to send bank details.

Bizarre? Yes. One-fifth of Britons believe that nobody will ever steal information from their phone, while almost one in three believe that security applications are not necessary on mobile phones. Some 43% of users save passwords in the Notes app, 28% 'conceal' them as the names of the organisation in their contacts list and another 26% save them under celebrity names. Furthermore, 43% do not use a numerical passcode to secure access to their phones. When you can get good antivirus software for mobiles for nothing, why go online unprotected? Just make a Google search for 'free smartphone antivirus' and do it now!

Do you suffer from too much EMF?

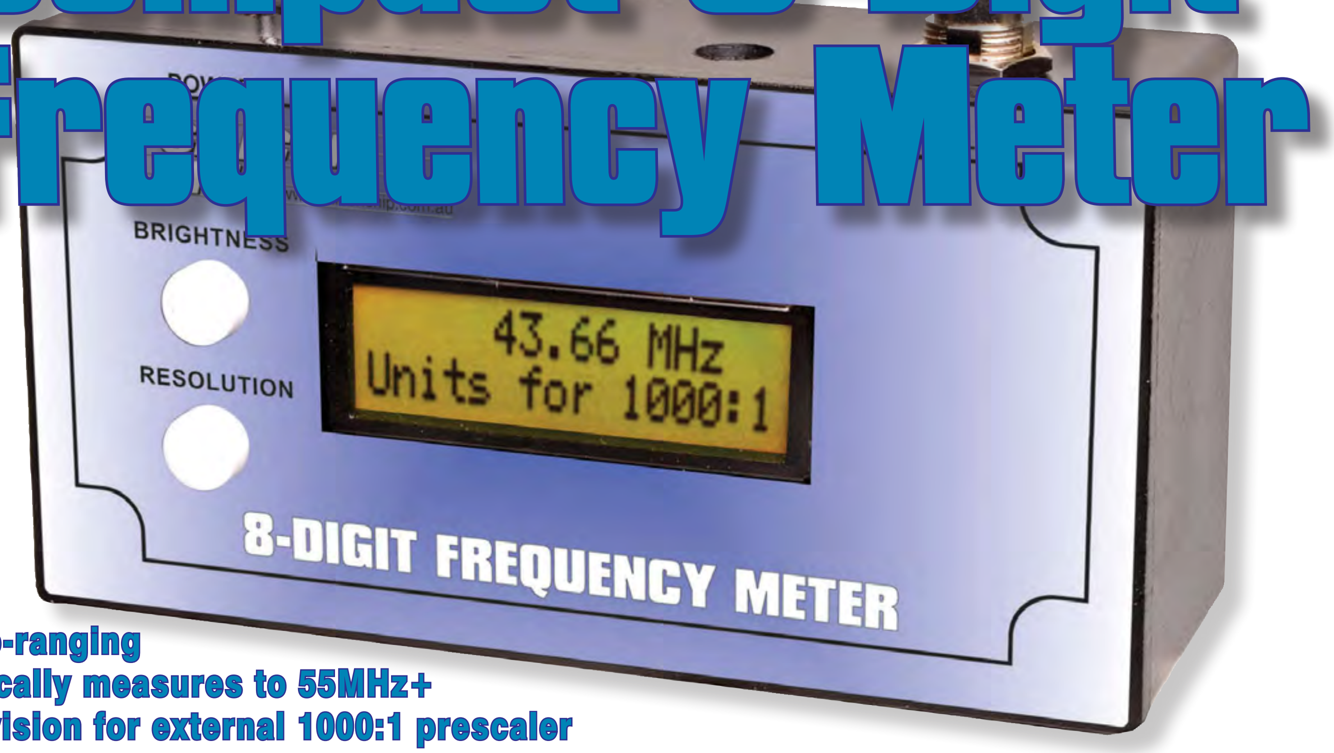
I leave it to you evaluate the following. 'Are you looking for EMF solutions? Invest in your health by purchasing a Tesla Gold Cube Blushield, which is suitable for homes with high EMF, homes within sight of a mobile phone antenna, homes with smart meters, high-rise apartments, all workplaces and schools and hospitals. Reassuringly, it is a subtle energy device, mimicking nature but with much more power. The body resonates with the fields from the Blushield device rather than from the many different artificial and harmful EMFs that now surround us constantly. The coherent field the Blushield emits is designed using natural laws and principles.'

If, like me, you cannot wait to get your hands on this miraculous device, put down this magazine and scoot off to: **http://emf-protection.us/blushield-whole-house-plug-in/** where you can get whole-house protection. Even though it uses less power than a 5W LED lamp bulb, it reduces fatigue and EMF symptoms, promotes emotional stability and helps maintain a level of alertness. Even better, it is compatible with all game types and is recommended for computer users. It plugs into any mains outlet and costs *only* $349.Outside the US you may need a plug adapter, but the device itself works from 100V to 240V, making it compatible with voltages worldwide!

Completely useless – his words, not mine

Actually, the following is not useless at all, unlike the previous item. If you have nostalgic memories of Ceefax and the seemingly interminable wait for pages to rotate and refresh, you can now relive the ultra-low-res masochism. Some incredibly clever chaps have recreated the teletext service online, and if you haven't seen it already, it's well worth a look (and listen, because the blocky graphics are accompanied by music of the kind that used to accompany the TV test card). Catch the latest news and weather at: **www.pagesfromceefax.net** or discover much more by googling the search term 'Teefax'. Peter Kwan, who is leading the project, told *The Times*: 'It's like the modern-day equivalent of restoring steam engines. It's completely useless but it keeps us occupied.' The system runs from a Raspberry Pi server and team members have even managed to decode and resurrect ancient teletext pages trapped within old VHS tape recordings.

Compact 8-Digit Frequency Meter



Auto-ranging
Typically measures to 55MHz+
Provision for external 1000:1 prescaler

Fully auto-ranging, this compact *8-Digit Frequency Meter* is ideal for hobbyists and technicians, for general servicing and for laboratory use. It will even cover the 6m amateur band. Accurate calibration can be done without any specialised equipment.

Frequency meters are used in virtually all areas of electronics and are invaluable for testing, servicing and diagnostics. Among other tasks, they are ideal for checking the frequency of oscillators, counters, transmitters and signal generators.

It is true that frequency measurements are available on many multimeters these days. However, they do not have high sensitivity nor the necessary number of digits for decent resolution at frequencies above 1kHz, and most do not measure in the MHz region.

This new design is an upgrade over older designs that used the old ECL (emitter-coupled-logic) MC10116 differential amplifier in the front end. Instead, we are using three 600MHz high-speed op amps to do the same job (to provide increased sensitivity).

In other respects, this version is quite similar to previous designs in that it is auto-ranging and displays the frequency in Hz, kHz or MHz with 8-digit resolution on a 2-line 16-character LCD. It automatically selects the correct range and decimal place for any frequency reading.

There is provision for use with an external prescaler. If you want to measure frequencies above 55MHz you will need an external prescaler that divides the input frequency so that it is less than 50MHz. (We described a *UHF 1000:1 Prescaler* in the January 2009 issue of *EPE*.) When using a 1000:1 prescaler, the LCD shows GHz instead of MHz, MHz instead of kHz and kHz instead of Hz. However, do note that this prescaler will not let you read frequencies to 55GHz+ since it has its own limitation of about 2.8GHz.

By JOHN CLARKE

We have included a useful feature for radio control modellers, allowing the *Frequency Meter* to display the reading in multiples of 10kHz steps for frequencies above 36MHz, ie, the resolution is set to 10kHz. When a standard frequency meter is used to measure crystal-locked PPM (pulse position modulation) radio control transmitters, the modulation will result in incorrect readings. Setting the resolution to 10kHz eliminates these errors.

The design is easy to build, with all parts mounted on one PCB, so there is no fiddly wiring.

There are just five ICs, one is the PIC microcontroller plus four surface-mount ICs that are quite straightforward to solder to the PCB. Apart from the ICs, there's an LCD module, three transistors, a 3-terminal low-dropout regulator and a few resistors and capacitors.

Frequency limit

Typical examples of this *Frequency Meter* should be OK for signals up to 55MHz or more. In fact, our prototype meter is good for 60MHz but with falling sensitivity above 50MHz. See the graph of Fig.1.

Calibration

Calibration of this *Frequency Meter* does not require specialised equipment. We have devised a calibration procedure that just requires the accurate clock in a computer (synchronised via a network time server), mobile phone or any other clock or timepiece that has proven accuracy over time. The details are in a panel at the end of this article.

Resolution modes

Three resolution modes are provided: low-resolution mode with fast updates (suitable for most measurements), a high-resolution mode for greater precision when required and the above-mentioned 10kHz rounding up feature.

In low-resolution mode the resolution is 1Hz for frequencies from 1-999Hz and 10Hz for frequencies above this. The corresponding display update times are one second from 1-999Hz, and 200ms from 1kHz-50MHz.

High-resolution mode provides 0.1Hz resolution for readings up to 100Hz, and 1Hz resolution for frequencies from 100Hz-16.77721MHz. Above this, the resolution reverts to 10Hz. The display update time is one second but is somewhat longer for frequencies below 10Hz.

0.1Hz resolution makes the unit ideal for testing loudspeakers, where the resonant frequency needs to be accurately measured.

Accuracy is 20ppm (0.002%) without calibration, but it can be trimmed for even better precision.

The three resolution modes are selected by pressing the Resolution switch. When pressed, the meter displays 'Low Resolution', 'High Resolution' or 'Rounding @>36MHz' to indicate which mode is currently selected. When the switch is released, the high or low-resolution indication is not displayed. In the rounding mode, the 10kHz rounding-up only occurs above 36MHz. Below this, the standard 10Hz resolution frequency reading is displayed. Whenever the display is showing frequency rounding, the second line of the display indicates this with '10kHz Rounding'.

The selected resolution is stored in Flash memory and is automatically restored if the *Frequency Meter* is switched off and on again. In low-resolution mode, the display will show 0Hz if the frequency is below 1Hz. By contrast, in the high-resolution mode, the display will initially show an 'Await Signal' indication if there is no signal. If there is no signal for more than 16.6s, the display will then show 'No Signal'

The 0.1Hz resolution mode for frequencies below 100Hz operates in a different manner to those measurements made at 1Hz and 10Hz resolution. Obtaining 0.1Hz resolution in a conventional *Frequency Meter* normally means measuring the test frequency over a 10s period. And that means that the update time is slightly longer than 10s. This is too long time to wait if you are adjusting a signal generator to a precise frequency.

In this *Frequency Meter*, the display update period is one second. So for normal audio frequencies, the display will update at one-second intervals. We shall explain just how this is achieved shortly.

Features

- Compact size (130 x 67 x 44mm)
- 8-digit reading (LCD)
- Automatic Hz, kHz or MHz units
- kHz, MHz and GHz units for 1000:1 external prescaler
- Three resolution modes, including 10kHz rounding up
- 1MΩ input impedance
- 0.1Hz resolution up to 100Hz
- 1Hz resolution up to 16.777216MHz
- 10Hz resolution above 16.777216MHz
- Display back-light with dimming
- DC plugpack or USB supply
- Calibration without requiring a precision frequency reference

Prescaler selection

When selected, the words 'Low R Prescaler' or 'High R Prescaler' are shown whenever the Resolution button is held down and 'Units for 1000:1' are shown on the second line of the LCD once the switch is released. 10kHz rounding is not available when using the prescaler feature.

Block diagrams

Fig.2a shows the general circuit arrangement of the *Frequency Meter*. It's based mainly on the microcontroller, IC5. In operation, the input signal is buffered and amplified by Q1 and IC1-IC3, and passed through gating and clocking gates (IC4) before being applied to input RA4 of IC5.

The clocking gate (IC4a) allows pulses from RA2 to toggle input RA4, to inject extra pulses while the gating stage (IC4b) is switched off. The reason that this is necessary is explained below. Note that since IC4a and IC4b have Schmitt-trigger inputs, they also serve to square up the waveform.

The RA4 input of IC5 drives an internal divide-by-256 prescaler and its output then clocks timer TMR0 which counts up to 256 before clocking 8-bit Register A, and which also counts up to 256 before returning to zero.

Combining all three counters (the prescaler, TMR0 and register A) allows the circuit to count up to 24 bits, or a total of 16,777,216. By counting over a one-second period, the counters can make readings up to 16.777216MHz. However, if the frequency is counted over a 100ms period, the maximum frequency count amounts to just over 167.77721MHz.

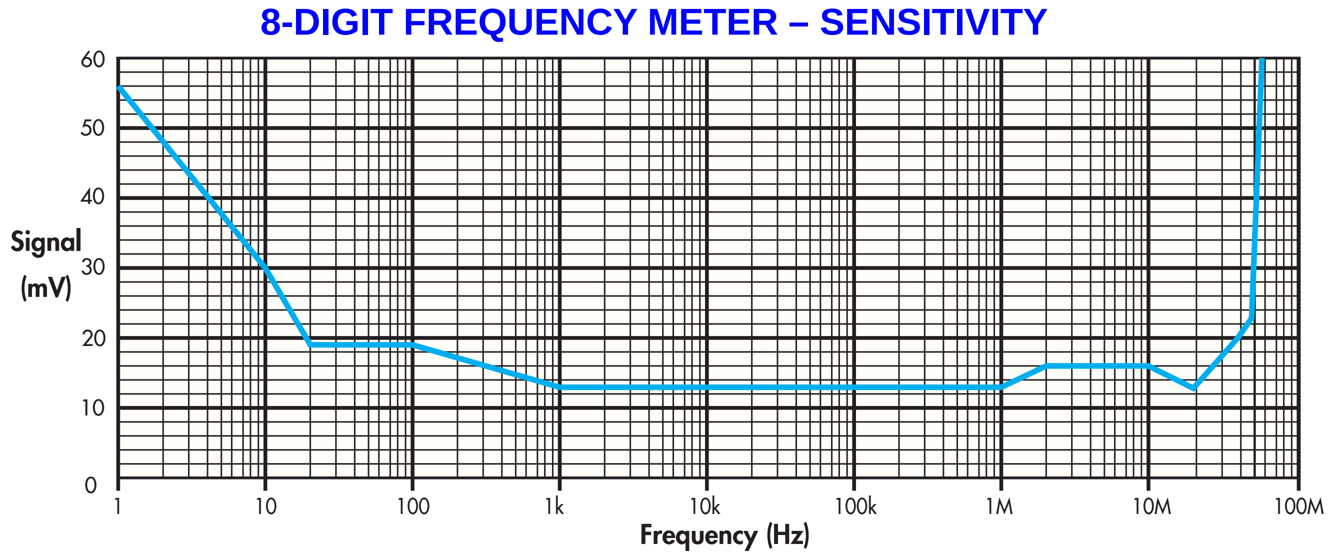


Fig.1: here's the performance of the prototype. While sensitivity is reduced above ~55MHz, we found it usable to 60MHz.

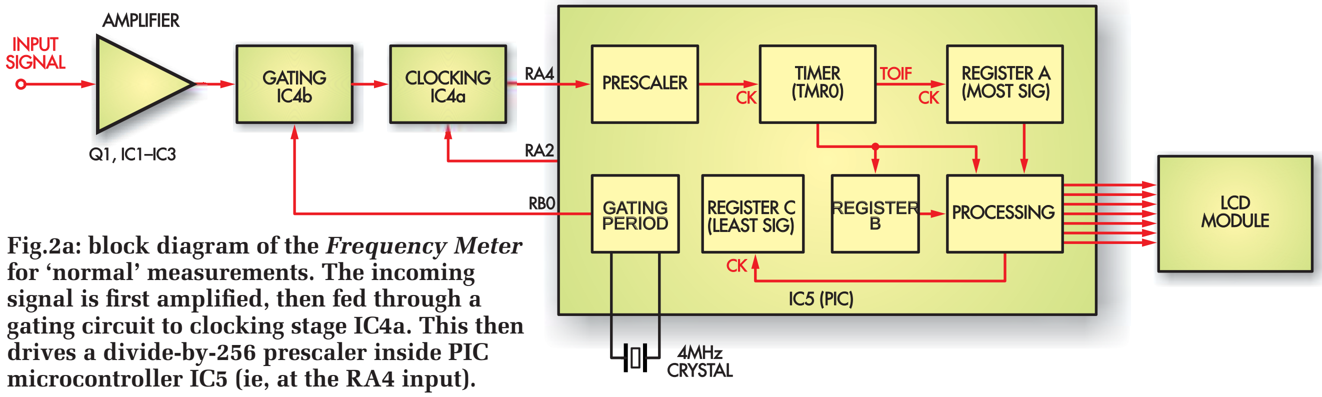


Fig.2a: block diagram of the *Frequency Meter* for 'normal' measurements. The incoming signal is first amplified, then fed through a gating circuit to clocking stage IC4a. This then drives a divide-by-256 prescaler inside PIC microcontroller IC5 (ie, at the RA4 input).

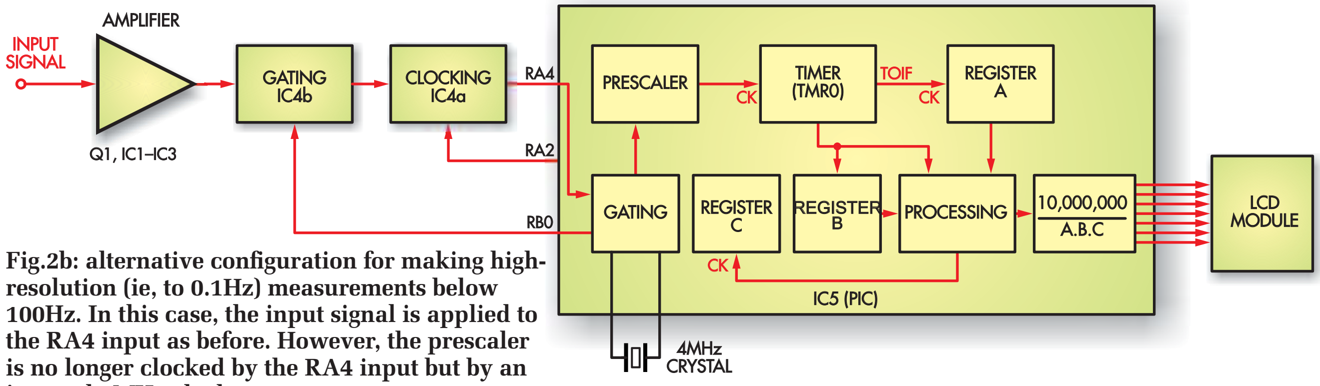


Fig.2b: alternative configuration for making high-resolution (ie, to 0.1Hz) measurements below 100Hz. In this case, the input signal is applied to the RA4 input as before. However, the prescaler is no longer clocked by the RA4 input but by an internal 1MHz clock.

This limit is somewhat restricted by the frequency limit of the internal prescaler of around 55-60MHz.

The input signal from IC3 is fed to gating stage IC4b and drives clocking-stage IC4a which is controlled by IC5's RA2 output. Normally, IC4a and IC4b allow the signal to pass through to the prescaler at IC5's RA4 input. Depending on how long IC5's RB0 output is high, the signal will pass for either a 100ms period or a one-second period.

During the selected period, the signal frequency is counted using the prescaler, timer TMR0 and register A, as above. Initially, the prescaler, the timer and register A are all cleared to zero and the RB0 output is then set high, to allow the input signal to pass through to the prescaler for the gating period.

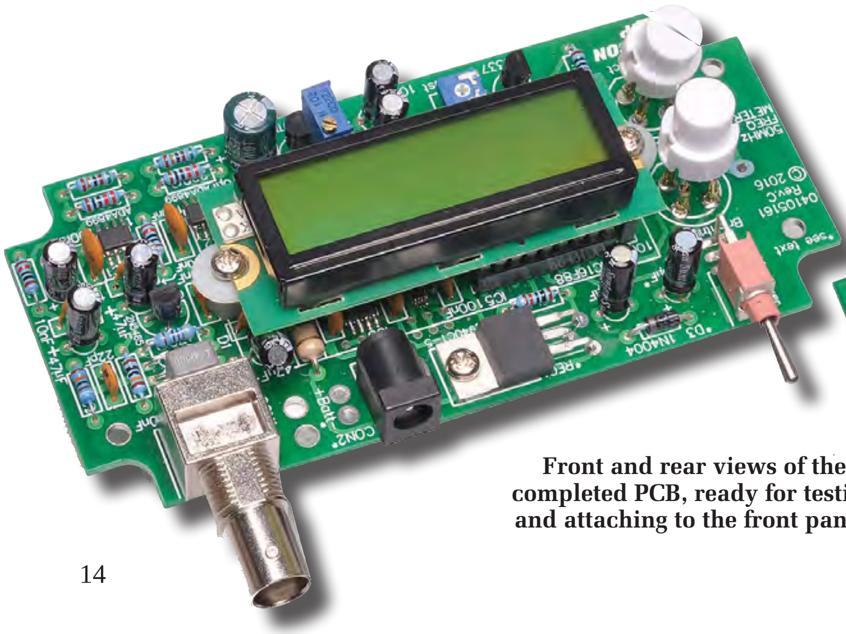
During this period, the prescaler counts the incoming signal applied to RA4. Each time its count overflows from 255 to 0, it automatically clocks timer TMR0 by one count. Similarly, whenever the timer output overflows from 255 to 0, it sets a Timer Overflow Interrupt Flag (TOIF) which in turn clocks Register A. At the end of the gating period, IC5's RB0 output is brought low, stopping any further signal from passing through to the prescaler. The value of the count in TMR0 is now transferred to Register B.

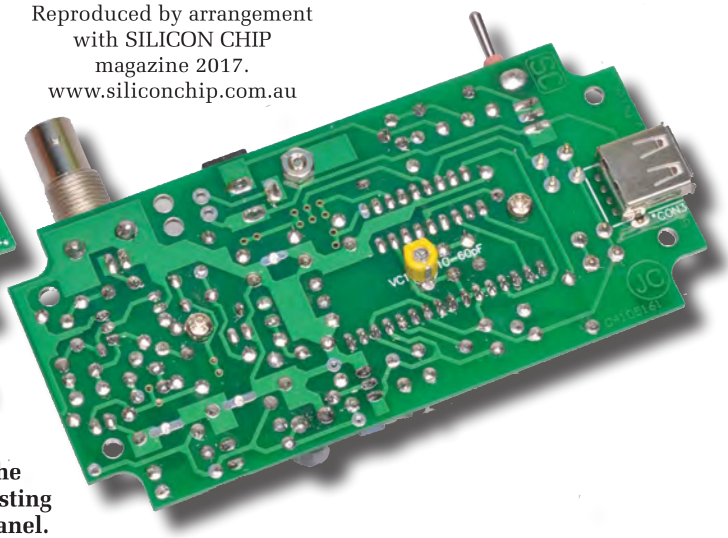
The count in the prescaler cannot be directly read by IC5 and so we need to derive the value. This is done by first presetting register C with a count of 255 and the RA2 output is taken low to clock the prescaler. TMR0 is checked to see if its count has changed. If TMR0 hasn't changed, the prescaler is clocked again with RA2.

During this process, register C is decreased by one each time the prescaler is clocked. The process continues, with RA2 clocking the prescaler until timer TMR0 changes by one count. When this happens, it indicates that the prescaler has reached its maximum count. The value in Register C will now be the value that was in the prescaler at the end of the counting period.

The processing section within IC5 then reads the values in registers A, B and C, and this is the frequency reading of the incoming signal.

Based on this information, it then decides where to place the decimal point and what units to display on the LCD. If





Front and rear views of the completed PCB, ready for testing and attaching to the front panel.

the input signal frequency is greater than 16MHz and the gating period is one second, register A will initially have overflowed. In this case, the gating period is automatically changed to 100ms and the frequency is re-read.

Alternative configuration

If the high-resolution mode is selected and the frequency is below 100Hz, IC5 changes its configuration to that shown in Fig.2b.

The input signal is applied to the RA4 input as before, but the prescaler is no longer clocked by the RA4 input but by an internal 1MHz clock instead. RA2 and RB0 are both taken high to allow the signal to pass through to RA4. The RA4 input is now monitored for a change in state from low to high, indicating a signal at the input.

When this happens, the prescaler, TMR0 and Register A are cleared and counting the 1MHz internal clock signal begins. The overflow outputs from the prescaler and timer TMR0 are carried to register A as before.

Counting continues until the input signal goes low and then high again. That's a full cycle of the incoming waveform. At this point counting stops.

If the counting causes register A to overflow, then the display will show 'No Signal' (this will happen after 16.7s if the signal does not go low and high again). Conversely, if the counting is within range, the prescaler value is determined by clocking IC4a using the RA2 output as before.

The values in Register A, B and C are now used to calculate the frequency. So if the input frequency is 1Hz, it has a one-second period and so the value in the A, B and C registers will contain a value of 1,000,000. That's because the prescaler is clocked at 1MHz over the one-second period. Similarly, the count will be 100,000 for a 10Hz signal and 10,000 for a 100Hz input signal.

Finally, the value in the registers is divided into 10,000,000 and the decimal point placed immediately before the last digit. This gives a readout in Hz with 0.1Hz resolution on the LCD.

This technique cannot be used for measuring very high frequencies because the value in the counter becomes smaller as the frequency increases and so we begin to lose accuracy.

For example, at 500Hz, the counted value would be 2000 and at 500.1Hz it would be 1999. The result of the division of 1999 into 10,000,000 would be 500.2 instead of the 500.1 required. The 0.1Hz resolution has therefore been restricted to readings below 100Hz to ensure 0.1Hz accuracy.

Circuit details

Now refer to Fig.3 for the full circuit details. The input signal is AC-coupled from CON1, the BNC connector, via a 470nF capacitor to block any DC component. This signal is then clipped to about 0.6V peak-to-peak by diodes D1 and D2, and any shunt current is limited by the 100kΩ series resistor.

The 22pF capacitor across the 100kΩ resistor compensates for the capacitive loading of the diodes.

From there, the signal is fed to the gate of Q1, a 2N5485 JFET. This provides a high input impedance. Q1 is self-biased using a 910kΩ resistor from its gate to ground and its 470Ω source resistor. The output at its source is about 70% of the signal level at the gate (ie, the normal signal loss in a source follower configuration).

The signal is then AC-coupled to pin 3 of amplifier stage IC1 via a 47µF electrolytic capacitor and a parallel 10nF capacitor. The 47µF capacitor is large enough to allow for a low-frequency response to less than 1Hz. However, this capacitor loses its effectiveness at higher

PARTS LIST
8-DIGIT FREQUENCY METER

1 double-sided PCB, available from the *EPE PCB Service*, coded 04105161, 121 × 58.5mm
1 UB3 plastic case, 130 × 68 × 44mm
1 pre-drilled front panel 130 × 68mm
1 front panel label 130 × 68mm or screen-printed panel
1 LCD module
1 PCB-mount SPDT toggle switch (S1)
2 momentary contact pushbutton switches (S2,S3)
1 PCB mount BNC socket (CON1)
1 low-drift 20ppm 4MHz crystal HC49S (X1)
1 18-pin DIL IC socket (for IC5)
1 16-pin DIL IC socket, cut into two 8-pin SIL IC sockets (for the LCD)
1 16-way SIL pin header (to connect to the LCD)
2 M3 tapped spacers × 9mm (LCD mounting)
4 M3 tapped spacers × 6.3mm (PCB to lid)
4 M3 tapped spacers × 12mm (PCB to lid)
2 M3 nylon washers (LCD mounting)
4 M3 × 6mm screws (LCD mounting)
4 M3 × 12mm screws (PCB to lid)
4 M3 × 10mm countersunk screws (PCB to lid)
10 PC stakes (for S2,S3,TP1 and GND)
8 PC stake wiring sockets
4 No.4 × 15mm self tapping screws (when using acrylic front panel)

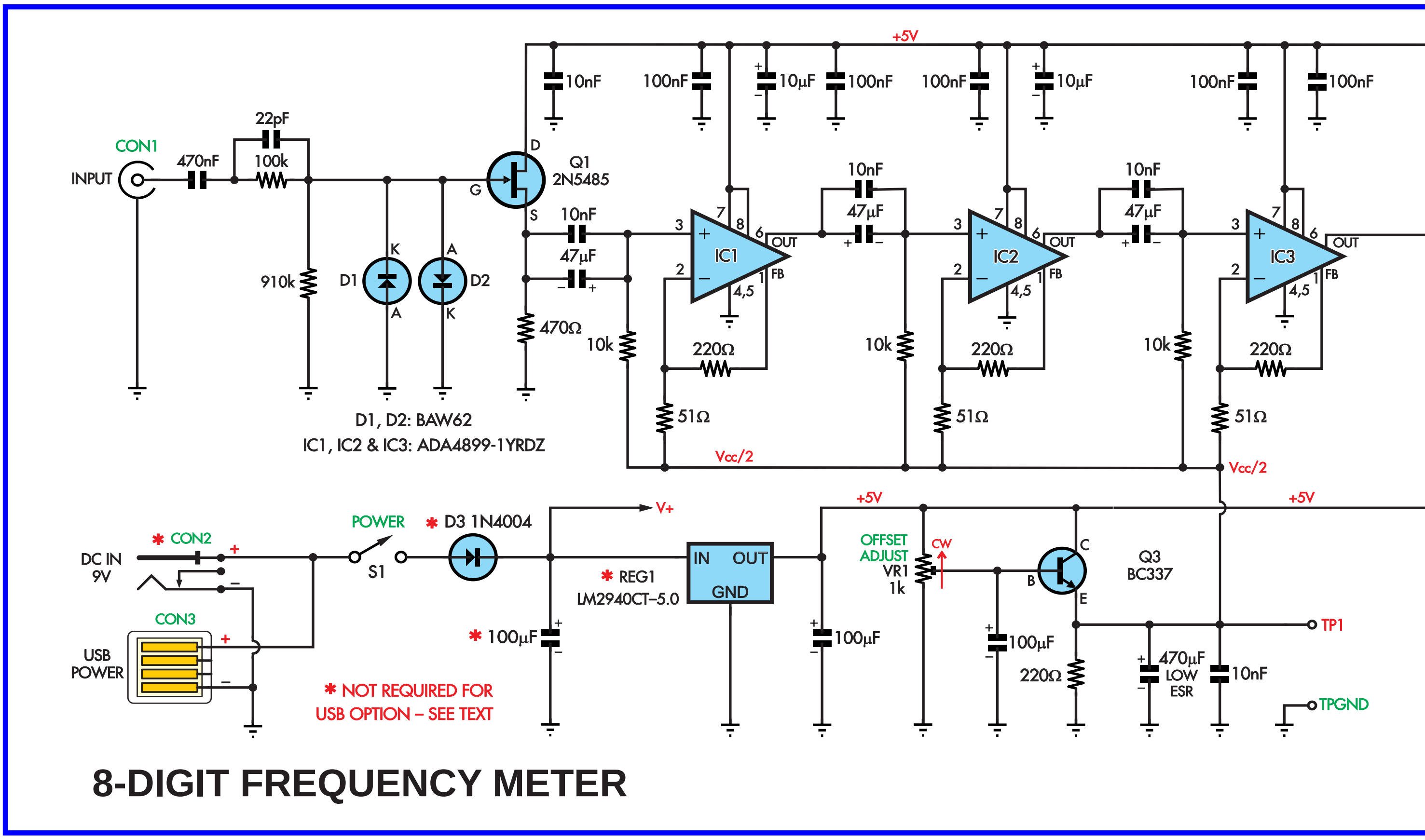
Semiconductors
3 ADA4899-1YRDZ high-speed op amps (IC1-IC3)
1 SN74LVC2G132DCUT dual 2-input Schmitt NAND gates (IC4; element14 1236369)
1 PIC16F88-I/P microcontroller programmed with 0410516A.hex (IC5)
1 2N5485 N-channel VHF JFET (Q1)
2 BC337 NPN transistors (Q2,Q3)
2 BAW62 diodes (D1,D2)

Capacitors
1 470µF 10V low ESR PC electrolytic
3 100µF 16V PC electrolytic
3 47µF 16V PC electrolytic
2 10µF 16V PC electrolytic
1 470nF MKT polyester
1 100nF ceramic or MKT polyester
6 100nF ceramic 5 10nF ceramic
1 33pF NP0 ceramic 1 22pF NP0 ceramic
1 10-60pF trimmer capacitor (VC1)

Resistors (1%, 0.25W)
1 910kΩ 1 100kΩ 4 10kΩ 1 1kΩ
1 470Ω 4 220Ω 3 51Ω
1 1kΩ multi-turn top adjust trimpot (VR1)
1 10kΩ miniature horizontal mount trimpot (VR2)

Power supply options 9V DC plugpack input
1 PC mount DC socket with 2.1 or 2.5mm connector pin (CON2)
1 M3 × 6mm screw and M3 nut for REG1
1 LM2940CT-5 low dropout regulator (REG1)
1 1N4004 1A diode (D3)
1 100µF 16V PC electrolytic capacitor
1 390Ω ½W 5% resistor

USB supply
1 PCB-mount USB socket
1 100Ω ½W 5% resistor



frequencies due to its high internal inductance and the signal is coupled via the 10nF capacitor instead.

High frequency amplifiers

IC1, IC2 and IC3 are AD4899 high-frequency op amps with a unity gain bandwidth (-3dB) of 600MHz. Each is connected as a non-inverting amplifier with a gain of 5.3, using 220Ω and 51Ω feedback resistors.

The op amps have two outputs: one labelled FB (feedback) at pin 1 and the other at pin 6. Both provide the same connection inside the op amp package, with the FB pin included to allow an optimum PCB layout for the feedback resistor.

The three op amps are cascaded with AC-coupling via parallel 47μF and 10nF capacitors that terminate to a 10kΩ input load resistor.

Each of the 10kΩ resistors and the 51Ω feedback resistor connect to a Vcc/2 supply that biases each of the op amp outputs to around half the supply voltage.

Half-supply rail

This half supply is required for two reasons: first, to have the op amp outputs operate within their specified output range; and second, so that IC3's output level will match the input voltage levels required for the following Schmitt-trigger NAND gate, IC4b.

An adjustment is provided with the half-supply circuitry to set the output voltage level to match best with IC4b's high and low trigger thresholds.

The half supply is made up using trimpot VR1 and transistor Q3, which is connected as an emitter follower.

The voltage at VR1's wiper is used to bias transistor Q3 and the emitter is about 0.7V lower than its base, as set by VR1. Q3's emitter is bypassed with a 470μF and 10nF capacitor to reduce the voltage ripple on the half supply, due to AC currents through the low-value feedback resistors used with the op amps.

Signal gating

Gating and clocking of the signal from IC3 is performed by IC4, which is a dual 2-input Schmitt NAND gate package. IC4b inverts the signal applied to its pin 5 input whenever its pin 6 is held at +5V by IC5's RB0 output. When RB0 is at 0V, IC4b's pin 3 output remains high and the input signal is blocked. Essentially, the signal is allowed through to IC4a at pin 2 when RB0 is high and is blocked when RB0 is low.

IC4a's pin 1 input is normally held high by IC5's RA2 output, so that the signal from IC4b is again inverted at pin 7.

When RB0 is brought low, pin 3 of IC4b remains high and so pin 2 of IC4a is also high. RA2 can clock the RA4 input using IC4a, because when RA2 is taken high and low, this produces a low and high signal at RA4.

Driving the LCD

Microcontroller IC5's RA0 and RA1 outputs drive the control inputs (Enable and Register select) of the LCD.

The data lines of the LCD module (DB4, DB5, DB6 and DB7) are driven by the RB4, RB5, RB6 and RB7 outputs of IC5. VR2 is included to adjust the contrast of the display.

Back-lighting

The back-lighting on the *Frequency Meter's* LCD module is provided by two LEDs in series that connect between pin 15 and 16 of the module. They have an overall voltage drop of about 3.6V. A 390Ω resistor from the raw 9V supply connects to the back-lighting LED anode and a transistor (Q2) switches the cathode side. This

The view of the assembled PCB mounted on the front panel, from the input socket/DC supply/power switch side.

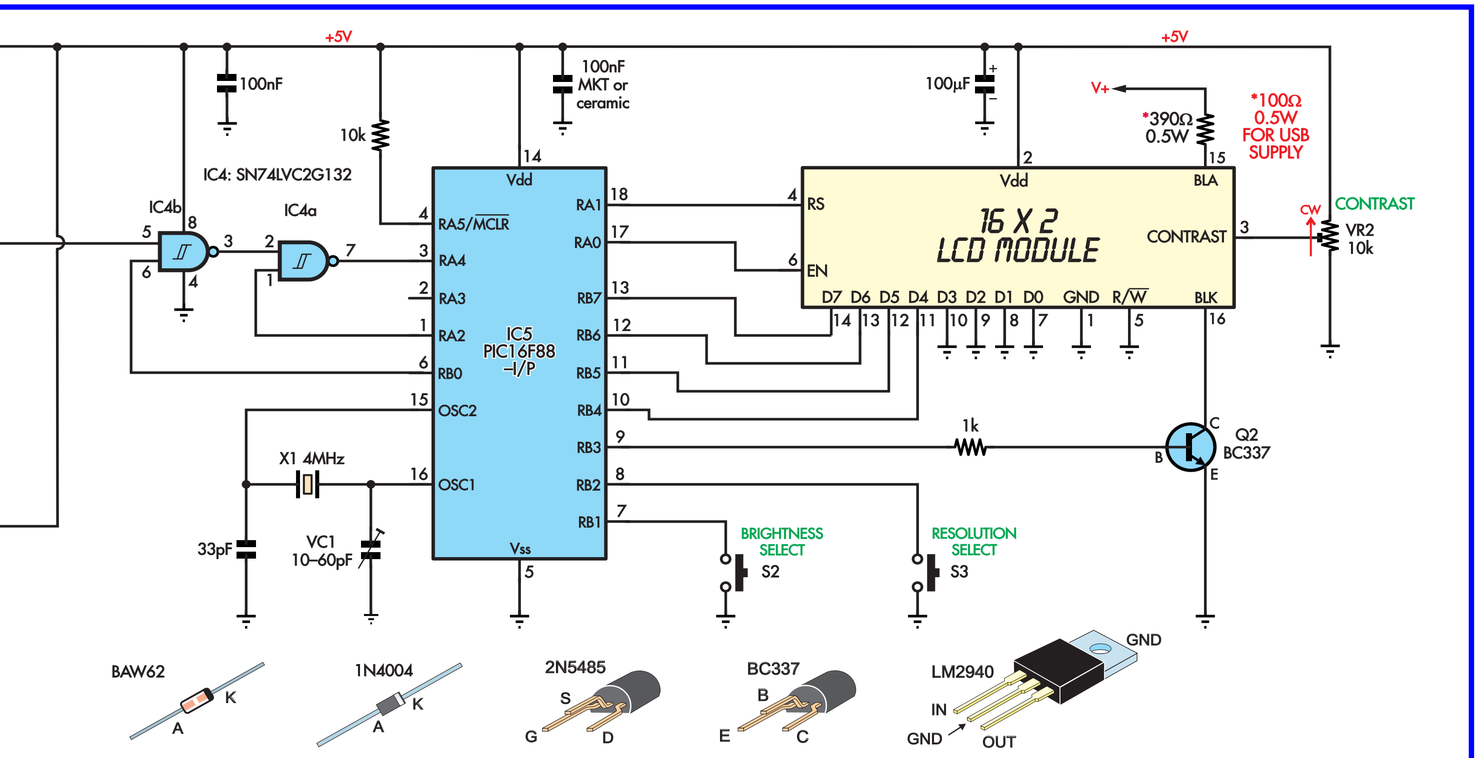


Fig.3: the input signal is fed to a JFET which provides a high input impedance (1MΩ) and then it is amplified by three cascaded wide-bandwidth op amps. The signal is then gated and 'squared up' by the NAND Schmitt triggers. The PIC microprocessor then does all the counting and housekeeping and drives the LCD module.

sets the current to about 20mA when Q2 is switched on.

If the circuit is to be powered by a USB (5V) supply, this resistor should be reduced to 100Ω 0.5W, to achieve a similar back-lighting current.

Transistor Q2 is driven via the PWM (pulse-width modulation) output from pin 9 of IC5. This allows the brightness to be varied from full brightness to no back-light. Switch S2 is held down to set the brightness of the back-lighting. When the switch is not pressed, input RB1 is pulled high via internal pull-up current in IC5. Similarly, S3 is used to select the resolution and it too has an internal pull-up.

A 4MHz crystal connected between pins 15 and 16 of IC5 provides the clock signals for the *Frequency Meter*. The recommended crystal has low drift, but a standard 4MHz crystal could be used if accuracy is not critical. The capacitors at pins 15 and 16 provide the necessary loading for the crystal, while variable capacitor VC1 allows the clock frequency to be adjusted slightly to provide calibration.

Power supply

Power for the circuit can be from a 9V DC plugpack or a 5V USB supply. Diode D3 protects the circuit against reverse polarity when using a plugpack supply, while the low-dropout LM2940CT-5.0 regulator REG1 provides a +5V supply rail to power the circuit. The 9V variant is shown in the component overlay diagram of Fig.4a.

If you are using the USB supply option, REG1, D3, CON2 and one of the 100µF capacitors are not used. These are replaced by links, where appropriate, as shown in the component overlay of Fig.4b.

Construction

All components for the *Frequency Meter* (except the LCD module) are mounted on a double-sided PCB, available from the *EPE PCB Service*, coded 04105161 and measuring 121 × 58.5mm. The PCB fits in a standard plastic Jiffy box measuring 130 × 68 × 44mm.

A precision pre-cut Acrylic front panel is available from the *EPE PCB Service* which includes the holes required for the front panel switches and LCD module.

Alternatively, you *could* use the lid supplied with the Jiffy box and cut your own holes, but this is at best a little messy.

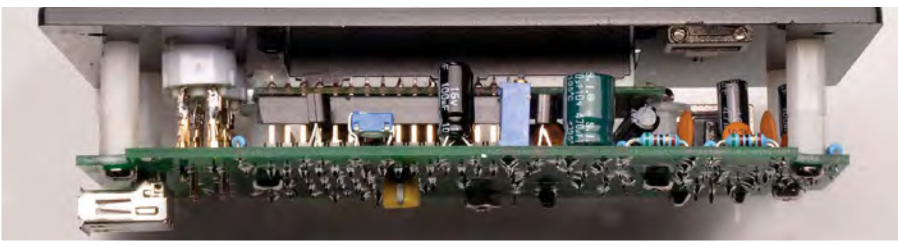
If you intend running this meter from a USB supply (either a 5V plugpack or a computer USB socket), a USB socket is installed underneath the PCB, as shown in our photos (instead of the 9V supply components, as mentioned above).

However, if you intend purchasing the PCB from *EPE*, note that after our initial stock of PCBs are sold, the replacement stock will come with pads for a micro/mini USB socket so that standard USB phone charging leads (you've probably got a few!) can be used to power the *Frequency Meter*.

Surface-mount ICs

Begin by installing the four surface mount ICs. You will need a pair of tweezers, a fine tipped soldering iron, 0.71mm-diameter solder, solder wick, flux paste, plus a magnifier and bright light. Start with IC1, IC2 and IC3. Orient each IC with pin 1 positioned as shown on Fig.4. First, tack solder a corner pin to the PCB pad. Check that the IC is aligned correctly onto the PCB pads before soldering the remaining pins. Any solder bridges between the IC pins can be removed with solder wick.

IC4 is a much smaller package but the process is the same. The IC is first tack-soldered at a corner pin and carefully aligned by remelting the solder, if required. Then solder the remaining corner pins. Pin 2 connects to pin 3



And this view is from the opposite side – note the switch mounting method.

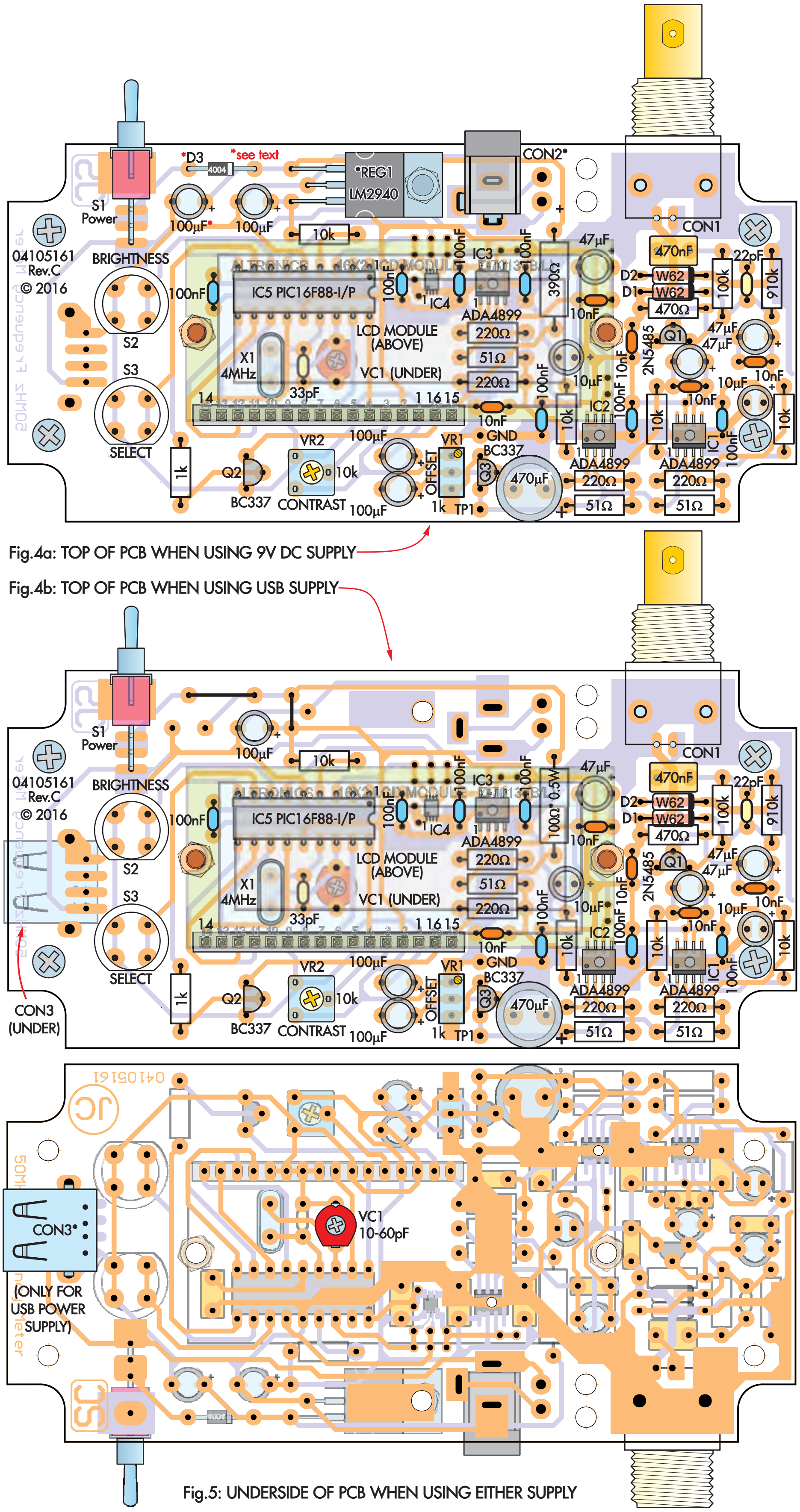


Fig.4a: TOP OF PCB WHEN USING 9V DC SUPPLY

Fig.4b: TOP OF PCB WHEN USING USB SUPPLY

Fig.5: UNDERSIDE OF PCB WHEN USING EITHER SUPPLY

Figs 4-5: at the top (Fig.4a) is the component overlay for a 9V supply version, while the 5V (USB) supply version is shown in Fig.4b – note the links replacing components. The underside of the PCB (Fig.5) is common to both versions.

so these can be soldered as a pair, but make sure there are no solder bridges between any other pins.

The resistors can be installed next. Check their value with a digital multimeter) before you install each one.

Next, fit the diodes. Make sure they have correct polarity with the striped end (cathode, k) oriented as shown in the overlay diagram. D1 and D2 are BAW62 diodes and D3 can be either a 1N4004 or 1N5819. We recommend using an IC socket for IC5. Take care with orientation when installing the socket and when inserting the IC.

There are 10 PC stakes to install. These are for TP1, GND (optional) and four each for S1 and S2. The latter are so that the switches can be raised off the PCB using PCB pin sockets.

Capacitors can be installed next. The electrolytic types must be fitted with the polarity shown, with the positive (longer) lead towards the right of the PCB. There are 10μF and 47μF capacitors in the region where the LCD module will sit – these two capacitors will need to tilt over so they are not any higher than 9mm above the PCB. The 100nF capacitor just to the right of S2 and the 470nF capacitor are both MKT polyester types. The remaining are ceramic – these and the polyester types are not polarised. VC1 is mounted on the underside to allow access for adjustment.

Next, fit the 2N5485 JFET (Q1) and the two BC337 transistors (Q2 and Q3) – make sure you don't mix them up because they look almost identical.

REG1, if required (for a 9V supply) can now be installed. This mounts horizontally on the PCB with the leads bent at 90° to insert into the holes. The metal tab is secured to the PCB using an M3 × 6mm screw and M3 nut. Secure this tab before soldering the leads.

Trimpots VR1 and VR2 are next. VR1 is a 1kΩ multi-turn vertical type, and may be marked as '102'. This is placed with the adjusting screw towards the middle of the PCB. VR2 is 10kΩ and may be marked as '103'.

Crystal X1 is mounted as shown. The recommended 3.5mm-high HC49S type will sit flush on the PCB, but if you are using the standard 13.5mm crystal package (HC49U) instead, it will need to be placed horizontally on the PCB (ie, with the leads bent down 90°) so the LCD module will fit without fouling the crystal.

The LCD module mounts on the PCB via an in-line 16-way header. The socket, which is soldered to the LCD, can be cut from a dual-in-line 16-pin (DIL16) socket to give two 8-pin socket strips, which are mounted end-to-end on the underside of the LCD module (see photos).

Install the BNC socket, power switch S1 and CON2 or CON3 depending on the supply option you are using.

Two methods for calibrating the Frequency Meter

Strictly speaking, there is no need to calibrate this frequency meter if you use the specified 20ppm crystal. At 50MHz, the error should be within ±10kHz. So your reading could be anywhere between 49.99MHz and 50.01MHz. There will also be changes in the frequency reading with temperature.

If you want better accuracy, then the *Frequency Meter* will need calibration. Two methods are available: one that requires a fixed frequency reference (the quickest method) or using an accurate clock.

The first method involves applying an accurate frequency reference signal (typically 10MHz) to the unit and adjusting VC1 (via a hole drilled in the back of the case) to get the right frequency reading. Typical frequency references have a frequency output derived from a GPS timebase or a temperature-controlled crystal oscillator. If you want to build your own GPS-based frequency reference, we have a suitable design. See the April-May 2009 issues of *EPE*.

Note that the reference frequency should be between 1MHz and 16.77MHz, allowing the meter to operate with 1Hz resolution for best precision.

Software calibration

Another method of adjustment is to use a calibration feature incorporated in the *Frequency Meter* software. This is accessed by holding the Brightness switch down as power is applied, then releasing the switch. The display will show frequency in Hz on the top line and a calibration value in parts per million (ppm) on the second line. The calibration value is initially 0ppm and can range between –50 and +50ppm. Use the Select switch to decrease the value and the Brightness switch to increase the value.

Note that you may have to press and hold a switch for up to one second before the value changes. The switch must be released and repressed to increment or decrement the value again. The one-second period wait is because the frequency reading section, as shown on the top line, takes one second to update.

The frequency displayed is in Hz rather than the kHz and MHz units when the frequency meter is used normally. So 10MHz will be shown as 10,000,000Hz without the comma breaks.

Adjust the ppm value so the frequency reading matches the reference frequency. Positive adjustments will have the effect of lowering the frequency reading and negative values will increase it. Once set, the ppm value is stored in Flash memory and will be used every time the frequency meter is switched on. Normal frequency meter operation is restored by cycling power to the unit.

Calibration with a clock

This method also involves software calibration, as described above. In theory, you could adjust VC1 when calibrating against a clock, but it's too difficult to make the right adjustment.

Our *Frequency Meter* software incorporates a real-time clock function that can be set to the same time as an accurate clock. The drift in time over an extended period will allow the parts per million error to be calculated. This ppm value is then entered to correct the clock in the *Frequency Meter* .

The clock function is accessed by pressing and holding the Select switch as power is applied to the *Frequency Meter* . The top line on the LCD will show the time in 24-hour format, initially 00:00:00. The lower line shows '^h' and '^m' to indicate that the hours and minutes are adjustable using the Brightness and Select switches respectively. The seconds are cleared on each minutes change.

First, set the hour, then the minutes and finally, press the Select switch as the reference clock rolls over to the next minute.

Note that if using the clock in a computer, it should be synchronised with the same on-line time server both before setting the *Frequency Meter* clock and when comparing the *Frequency Meter* clock drift. Make sure there isn't a leap second within this period. Any other clock or watch can be used, but it must be known to be accurate and have a seconds display.

A clock that uses the 50Hz (or 60Hz) mains frequency as its reference is not suitable since short-term accuracy is not guaranteed. Typically, the clock in a smart-phone is very accurate if set to automatically synchronise with network time. Alternatively, the time may be synced to GPS signals.

A counter on the second line of the LCD shows the number of seconds that the clock has been running. This should roll over to a reading of 100,000 after about 28 hours. This is the minimum period that you should leave it running before calculating the calibration adjustment; longer is better. You cannot make frequency measurements during this time.

Now compare the clock on the *Meter* to your reference clock (after syncing it, if necessary) and calculate the number of seconds difference. Multiply this by 1,000,000 and divide by the number of seconds on the second line of the LCD. This is the required ppm adjustment. If the clock on the *Meter* is slow compared to the reference clock, the required ppm adjustment will be positive, whereas if the *Meter* clock is fast, it will be negative.

The minimum time period required to get 1ppm accuracy is 11 days and 12 hours (11.5 days). You can check the clock at this time, when the seconds reading rolls over to 1,000,000, to make the calculation simpler, ie, the required ppm correction value is simply the number of seconds difference between the *Meter* clock and the reference clock.

Once you've calculated the required ppm adjustment, enter it by switching the *Meter* off and switching it back on while holding the Brightness switch. The adjustment procedure is described above. Then cycle the power to return the *Meter* to its normal measurement mode.

Switches

Switches S2 and S3 need to be mounted above the PCB so they just poke through the front panel.

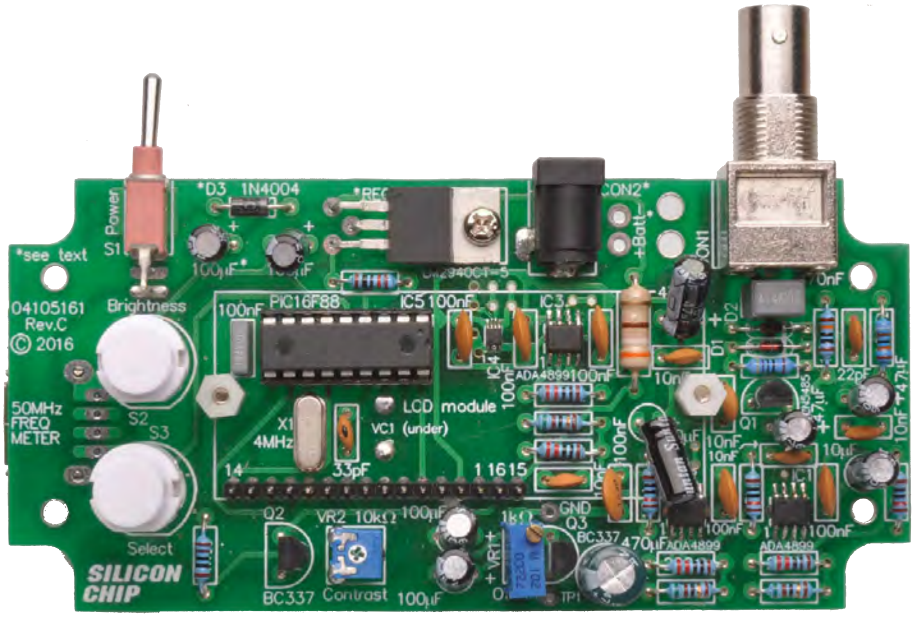
They are installed by first inserting the PC stake sockets fully onto the PC stakes. Then the switches are placed over these sockets and the switch pins soldered to the socket ends. The switches should sit with about 26mm from the top face of the switch to the top of the PCB.

Final PCB preparation involves attaching M3 tapped standoffs to the top of the PCB to mount the LCD module and the front panel/lid.

The LCD module mounts on two 9mm standoffs with a 1mm-thick nylon washer (or use 10mm standoffs). It is secured with M3 × 6mm screws. For the lid, the mountings comprise 6.3mm and 12mm standoffs stacked together. Each 6.3mm standoff and 12mm standoff are secured with an M3 × 12mm screw to the PCB. The front panel is secured with M3 × 6mm countersunk or cheese-head screws. The front panel/lid should not be attached until the PCB is installed first in the box.

Before mounting the PCB in the box, apply power and check that the display shows valid characters. Adjust VR2 for best contrast.

Check that the brightness switch works and varies the back-lighting with switch pressing. Holding the brightness



Completed prototype PCB without the LCD module in place; shows how the module mounts and also the components which fit underneath it. Some of these need to be laid over to accommodate the LCD module, as explained in the text.

The LCD module shown here has a 16-way header socket soldered to the underside, which mates with a 16-way header pin on the top of the PCB.

switch will cause the back-light to either continue dimming or increase in brightness.

The maximum or minimum setting can be achieved by holding the switch pressed for five seconds. Each time the brightness switch is released and then pressed again, the dimming direction will change. Similarly, each press of the Resolution switch should change the display resolution to the next selection in a cyclic fashion, and this also includes the prescaler selections.

Offset adjustment

VR1 is adjusted so that the IC3 output swing corresponds to the input thresholds of Schmitt trigger IC4. TPGND and TP1 are provided to enable a basic setting. Adjust VR1 so TP1 is at 2.5V. Final adjustment can be made to set the signal sensitivity by applying a signal at say 100kHz and reduce the signal level until the *Frequency Meter* just starts to become erratic in readings. This is the sensitivity threshold.

Readjust VR1 and check if the sensitivity can be improved by winding both clockwise and then anticlockwise to find the setting that gives best sensitivity. You may need to reduce the signal level as the sensitivity improves with VR1 adjustment to maintain the sensitivity threshold.

If you find that the *Frequency Meter* shows erratic values above 40MHz, a small adjustment of VR1, either clockwise to increase the offset, or anticlockwise should fix this. For our prototype, a 2.69V setting at TP1 proved ideal.

Mounting the PCB in the box

If you are using the pre-drilled front panel, then the only holes to drill are in the base of the box. A drilling template, which can be downloaded from the *EPE* website, shows the position of each hole on the box. Note that this does not include a hole in the base to access VC1 for trimming. This may be required; see the panel on calibration in the previous page for details.

The positioning for the front panel holes and cut outs are also provided if you are doing this yourself. If you are not using the USB connector, there is no need to cut this hole out.

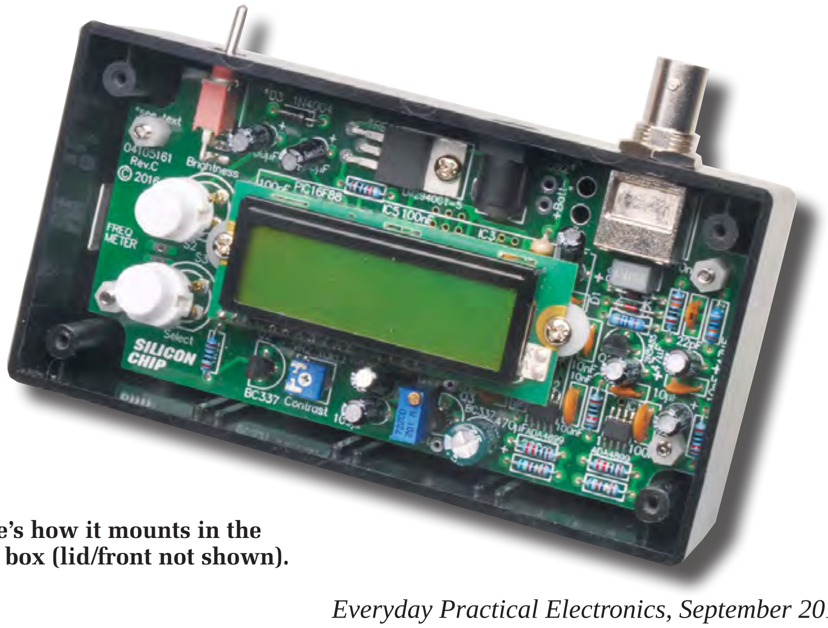
The front panel artwork (as seen in the lead photo) can also be downloaded from the *EPE* website and printed. To produce a rugged front panel label, print onto clear overhead projector film (using film suitable for your type of printer) as a mirror image, so the ink will be on the back of the film when it is attached. You can use white or off-white silicone sealant to do this.

Final assembly

Place the completed (and tested) PCB into the box with the spring washer already on the BNC shaft. With the PCB angled inward, the switch and BNC parts are passed through into their holes in the side of the box and the PCB is then lowered into the box and held using the BNC nut, securing this to the side panel.

Once the PCB is in the box, the front panel can be attached to the PCB using M3 × 6mm screws into the tapped spacers and then to the box, via the four outer holes.

Note that when using the acrylic front panel instead of the original box lid, the screws supplied with the box may be too short. If so, use No.4 × 15mm self-tapping screws as detailed in the parts list.



Here's how it mounts in the jiffy box (lid/front not shown).

Win one of Two Microchip MCP9600 Evaluation Boards

EVERYDAY PRACTICAL ELECTRONICS is offering its readers the chance to win a Microchip MCP9600 Evaluation Board (ADM00665). The MCP9600 Evaluation Board is used to digitise the EMF from a K-type thermocouple and outputs a signal proportional to degrees Celsius with ±1ºC accuracy. The device also supports thermocouple types J, T, N, E, B, S and R. Each of these types are recognised by replacing the K-type thermocouple connector with the alternative thermocouple's corresponding connectors (not included). The evaluation board connects to a PC via a USB interface. Temperature can be data-logged using Microchip Thermal Management Software Graphical User Interface (GUI).

The MCP9600 includes integrated thermocouple cold-junction compensation.

The MCP9600 digital temperature sensor comes with user-programmable registers, which provide design flexibility for various temperature-sensing applications. Temperature can be data-logged using the Microchip Thermal Management Software Graphical User Interface (GUI).

The MCP9600 includes a temperature-data digital filter, which minimises the effects of temperature fluctuations, system noise and electromagnetic interference. Its shutdown modes reduce overall system power consumption, while its four user-programmable temperature-alert outputs reduce the system microcontroller's overhead and code space, further simplifying designs. Finally, the MCP9600 comes in a 5×5mm, 20-lead mQFN package, which reduces board area.

HOW TO ENTER

For your chance to win a Microchip MCP9600 Evaluation Board, visit **http://www.microchip-comps.com/epe-mcp9** and enter your details in the online entry form.

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May 2017 ISSUE WINNER

Mr Michael Wray, from Alnwick, Northumberland, UK

He won a Microchip Curiosty PICMZ EF Development Board, valued at £40.00

Low-cost, compact Attenuators

by Mike Rogers

Traditional attenuators are large with custom switch wafer assemblies and weird-value resistors. Fine if you are a company with a large production run, but too expensive for a home constructor making one-offs. In this article we present a method of making attenuators using ordinary single-wafer rotary switches that are both small in size and cost.

I've built several small battery-powered signal generators for audio and radio frequency work, and one recurrent problem I've faced is how to make a good output attenuator that doesn't break the bank or take up half the enclosure.

Background

A traditional type of attenuator, as shown in Fig.1, is a large rotary switch with four wafers and precision resistors mounted axially between the wafers. Note that for clarity, I have only shown eight resistors here, but there are over twenty in all, half on the front (right-hand in the diagram) pair of wafers spread around 180° and half on the rear pair spread around the second 180°. An electrostatic screen separates the two banks. The parts of the multi-wafer switches are bought separately and assembled to make the required configuration. These individual parts are expensive and the assembly is often too large to accommodate in small enclosures. (Commercial, heavy-duty attenuator assemblies are shown in Fig.2 – neither cheap, nor compact.)

The switch wafers shown in Fig.3 are a single pole twelve way on the left and a dummy to the right. The dummy provides holding tags for components. These are modern plastic wafers, older ones were thinner and made of Tufnol/SRPB (synthetic resin-bonded paper).

Traditional signal generators were used to drive long lines – 'long' as in many miles, so line impedance was significant. These generators had to drive large signal voltages, up to 10Vrms. The output attenuators were designed to match the line impedances, 600Ω for traditional two-wire telephone lines and 50Ω for coaxial radio frequency lines (see last month's *Circuit Surgery* for an explanation of impedance matching). The loading by the lines meant there was a 50% voltage drop into the load, so the output amplifiers had to drive up to 20Vrms into the attenuators. The amplifiers and attenuators were often discrete-component designs running from high-voltage supplies.

However, life was not always that simple and you may find old audio signal generators designed not only for 600Ω attenuators, but also 300Ω or 150Ω versions, in both balanced and unbalanced versions. Modern telecommunications systems are even more complicated, with specialised equipment matching into complex resistive-reactive impedances.

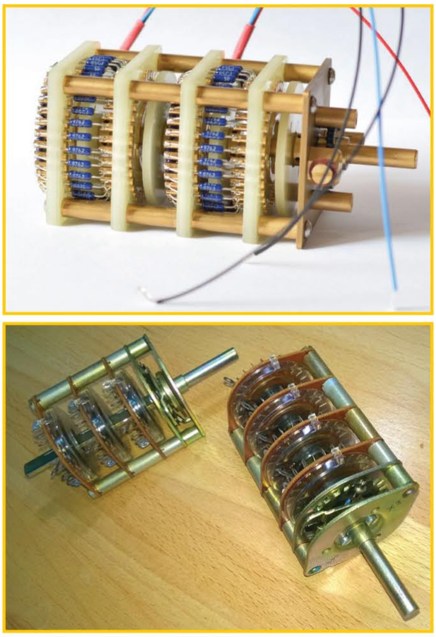


Fig.2. These well-made attenuator multi-way switches do a good job, but they are bulky and expensive (lower image courtesy of Fred Musset, http://a-direct-heating-triode.blogspot.co.uk)

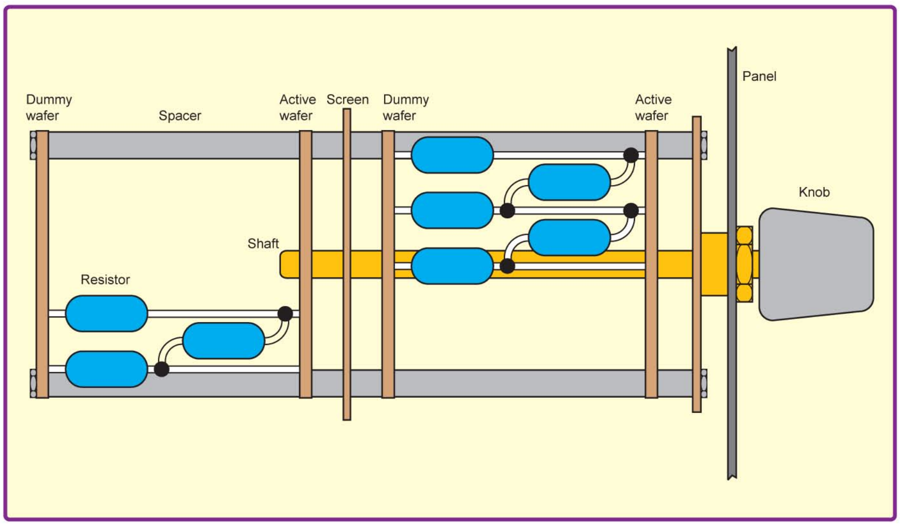


Fig.1. Traditional attenuator (this diagram is based on a device from a Radford LDO3 manual (rotating contacts not shown)

Attenuators

The function of an attenuator is to reduce the signal amplitude without introducing distortion and noise, to match the desired load impedance, and to provide a means

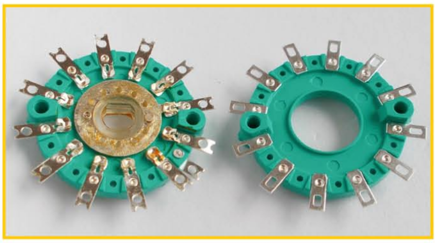


Fig.3. Switch wafers

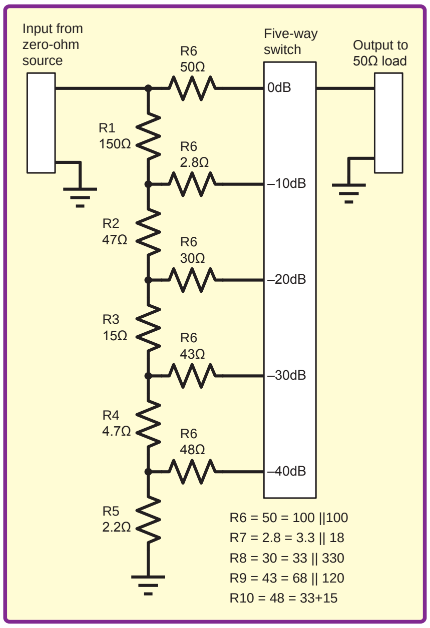


Fig.4. Circuit of simple 50Ω radio frequency attenuator (remember to add –6dB when loaded)

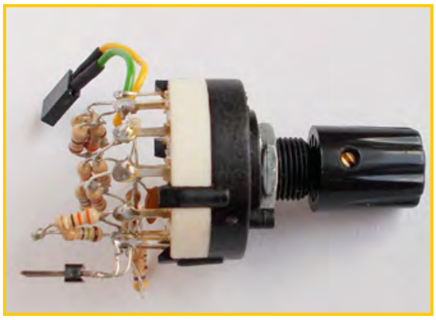


Fig.5. Simple 50Ω attenuator built on single wafer switch (from Lorlin)

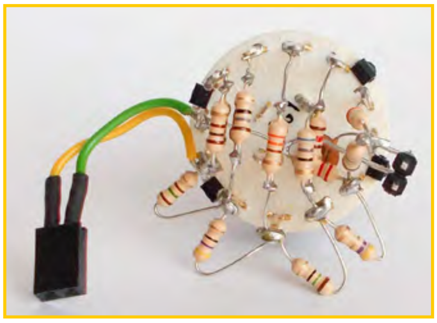


Fig.6. Simple 50Ω attenuator (rear view)

of measuring the output signal. It passes an exact proportion of its input signal to the output so you can measure the voltage at the attenuator input and, for a given attenuator setting, deduce the output voltage, even if it is too small to measure directly. Attenuation should be the same at all frequencies of interest.

Attenuator switch positions may be marked in dB relative to input voltage; in dBv, that is to say dB relative to 1Vrms; or dBm, which is output relative to 1mW in the specified load impedance, or in volts rms, depending on application. The direction of switch rotation is usually clockwise for maximum attenuation when marked in dB or clockwise for maximum voltage when marked in volts. Signal generator internal meters are calibrated for on-load output voltage and there may be a switchable dummy load to keep the meter honest when driving into a high impedance.

In my home laboratory (the kitchen table) I use the attenuator of my audio signal generator as a wide range 'volume control' to set and measure a desired signal level. It is useful to have low output impedance and it should remain constant when different signal levels are selected, but it does not have to be any specific value. Output loading is not a problem because I usually drive high impedances. What I need is functionality along with low cost and small size.

First 50Ω design

My first attempts at low-cost attenuators were reasonably successful and I found it was possible to build one using readily available off-the-shelf components, such as easily sourced and inexpensive single-wafer switches and E6 series resistors. It was fairly easy to build attenuators with 10dB steps going from 0dB to –40dB, but further attenuation was not practicable.

Fig.4 shows the circuit of a simple 50Ω attenuator I made for an RF signal generator. There is a chain of resistors, which progressively drops the voltage in 10dB steps, and there is a series resistor at each position to ballast the output impedance to 50Ω. The dropper chain is made of preferred-value resistors and the ballast resistors are combinations of preferred values.

The dropper resistor values are made as high in value as possible. Nevertheless, the lowest value is 2.2Ω, so adding more 10dB steps is not realistic in this 50Ω attenuator. Audio versions, such as 150Ω and 600Ω are possible, but in each case going beyond –40dB is difficult.

Fig.5 and Fig.6 show this simple attenuator was built on a low-cost, one-inch-diameter, single-wafer rotary switch. The switch is a two-pole six-way switch, stopped down to five ways. The active pole selects the attenuation and the unused pole provides holding tags for the dropper chain resistors. The two unused sixth positions are used to hold ground and output. The input connector leads are yellow for signal and green for ground. The dropper chain runs from left to right around the tags of the unused switch pole below and the ballast resistors connect across to the active pole at top. Just visible is the capacitor connecting the output. Maximum voltage is clockwise when viewed from the front (knob side).

I built this simple attenuator using 5% CR25 resistors because 1% resistors were not available in the lower values. Statistical calculation yields a typical accuracy of ±0.2dB.

Raising the attenuation

For my audio signal generator I need more attenuation. The circuit shown in Fig.7 is a ladder attenuator that uses repeated resistor values and provides a wide range of attenuations. I have shown the ideal resistor values, but in practice, designers choose the nearest E192 values. A typical traditional attenuator had four switch wafers, two acting as switches and two serving as holding tags for the precision resistors.

There are three problems with this type of attenuator; multi-wafer switches are large and expensive, the E192 resistor values are difficult/expensive to obtain in small numbers, and there is a voltage loss between the input and the maximum output, requiring additional drive voltage.

Fortunately, modern close-tolerance resistors are small in size and it is possible to build an attenuator on a single wafer switch, so long as you avoid capacitive coupling from high-level signals to the low-level signals. Traditional attenuators used separate pairs of wafers for high and low-signal levels. I keep high and low levels separated by using a peripheral

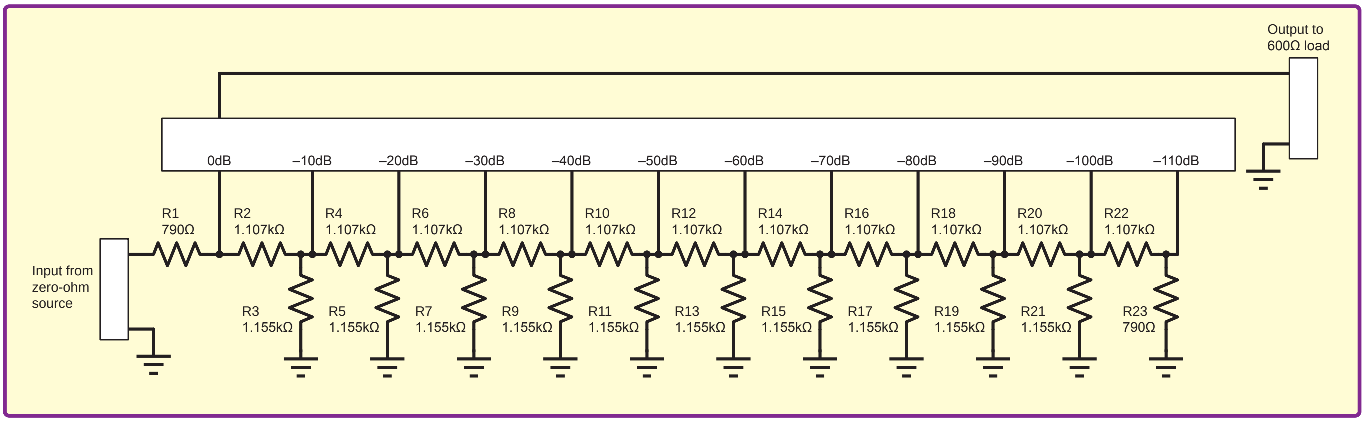


Fig.7. Ideal 600Ω audio attenuator

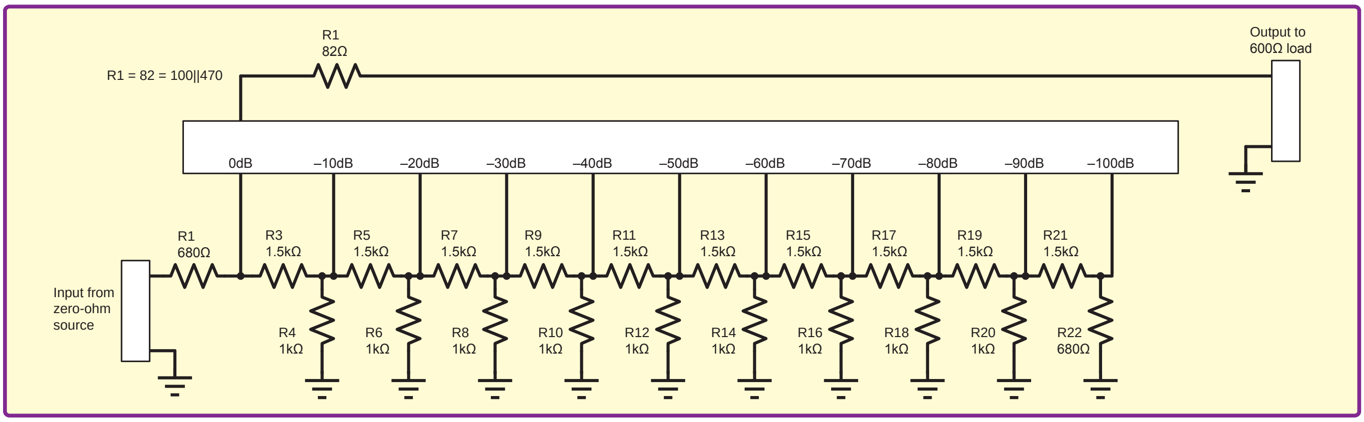


Fig.8. 600Ω attenuator using common resistor values

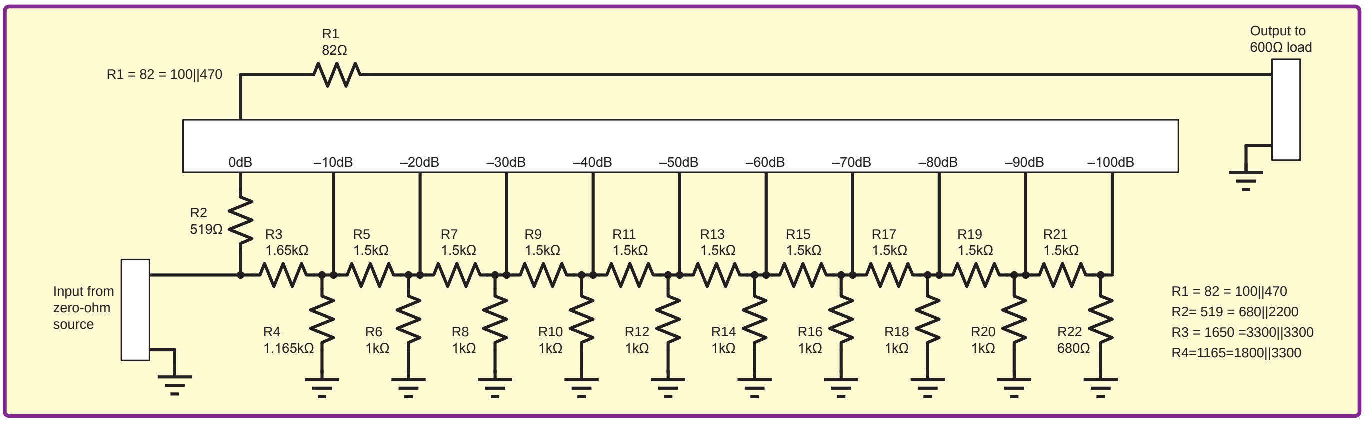


Fig.9. 600Ω attenuator combining simple and traditional circuits

signal path, using only eleven switch ways and grounding the twelfth way to create an electrostatic shield.

The 'difficult' E192 resistors are required when an attenuator is designed specifically for a required impedance. I scaled the design values to a lower-impedance version, which makes use of easier-to-source resistor values, as shown in Fig.8. The computer-modelled attenuation error is less than 1dB at –100dB when all resistors are at their nominal values. The design impedance is 519Ω and a ballast resistor after the switch makes this up to 600Ω. The ballast resistor (R1) may be omitted if 519Ω output impedance is acceptable.

Combined design

In the traditional circuit (Fig.7 and Fig.8) the attenuator drive amplifier has to provide about 30% more output than when open circuit. This requires a higher supply voltage and more amplifier drive capability.

To reduce the amplifier voltage swing requirement I combined the features of my simple 40dB attenuator with the traditional design and came up with the 600Ω circuit shown in Fig.9. The 0dB output is separate and comes direct from the amplifier via ballast resistors R2 and R1. The resistors R3 and R4 drop the signal to –10dB and provide a match into the main attenuator. Then the usual attenuation continues to –100 dB, where resistor R22 terminates it. Again, the ballast resistor R1 can be omitted if an exact 600Ω match is not required. Shorter ladders may be constructed by omitting some sections.

Fig.10 shows the resistor values for a 50Ω radio frequency version of the attenuator for matching into 50Ω cable. If the ballast resistor is omitted the impedance is 36Ω.

To design for any other impedance, remove the ballast resistor R1 and scale all the resistors by a fixed factor that gives you preferred values with a value of R2, which is less than but near to your required impedance. Add a new ballast resistor R1 to make this up to your required impedance. Happy number crunching!

I built two of the 600Ω version, shown in Fig.11. The one on the left will go in my function generator and the one on the right is for my yet-to-be-built high-purity sinewave oscillator. Soldering 20+ tiny resistors onto a one-inch diameter switch wafer is a task that needs a lot of planning, a small soldering iron, and fine gauge solder. It is useful to have a jig to hold the switch while you are soldering. For optical assistance I use a pair of close-up spectacles, custom made for me by my local high street optician. If you don't need prescription specs a cheap pair of +2 dioptre 'readers' should help.

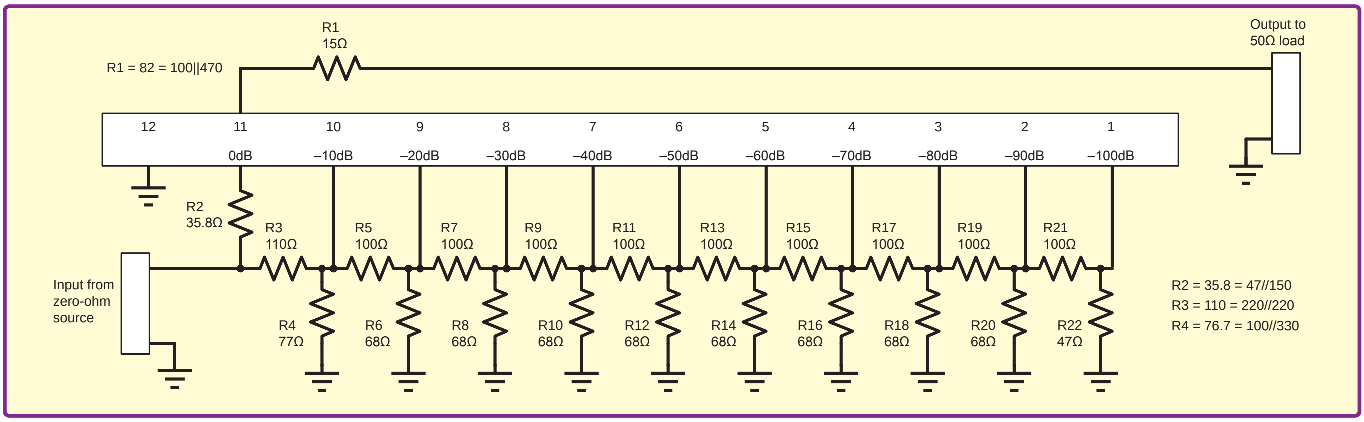


Fig.10. Resistor values for 50Ω radio frequency attenuator

Fig.11. Two 600Ω attenuators

Fig.12 and Fig.13 show the rear of the completed 600Ω attenuator. Please don't criticise my soldering until you've built one yourself! The switch is one inch (25mm) in diameter and the tags are 5mm apart. The 1%, 0.25W metal film resistors are 3mm long and fit nicely between the tags. Tag 12 is grounded to provide an electrostatic shield between the highest signal level on tag 11 and the lowest level on tag 1. The ground is extended as a halo to pick up all the shunt resistor earthy ends. The output wire exits between the lowest level signal tag 1 and the grounded tag 12 so as not to pick up any unwanted high level signals. The ballast resistor is not shown here, it can be added elsewhere if needed.

Reasonable accuracy should be possible with 1% metal film resistors, which are tiny and can be mounted directly on the switch. If you are not too worried about accuracy and size then 5% E6 series CR25 carbon film resistors from your spares box may be used.

I measured the attenuation by applying 10V DC. The attenuation was –10.1dB on each –10dB step and –100.9dB overall, exactly as predicted by circuit modelling. With the input shorted, the output resistance was constant within ±0.15% on most settings and within ±0.3% at each end. Very pleasing results!

In my sinewave signal generator, the attenuator will be driving a high-impedance load and producing only a modest output voltage, so I will be able to use an op amp to drive the attenuator. I intend to mark the switch positions in volts-rms, from 1Vrms down to 10µVrms.

I'm very pleased with the results – I have a wide-range, reasonably accurate attenuator built with low-cost easy-to-find components on a single wafer switch which fits nicely into my compact battery-powered kitchen-table signal generators. Audio folk with deep pockets may like to use two wafers to make an accurately balanced logarithmic stereo volume control. The wafers should be make-before-break to minimise switching noise.

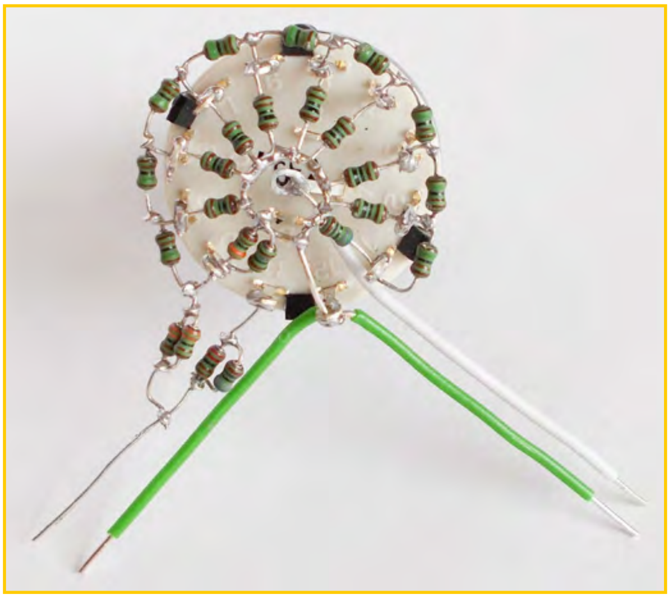


Fig.12. 600Ω attenuator (rear view) shown in Fig.10

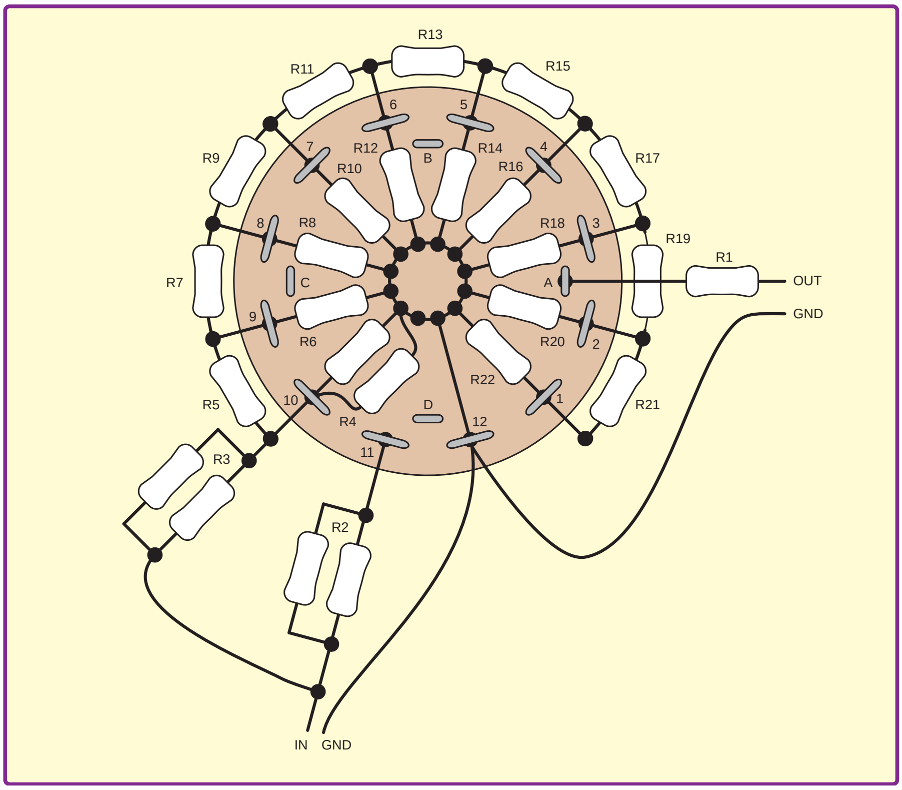


Fig.13. Connections for 600Ω attenuator shown in Fig.10 using a 12-way switch

- 5-inch touch screen
- Even more I/O pins
- Expansion slots
- USB and serial interfaces
- PS/2 keyboard socket

Micromite Plus Explore 100

Part 1:

By Geoff Graham

The *Explore 100* expands on the *Micromite Plus Explore 64* described last month, adding more I/O pins, two slots for mikroBUS Click expansion boards, provision for a real-time clock (RTC), USB-to-serial adaptors and a PS/2 keyboard socket. Perhaps, most importantly, it connects directly to (and mounts on) a 5-inch touchscreen for stunning graphics. It can be used as a fully integrated computer or as an advanced embedded controller.

THE *EXPLORE 100* combines a high-performance microcontroller, programmed with the Micromite Plus firmware, with a large and colourful display panel that can draw graphics and sophisticated on-screen controls such as radio buttons, check boxes, spin boxes and more.

Win an Explore 100!

EPE is running a competition to win a fully-assembled Explore 100 thanks to the generous sponsorship of Micromite online shop **micromite.org**

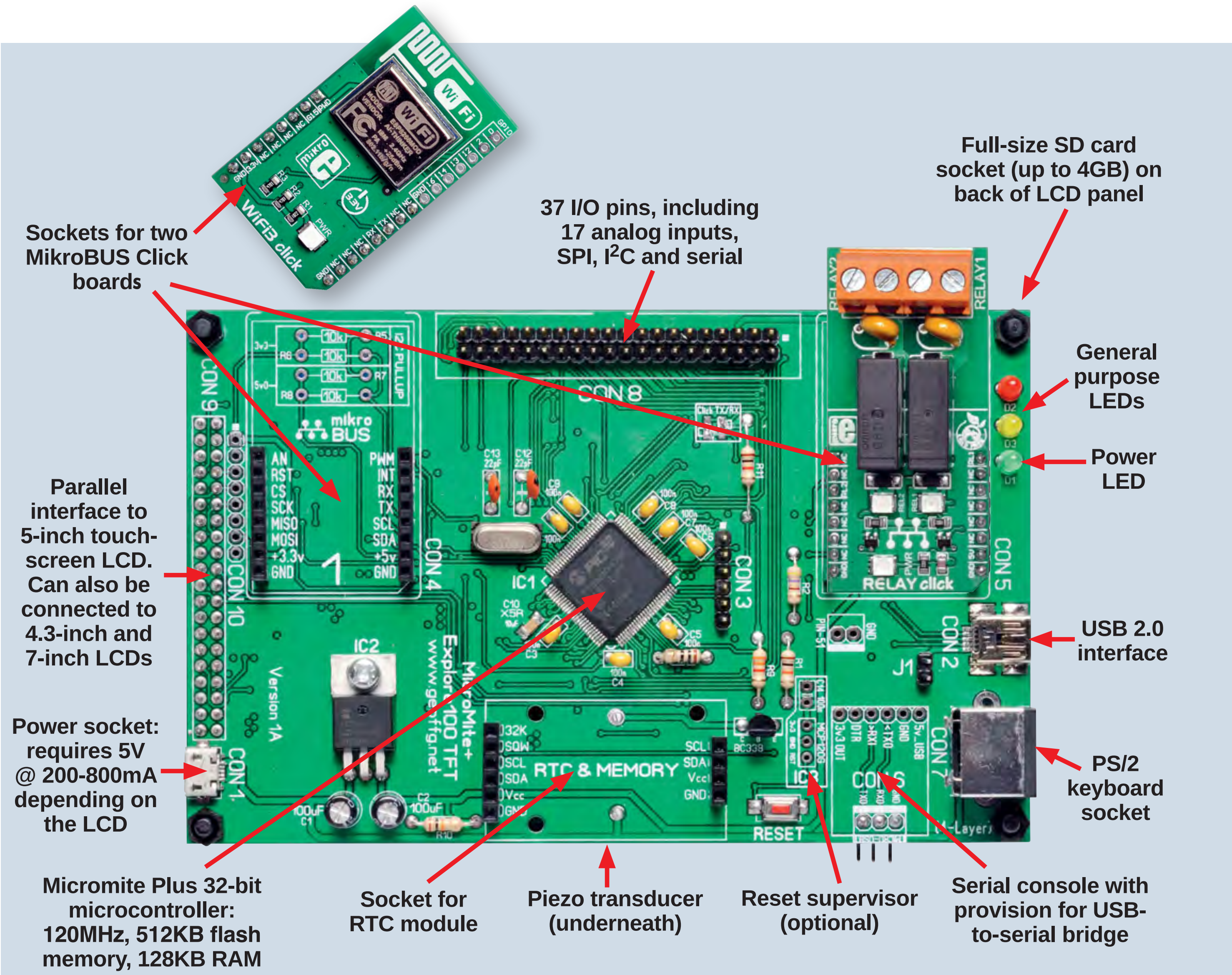
For entry details, please turn to page 35.

The *Explore 100* PCB is designed to match the dimensions of a standard 5-inch touch-sensitive LCD panel, so that when the two are mated, they make a slim 'sandwich'. This neat display/controller package can be treated as a single intelligent device and mounted in a control panel or on the front of an enclosure where it could display data and accept control input via the touch-sensitive screen.

At the core of the *Explore* series is the Micromite Plus, a fast microcontroller with a built-in BASIC interpreter and drivers for touch-sensitive LCD displays, PS/2 keyboards, SD/microSD cards and a host of special devices such as infrared remote controls and temperature sensors.

This project has a dual personality. First, it makes an ideal controller/interface for anything that needs an input system and control display panel. Examples include a sophisticated irrigation controller, an easy-to-use security system, a computer-controlled lathe and a general industrial controller.

The *Explore 100* can be mounted in a control panel where it can display graphs and numbers while accepting input commands on its touch-sensitive screen. It has 37 spare input/output lines that can be used for monitoring voltages, currents and switch



This photo summarises the features and capabilities of the *Explore 100*. These features include the 32-bit microcontroller with its in-built BASIC interpreter, 37 input/output pins for controlling external devices, two sockets for MikroElektronika click boards, a USB 2.0 interface, a connector for a PS/2 keyboard and on-board sockets for a super-accurate real-time clock (RTC) module and a USB-to-serial converter.

closures, and can control external devices by closing relays or illuminating LEDs.

Second, the *Explore 100* can act as a completely self-contained computer, similar to the Tandy TRS-80, Commodore 64 or Apple II of yesteryear. With its colourful LCD screen and PS/2 keyboard interface, you can learn to program it in the easy-to-use BASIC language and make use of the SD card facility to save and load programs and data.

Using BASIC, you can draw graphic objects on the LCD panel, including lines, circles and boxes, as well as turn individual pixels on (or off) in any one of 16 million colours. You can use it for educating your children, tracking astronomical objects, writing games or just exploring a fun, easy-to-use computer system.

LCD touch-screen panel

The *Explore 100* can use all the different LCD panels that were described in the Explore 64 article last month, ranging from a tiny 1.44-inch display up to a monster 8-inch touchscreen with a resolution of 800x480 pixels. But it's specifically designed to work with panels that use the SSD1963 display controller, ranging from 4.3 inches (diagonal) to 8 inches. The SSD1963 has a parallel interface, allowing the Micromite Plus to transfer data at high speed, so these screens are ideal for displaying complex graphics.

Compatible displays can be found on eBay for US$25 to US$60. In addition to the display itself, they feature a touch-sensitive screen surface and a full-size SD card socket, both of which are fully supported by the Micromite Plus.

The mounting holes and physical dimensions of the *Explore 100's* PCB are designed to match the 5-inch display version. The *Explore 100* is secured to the back of the display using four spacers, one at each corner, to create a single rigid assembly.

Input/output pins

The *Explore 100* has a 40-pin general purpose input/output (GPIO) connector. Various pins on this connector can be configured as analogue or digital inputs, digital outputs, frequency inputs, PWM outputs and much more. Also available on this connector are three high-speed serial ports (RS-232 TTL), an I^{2}C interface and an SPI interface.

In total, this connector has 37 I/O pins plus three pins for supplying power (ground, +3.3V and +5V). All of the I/O pins can act as either digital inputs or outputs, while 17 of them can also be used for measuring analogue voltages. The GPIO connector can be linked to another PCB via a 40-way ribbon cable or connected directly to another PCB, which can piggyback onto the *Explore 100*, making a 3-board sandwich.

If you want to develop additional circuitry on a breadboard, you can purchase adapter boards that take a 40-way cable and spread the signal

Explore 100: Features and specifications

- Mates with a 5-inch SSD1963-based touch-sensitive LCD with 800 x 480 pixels @ 16 million colours (4.3, 7 and 8-inch panels are also suitable)
- 32-bit CPU running at 120MHz with 512KB of Flash memory (100KB available for programs) and 128KB RAM (103KB available)
- In-built Microsoft-compatible BASIC interpreter with 64-bit integer, floating point and string variables, arrays and user-defined subroutines and functions
- 37 I/O pins independently configurable as digital inputs or outputs; 17 can be used as analogue inputs
- Two MikroElektronika Click board sockets. Almost 200 Click boards are available, including Ethernet, Wi-Fi, Bluetooth, relay outputs, current measuring and more
- USB 2.0 serial interface for program editing and upload/download from a PC
- Supports microSD and SD cards up to 64GB
- On-board sockets for accurate real-time clock and USB-to-serial converter
- PS/2 keyboard connector allows the Explore 100 to act as a fully self-contained computer and development system
- In-built graphics commands, including pixel, line, circle and box
- Six in-built fonts plus many more fonts that can be embedded in a program
- Advanced graphics commands include on-screen keyboards, buttons, switches, check boxes and radio buttons
- Standard Micromite features, including many communications protocols with SPI, I^{2}C and 1-Wire plus in-built commands to directly interface with IR remote controls, temperature sensors and other devices
- PWM or SERVO outputs and special embedded controller features such as variable CPU speed, sleep, watchdog timer and automatic start and run
- Runs from 5V DC at up to 750mA (depending on LCD panel and brightness)

lines out to 0.1-inch pins that can plug into a standard solderless breadboard. They are intended for use with the Raspberry Pi but they work well with the *Explore 100* (all except a few I/O pins are available).

mikroBUS Click boards

The *Explore 100* has two sockets for mikroBUS Click boards, which is a standard developed by the European company MikroElektronika. At last count, there were almost 200 of these little boards, providing just about any function that you can think of, including an Ethernet interface, Bluetooth, Wi-Fi and GPS (plus many more). They are ideal for adding a specific function to the *Explore 100* without the hassle of building it yourself.

The *Explore 100* uses a 100-pin Microchip PIC32MX470 microcontroller programmed with the MMBasic firmware. The pins on this surface-mount package have a 0.5mm spacing which can be soldered with a standard temperature-controlled soldering iron. (Photo courtesy of Microchip)

For example, by plugging in the TextToSpeech Click board, you can make voice announcements from your BASIC program and by using one of the Wi-Fi boards, your program can generate a web page for access via the Internet. Another example is the RF Meter click board, which can be used to measure RF power over a frequency range of 1MHz to 8GHz with a 60dB dynamic range.

The MikroElektronika catalogue also includes an adaptor Click board, which allows you to use the range of 10-pin Olimex UEXT Modules, and these add a further 100 or so modules to the available selection. You can find compatible Click boards by searching the Internet for 'click board' and UEXT modules by searching for 'UEXT'.

A self-contained computer

Perhaps the most exciting feature of the *Explore 100* is that it makes an excellent self-contained computer. It starts up instantly, contains its own programming language – just plug in a keyboard to start experimenting!

The keyboard interface will work with a standard PS/2 keyboard and has support for the number pad, function and editing keys. The keyboard is essential if you are using the *Explore 100* as a general-purpose, self-contained computer and is also useful when the *Explore 100* is mounted in a control panel. In that case, you can plug in a keyboard and make changes to the program without pulling out your laptop.

An important part of a self-contained computer is the program editor. The full-screen editor used in the Micromite Plus is quite advanced and allows you to scroll through your program, search for text and cut or copy text to the clipboard and paste it somewhere else. It also displays your program on the LCD panel with colour coding, so that keywords are in one colour, comments in another and so on.

The best part of the editor is that the run/edit/run cycle is very fast. When you have edited your program, you only need to press the F2 key on the keyboard to automatically save and run it. If your program contains an error, the BASIC interpreter will stop and display an error message.

You can then press the F4 key to take you back into the editor, with the cursor positioned at the line which halted the program. After you have corrected the fault, pressing F2 will save and run the program again. It doesn't get much easier than this.

You can save programs on an SD (or microSD) card for safekeeping, although this is not strictly necessary as the program in the Micromite Plus is held in non-volatile Flash memory, which means that it will not be lost when the power is turned off. However, using an SD card allows you to have multiple programs which you can load, edit and save at will.

As a self-contained computer, the *Explore 100* still has access to all the features of the Micromite Plus, including a USB (serial) interface, multiple fonts, an extensive suite of graphics commands and powerful input/output facilities. In addition, the two Click board sockets allow you to quickly add extra functions to expand the computer's capability. For example, you could plug in an RS-232 Click board and use the *Explore 100* to control an item of test equipment.

Display size

When you are using the *Explore 100* as a self-contained computer, the larger the screen size the better. We recommend the 5-inch display as it works well and matches the size of the *Explore 100* board. However, if you opt for a larger screen, the characters are correspondingly larger and easier to read.

Clearly, the 7-inch display will be easier to read than the 5-inch display and the 8-inch display easier again (available from EastRising at **www.buydisplay.**

com). **Note that the EastRising panel uses non-standard interface connector pin-outs, so you must use point-to-point wiring between the *Explore 100* PCB and the LCD panel.**

Incidentally, the LCD panels do not cost a huge amount so you could always purchase both a 5-inch and a 7-inch panel and see which one better suits your requirements. That will also give you a back-up panel which could come in handy during testing.

Console connections

On the lower righthand corner of the *Explore 100's* PCB are the serial console and USB console connectors. The console is an important part of the Micromite Plus, as this is how you configure and program it using a larger computer, running a terminal emulator. The serial console and USB console work the same, so you can use either as the console or even both at the same time.

In the *Explore 64* article last month, we discussed when and why a serial console is handy (rather than just using the USB console). Basically it's because the serial interface will remain working whenever the Micromite Plus is restarted, unlike the USB interface which will lose its connection on every restart.

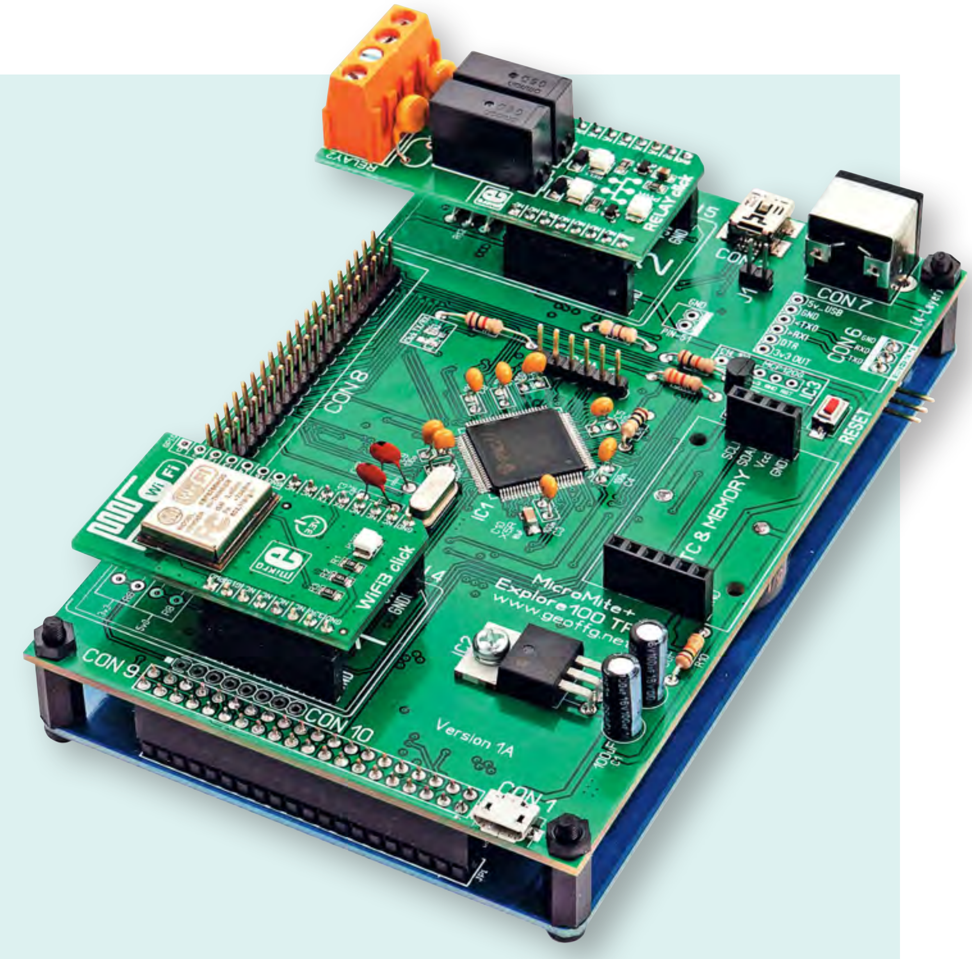
Depending on what type of development work you are doing, you may need to reset the Micromite Plus regularly and this is where the serial console is handy. If you are using the *Explore 100* as a self-contained computer, this is less of an issue and generally the in-built USB interface will be fine.

Serial port driver

If you are using a version of Windows earlier than Windows 10, you must install the SILICON CHIP USB Serial Port Driver on your PC (available for download from the *EPE* website) before you can use the USB console. The full instructions are included with this driver. The Micromite Plus uses the standard CDC protocol and drivers are built into the Mac and Linux operating systems (and also into Windows 10).

The PCB also features a header to allow an external USB-to-serial module to be connected. This gives the *Explore 100* a USB console that will not reset when the Micromite is reset.

A high quality USB-to-serial module (based on the FTDI chipset) is available from **micromite.org** and is simply connected to the appropriate pins using three jumper wires (GND, Tx, and Rx). There are no special configuration commands that need to be run because



The *Explore 100* has two sockets for mikroBUS-compatible Click boards. This is a standard developed by the European company MikroElektronika and covers a wide range of plug-in modules, including Ethernet, Bluetooth, Wi-Fi and GPS modules – perfect for adding extra functions to the *Explore 100*. A Wi-Fi board and a relay board are shown connected here

MMBASIC defaults to using a serial console unless told otherwise.

Other features

The *Explore 100* is designed to use the full-sized SD card socket which is mounted on all compatible LCD display panels. However, if you are mounting the *Explore 100* on the back of the 5-inch display as intended, the SD card will stick out the top.

This could be a bit awkward in some situations, so there is an optional SD card module available from **micromite.org**. This module is also useful when using the *Explore 100* without a TFT, but you still need access to an SD card.

You can open files to read or write data from within the BASIC program. All files created are compatible with standard desktop computers, so you can use the SD card to log data for later analysis.

MCP120 reset supervisor

The PCB also has provision for installing a Microchip MCP120 supervisor device. This is optional and if installed, will monitor the main 3.3V power rail and reset the Micromite Plus if the voltage drops below a critical level (around 2.7V for the specified part).

Basically, the MCP120 is designed to provide an extra level of protection in an industrial environment where power brownouts and electrical noise could cause a microcontroller like the Micromite Plus to run amok.

Yet another feature is a piezo buzzer. This is mounted underneath the board and produces a 'click' sound for audible feedback when a GUI element on the screen is activated.

The PCB also has three indicator LEDs. The green LED is the power indicator, while the red and yellow LEDs are general-purpose indicators that can be controlled by the BASIC program to signify some status.

The *Explore 100* has two sockets for mikroBUS Click boards, allowing a range of functions to be easily added to the Explore 100 (for example, the twin-relay board pictured here – there are lots more to choose from).

Circuit details

Referring to Fig.1, you can see that the *Explore 100* is mostly a carrier for the 100-pin PIC32 chip (programmed with the Micromite Plus firmware) and the various connectors. Other than the voltage regulator and two transistors, there are no other active devices.

The power input is protected from reverse polarity by Q1, which is a P-channel MOSFET. This is optional and the board is designed so that you can run a blob of solder over two pads and dispense with the MOSFET. Having said that, it doesn't cost much and has little effect on the circuit other than to protect it against damage, so we'd recommend you fit it.

The input 5V is routed to a number of locations, including the Click board sockets, the real-time clock module (RTC), keyboard and I/O connector (CON8). It is also routed to the LCD connector (CON9) as some displays, particularly the 7-inch versions, use this for powering the backlight.

REG1 is a low-dropout linear regulator delivering 3.3V to the PIC32 (Micromite Plus), the Click boards, I/O connector and the LCD panel. It is mounted on a large area of copper on the PCB which acts as a heatsink. As a result, it only gets slightly warm, even at full load.

As with most designs involving a microcontroller, there are 100nF capacitors across all supply lines to reduce voltage variations when pulses of current are drawn. These are through-hole components; the only surface-mount passive component is the 10µF multi-layer ceramic capacitor for the PIC32's internal 1.8V core regulator (connected to pin 85). The part used should have an X5R or X7R dielectric.

The circuit shows pin 51 from IC1 connected to a 2-pin header. This I/O pin was spare and rather than ignore it, we routed it to a header so it can be used for something if needed. The circuit also shows four 10kΩ resistors marked 'I^2C pull-ups'. These provide the option of pulling up the I^2C signal lines to either 3.3V or 5V. Normally, they are not required, as most modules using I^2C already have these resistors onboard.

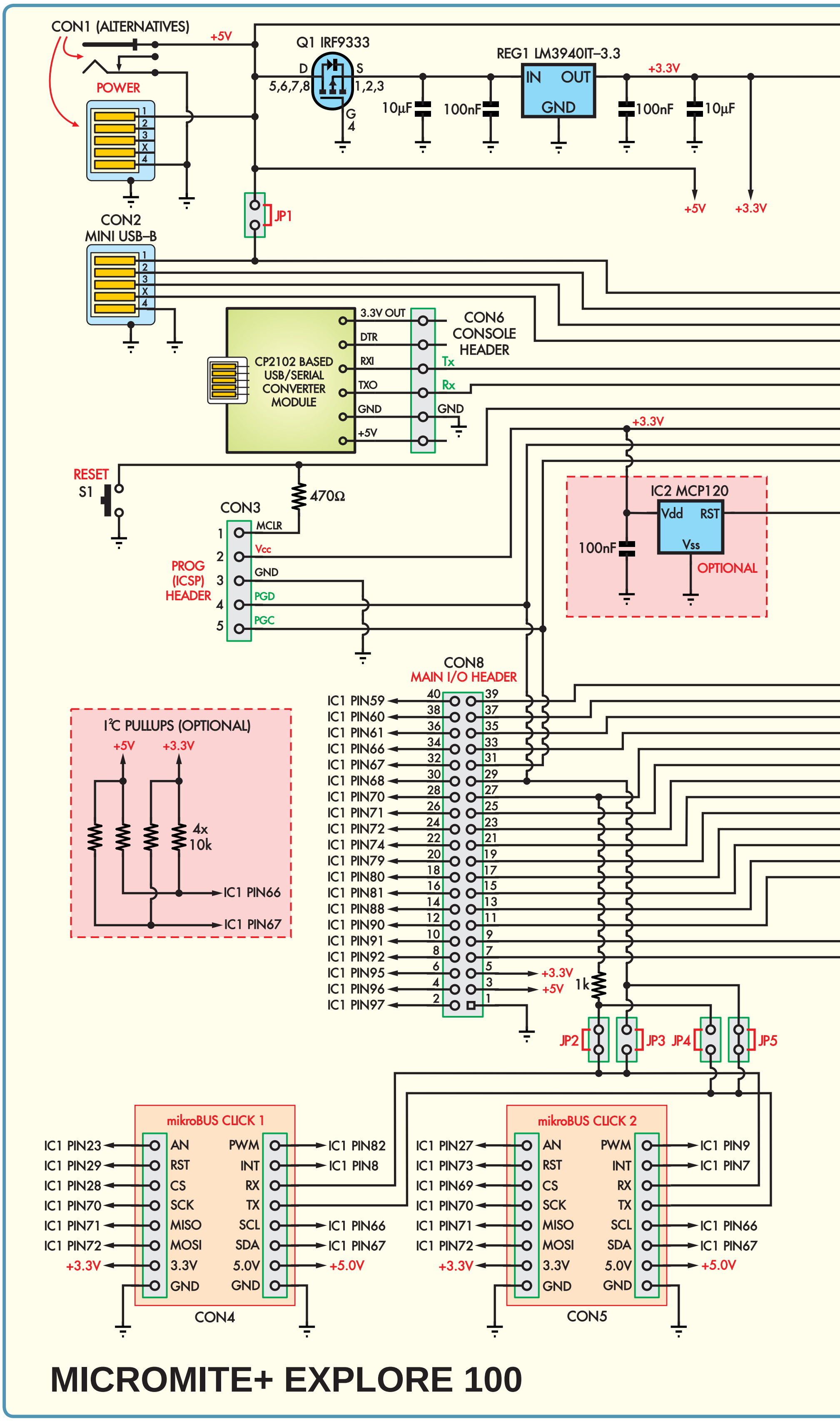
Jumper JP1 allows 5V from USB connector CON2 to supply power to the *Explore 100*. For normal use, a jumper should not be fitted as it could cause the 5V supply from CON1 to back-feed the USB host (a no-no!). However, if you want the USB connector to power the board, you can short JP1 but then you must not use CON1.

Power supply

The photos show an early version of the prototype which used a micro-USB connector for the power input. The final PCB has the option of using either a micro-USB or a standard DC power connector. It also has provision for the previously-described optional MOSFET to protect against accidental power polarity reversal.

The most convenient power source for the *Explore 100* is a 5V regulated plugpack. **Make sure you don't use one of the older transformer-style plugpacks which can easily deliver 8V or more when unloaded, even though they are labelled as 5V. Such a large over-voltage will destroy IC2, the keyboard and any attached Click boards.**

The current drawn by the *Explore 100* depends on the LCD panel used. With a standard 5-inch panel it will



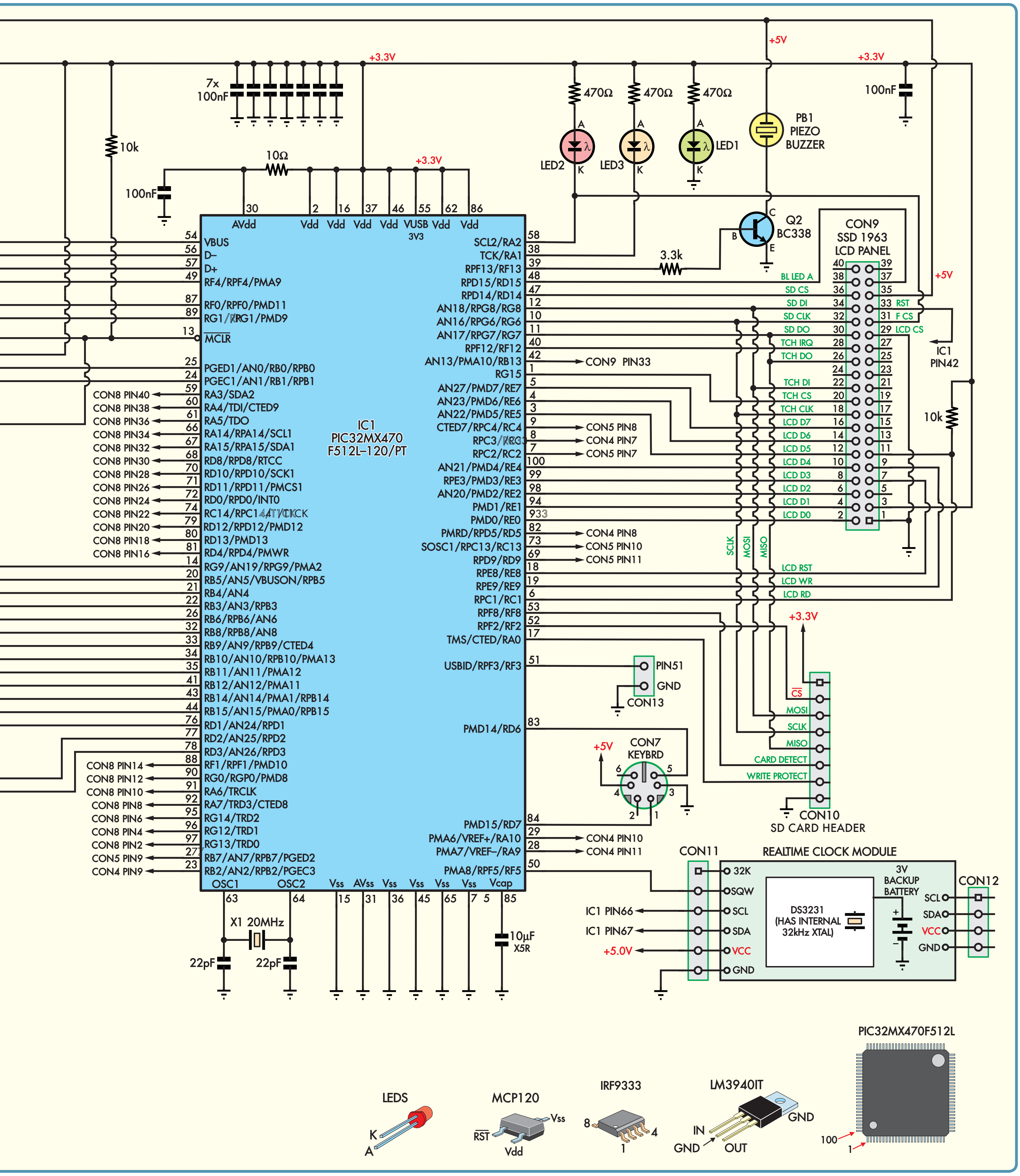


Fig.1: the complete circuit of the *Explore 100* module. It's based on a 100-pin PIC32MX470F512L microcontroller IC1, running the Micromite Plus firmware. Many of the pins on IC1 are routed to various connectors for GPIO, the LCD panel, Click boards and other modules. The remaining circuitry consists of a power supply (based on REG1) and an optional supply supervisor (IC2).

be about 500mA, not including the power drawn by the Click boards or I/O pins. With a 7-inch LCD, it will be about 750mA with the same provisos.

PCB design

The *Explore 100* is built on a four-layer PCB which, like the *Explore 64* described last month, was designed by Graeme Rixon of Dunedin, New Zealand. Normally you would expect something of this complexity to fit on a double-sided board, but because the 100-pin Micromite Plus in the centre connects to almost every other place on the board, a 4-layer design was required.

A 4-layer PCB essentially consists of two thin double-sided PCBs glued in a sandwich, with a dielectric (insulator)

Explore 100 Parts List

1 4-layer PCB, 135mm × 85mm
1 5-inch LCD panel with SSD1963 controller, touch interface and SD card socket ***OR***
1 4.3-inch, 7-inch or 8-inch LCD panel with SSD1963 controller
1 5V DC 1A+ regulated DC power supply with 2.1/2.5mm inner diameter DC connector (centre pin positive) or micro-USB plug
1 PCB-mount DC socket, 2.1/2.5mm inner diameter, to suit power supply (CON1) ***OR***
1 SMD mini USB Type B socket (CON2)
4 8-pin, two 6-pin and one 4-pin female header sockets (CON4-CON6,CON11a,CON11b) ***OR***
2 40-pin or 1 50-pin female header socket cut into sections (as above)
1 40-pin or 50-pin male header, 2.54mm pitch, snapped into two 2-pin, one 6-pin and one 8-pin sections (JP1, CON3, CON10)
1 3-pin right-angle header, 2.54mm pitch (CON6)
1 6-pin PCB-mount mini DIN socket (CON7)
1 dual-row 40-pin header, 2.54mm pitch (CON8)
1 dual-row 40-pin female header, 2.54mm pitch, or dual-row 40-pin male header and matching IDC cable (CON9; see text)
1 shorting block (JP1)
1 20MHz crystal, low profile (X1)
1 23mm buzzer or 14mm buzzer (PB1; see text)
1 tactile pushbutton switch, four pin, through hole (S1)
4 M3 × 12mm tapped spacers and 8 M3 × 6mm machine screws ***OR***
4 M3 × 12mm untapped spacers and 4 × M3 × 16mm machine screws plus 4 × M3 nuts (LCD mounting)
1 M3 × 6mm machine screw with matching nut (for REG1)

Semiconductors
1 PIC32MX470F512L-120/PF (120MHz) ***OR*** PIC32MX470F512L-I/PF (100MHz) in 100-pin TQFP package, programmed with Micromite Plus firmware (IC1)
1 MCP120-270GI/TO reset supervisor, TO-92 package (IC2, optional – see text)
1 LM3940IT-3.3 regulator, TO-220 package (REG1)
1 IRF9333PbF Mosfet (Q1, optional – see text)
1 BC338 transistor, TO-92 (Q2)
1 green 3mm LED (LED1)
1 red 3mm LED (LED2)
1 yellow 3mm LED (LED3)

Capacitors
2 100µF 16V electrolytic
1 10µF SMD ceramic, 3216/1206 package, X5R or X7R dielectric
11 100nF ceramic disc or multi-layer ceramic
2 22pF NP0 ceramic disc

Resistors (0.25W, 5%)
2 10kΩ
4 470Ω
1 3.3kΩ
1 10Ω
1 1kΩ

Sourcing parts

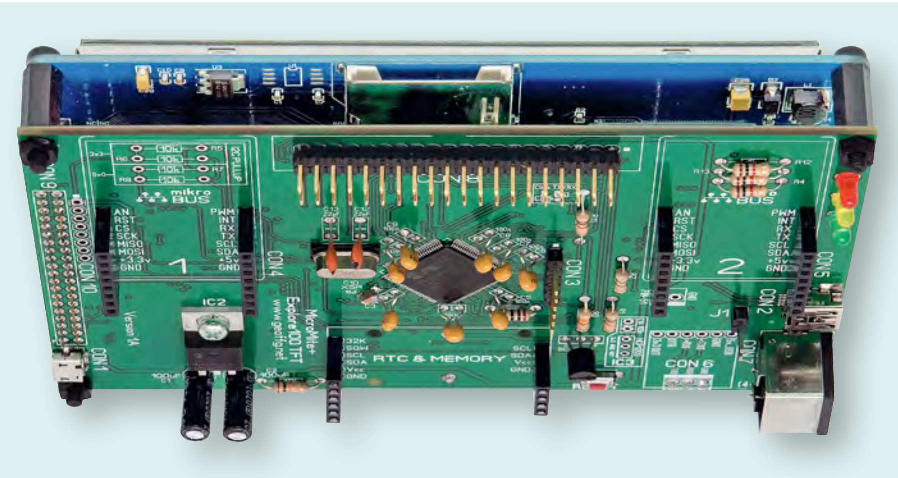
IMPORTANT!

Micromite truly straddles the globe! First and foremost, the on-going series of microcontrollers is designed and developed by Geoff Graham in Australia. Do visit his website for firmware updates and the latest Micromite news: **geoffg.net/micromite.html**

Many of the PCB designs come from Graeme Rixon in New Zealand, and now there is a UK online shop for all things Micromite-related, run by Phil Boyce at: **micromite.org**

We strongly recommend you make **micromite.org** your first port of call when shopping for all Micromite project components. Phil can supply kits, programmed ICs, unpopulated PCBs, PCBs with SMD parts pre-soldered, fully assembled PCBs and many of the sensors and other devices mentioned in recent articles – in fact, just about anything you could want for your Micromite endeavours.

Phil is not just another online vendor of assorted silicon. He works closely with Geoff Graham and is very knowledgeable about the whole series of Micromite microcontrollers.



The *Explore 100* is designed to work with LCD panels that use the SSD1963 display controller, which range in size from 4.3 inches (diagonal) to 8 inches. The mounting holes and physical dimensions of the PCB are designed to match the 5-inch version of this display. The PCB mounts onto the back of the display with four spacers, one at each corner, which creates a single rigid assembly.

in between. The layers are connected by drilled and plated vias which pass through all four layers.

Note that some 4-layer boards have vias which don't go all the way through. In fact, in some cases, they only pass through internal layers ('blind vias'), so they are not visible from the outside of the board. Our design doesn't use any such vias, though.

We're using the outer (top and bottom) layers for signal and power routing and ground planes, with the two internal layers for additional signal routing only. Typically, for a four or 6-layer PCB, the internal layers are used for power and ground planes and the outer layers for signal routing but this is a signal-heavy board so a different scheme was used.

Next month

In Part 2 we'll give the full assembly details, describe the display mounting and run through the setting-up, testing and fault-finding procedures.

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Another fantastic Micromite prize is up for grabs this month thanks to the team at **micromite.org**

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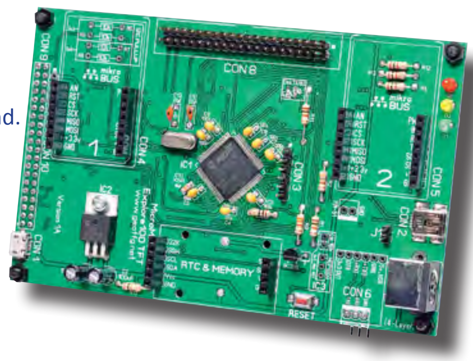
For your chance to win, have a think about what other feature you would like to see for the Micromite. This could be a hardware add-on module or a new software command.

Hint: Think about what your fellow Micromite users would find useful, simple and fun!

Email your idea(s) to: **epe@micromite.org** before **31st August**

Make the email subject **E100**.

The name of the lucky winner will be published in a future edition of *EPE*.



(**PLEASE NOTE:** No TFT Screen, or Click Modules, are included)

Look out for future competitions to win other fantastic Micromite products

Good Luck!

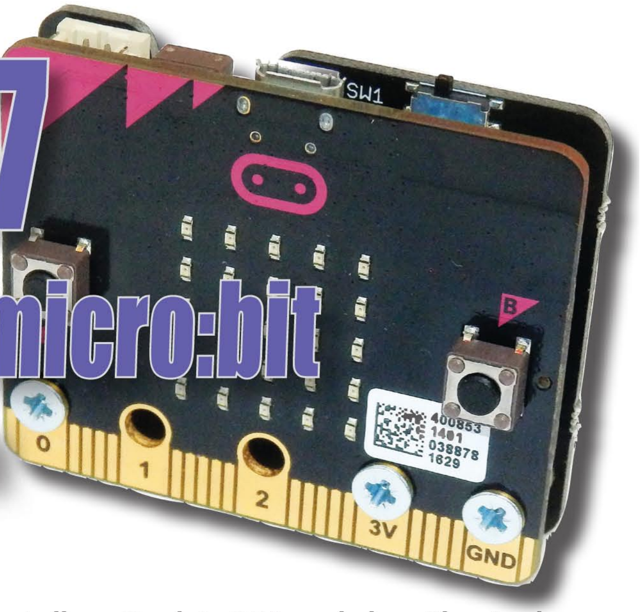
T&Cs

1. You may enter as many times as you wish
2. All entries must be received by the closing date
3. Winners will be notified by email within one week after the closing date
4. Winners will need to confirm a valid address for their prize to be shipped
5. UK winners will have their prize sent via Royal Mail's Special Delivery service
6. Overseas winners will have their prize sent by Royal Mail's International Tracked & Signed service

Teach-In 2017

Introducing the BBC micro:bit

Part 4: Serial data transmission



by Mike Tooley

Welcome to *Teach-In 2017 – Introducing the BBC micro:bit*. Following on from our popular *Teach-In 2016* series on the Arduino (and previously the Raspberry Pi), Mike Tooley has extended his investigation of low-cost microcontrollers to the recently introduced BBC micro:bit. Not just an educational resource for teaching kids coding, this tiny low-cost microcontroller provides you with yet another solution to the problem of controlling a wide range of electronic projects, ranging from simple domestic gadgets to more complex control systems such as those used for lighting, central heating and security applications. To get you up and running quickly, each *Teach-In 2017* concludes with a simple but useful practical project. In this final part, Mike will be delving into serial communication using the micro:bit, and our practical project shows how a micro:bit can be used as the basis of a simple but nonetheless effective wireless-linked remote tamper alarm.

Sending serial data to a host PC

As explained last month, it is extremely easy to read analogue data and display it on the micro:bit's simple LED array. For example, the following code fragment continuously reads the analogue voltage present on pin-0, displaying the returned values on the micro:bit's data display. In this code, the 10-bit data returned from the ADC is converted to a decimal value in the range 0 to 1023, and the corresponding string of text is sent to the LED array.

```
from microbit import *

while True:
    value = pin0.read_analog()
    display.show(str(value))
    sleep(1000)    # Wait before getting another value
```

An alternative to displaying data on the micro:bit's rather limited LED array is sending it serially to a host PC, as shown in the following code fragment:

```
from microbit import *

while True:
    print("DATA = %s" % (pin0.read_analog()))
    sleep(1000)    # Wait before getting another value
```

To make this work, all you need to do is connect the micro:bit's USB port to a PC (or other device) using an appropriate USB cable and the `print` function will send the string via the serial connection. Provided you already have a virtual COM port driver installed on your PC, this is just about all there is to it.

To receive data on a PC (or other device) you will find it easier to make use of a serial terminal application such as PuTTY or Tiny Term. This software will allow you to set up and configure your PC for communication with the micro:bit and receive data from it. You will then be able to view the data as it is received and, if necessary, save the data to a file for later use. Note that the default settings for micro:bit serial communication via a virtual serial port are 115200 baud, with eight data bits, no parity and one stop bit. Fig.4.1 and Fig.4.2 show how a new serial connection is first made and then configured from within Tera Term, while Fig.4.3 shows the same process using PuTTY.

Once you have configured the serial port it is worth testing it to make sure that it is working as expected. Using the

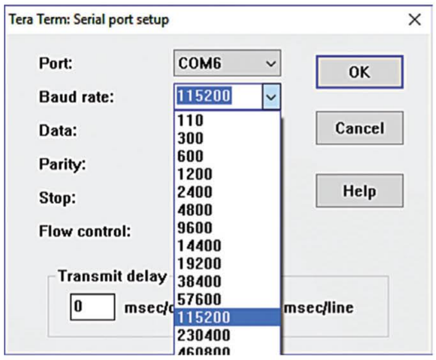


Fig.4.2. Setting up serial port connection in Tera Term

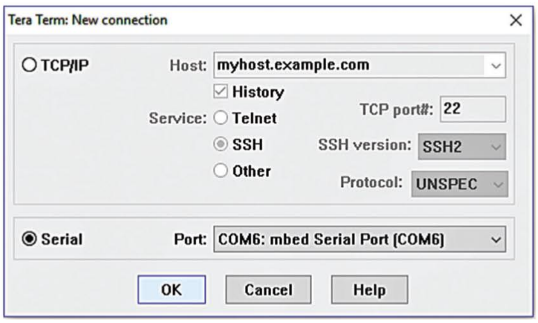


Fig.4.1. Making a new serial connection in Tera Term

Listing 4.1 Sending temperature data to a host computer

```
from microbit import *

while True:
    # First read the TMP36 and convert to deg.C
    sensor_data = pin0.read_analog()
    # The controller can be calibrated (see last month)
    millivolt_data = sensor_data * (3170 / 1023)
    temp_c = int((millivolt_data - 500)/10)
    # Then send the data in deg.C to the host computer
    print("TEMP = %s" % (temp_c))
    # Wait for a short time
    sleep(2500)
```

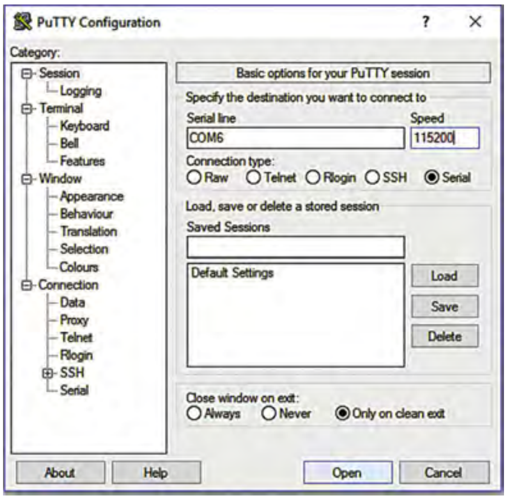


Fig.4.3. Configuring PuTTY

code fragment that we showed earlier, you should find that the data is updated every second and appears like that shown in Fig.4.4 (using Tera Term) or Fig.4.5 (using PuTTY). The received data stream will, of course, be interrupted if the serial cable is removed.

If you intend to capture data and save it in a file for later processing (or to import it into a spreadsheet or maths package) you might find it useful to enlist the help of a more sophisticated serial terminal package like RS232 DataLogger (see Fig.4.6). Once captured, you will be able to save your data, then

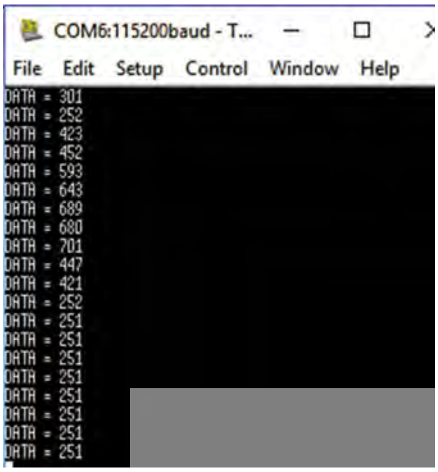


Fig.4.4. Serial data received by Tera Term

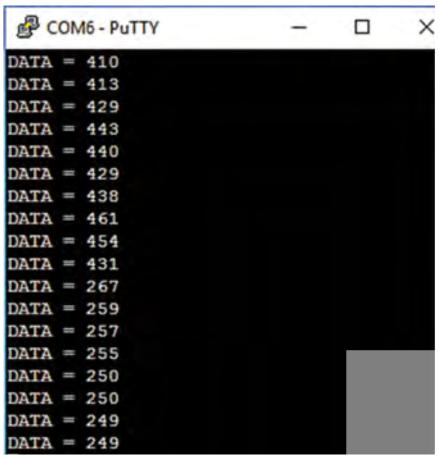


Fig.4.5. Serial data received by PuTTY

open it in a simple text editor for inspection and editing (see Fig.4.7). For example, Listing 4.1 shows how you might send temperature data to a PC with values in Celsius sent every 2.5s for later spreadsheet analysis.

The micro:bit's wireless interface

A significant feature of the micro:bit is that it has its own on-board wireless interface and printed antenna designed for operation using the Bluetooth Low Energy (BLE) protocol (see Fig.4.8). This feature opens a number of interesting possibilities, including being able to develop your code using a nearby mobile device such as a smartphone or tablet.

Pairing

If you intend to use a mobile device such as a smartphone, laptop or tablet to communicate with the micro:bit, your device must first be *paired* with it. Once paired, it will be possible for the mobile device to exchange data with the micro:bit using Bluetooth services.

Pairing is achieved easily. First, you will need to prepare the micro:bit by holding down buttons A and B simultaneously. With these two buttons held down you will next need to press and release the micro:bit's Reset button. Note that you should continue to hold down buttons A and B while you press and release the Reset button. When successful, you should see a message scrolling on the LED display informing you that the device is in 'Pairing Mode'. When this message appears, you can release buttons A and B, at which point a pattern will appear on the LED display telling you that the micro:bit is ready to be paired with your mobile device.

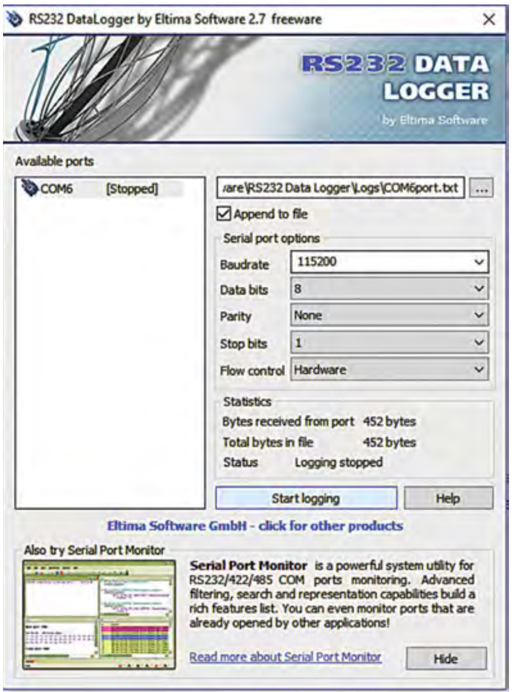


Fig.4.6. Configuring RS232 DataLogger

The procedure for setting up your mobile device will depend on the type of device, but will usually involve going into the device 'Settings' and then selecting 'Bluetooth'. If you then 'Scan' for Bluetooth devices you should see the micro:bit listed. If you select this device and follow any prompts then the pairing operation should be complete.

Using a mobile device for coding

Using the micro:bit's Mobile App (**www.microbit.co.uk/mobile**) it is also possible to develop your code on an Android smartphone or tablet. Simply follow the pairing procedure described above and enter the unique PIN code which will scroll across the micro:bit's display. This process can sometimes be a little tricky, as it needs to be completed within a relatively short time and so may require

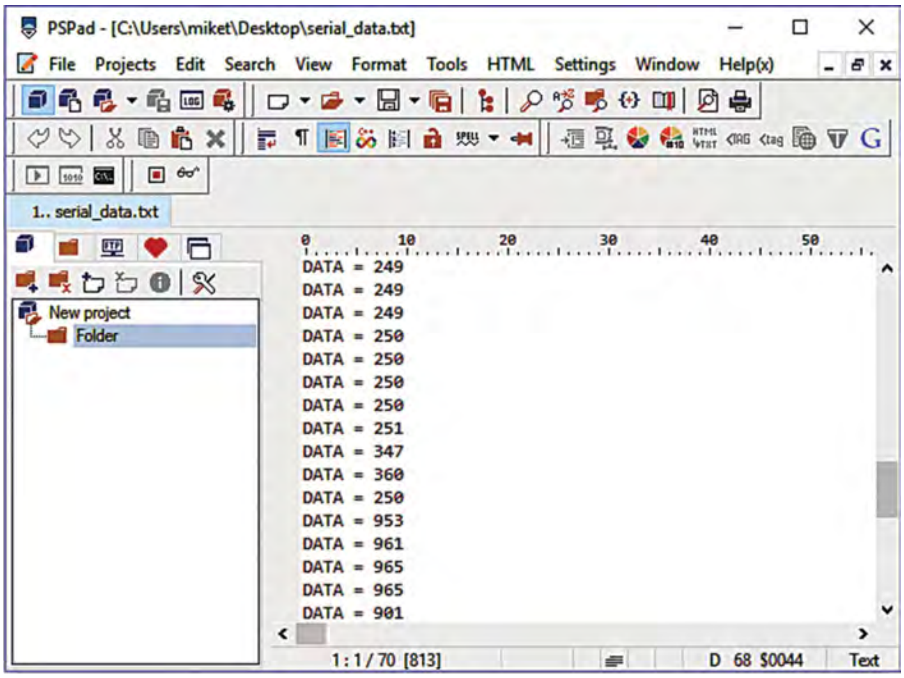


Fig.4.7. Captured data saved in a file for inspection and editing

Fig.4.8. The printed antenna (hidden at the top edge of the micro:bit's PCB)

several attempts to enter the code on your mobile device to finalise the connection. When the code has been accepted, a message will appear to confirm that the two devices are linked via Bluetooth and you can then operate the micro:bit's Reset button in order to begin coding.

You should not need to pair your micro:bit and mobile device every time you need to use them together. However, if, for whatever reason, the pairing settings cannot be found, you will need to repeat the pairing process (this may happen when code is flashed to the micro:bit from a mobile device). The pairing process is instrumental in establishing a trust relationship between devices, and if you do need to repeat the process you will first need to remove the pairing from your mobile device before establishing a new trust relationship.

Using the wireless interface

The default length of a data message is 32 bytes, but this can be adjusted for any length up to a maximum of 251 bytes. By default, three messages can be stored in the micro:bit's incoming message queue. If there is no space left in the queue then any further incoming data is dropped. It is important to note that the message queue occupies space in the micro:bit's memory. Depending upon the application that's running this might be rather limited!

The wireless channel number can be set to any integer value in the range 0 to 100, but the default is Channel 7. Messages will be sent via this channel and only messages received via this channel will be placed in the queue of incoming messages. The frequency used is in the 2.4GHz range, with a channel width of 1MHz and default data rate of 1Mbit/sec.

The micro:bit's radio frequency output power can be set using an integer value of 0 to 7 with a default value of 6. The power settings correspond to dBm (decibels relative to 1mW) values of –30, –20, –16, –12, –8, –4, 0, and 4dBm respectively. Thus, the default power setting corresponds to 0dBm or 1mW (one thousandth of a watt).

The micro:bit's radio library

In order to make use of the micro:bit's radio features you must first import the required library using:

```
import radio
```

Next you need to turn the radio 'on':

```
# Enable the radio
radio.on()
```

The sender and receiver both need to be configured to the same channel; for example:

```
# Set-up the channel to use
radio.config(channel = 5)
```

The data rate used by the wireless interface can be set for 256K, 1M or 2M bit/sec. For example, the following code fragment sets the speed of the wireless connection to the slowest available data rate (250Kbit/sec):

```
# Set speed to 250Kbit/sec
radio.RATE_250KBIT
```

Wireless messages are sent in the form of simple text strings. For example, to send 'EPE Teach-In' you would use the following:

```
# Send a message
radio.send("EPE Teach-In")
```

Alternatively, you could define a string using a variable:

```
# Send a message
message_to_send = "August 2017"
radio.send(message_to_send)
```

To receive a wireless message you need to place it in a string (in this case it will appear as a string named `message_received`):

```
# Receive a message
message_received = radio.receive()
```

Taking this one step further, if you need to receive a wireless message and then send the received data via a hardware serial connection to a PC (or other device) you could use:

```
# Receive a message
message_received = radio.receive()
print("%s" % (message_received))
```

Finally, when you've finished using the radio (and to save power) you can use:

```
# Turn off the radio
radio.off()
```

Listing 4.2 Code for sending a wireless message

```
# Send a wireless message
import radio
from microbit import *

radio.on()       # Turn wireless 'on'
radio.config(channel = 9)

while True:
   radio.send("EPE August 2017")
```

Listing 4.3 Code for receiving a wireless message

```
# Receive a wireless message
import radio
from microbit import *

radio.on()       # Turn wireless 'on'
radio.config(channel = 9)

while True:
   message_received = radio.receive()
   display.show(str(message_received))
```

Listing 4.4 Code used for receiving a wireless message and then sending it serially to a host PC

```
# Receiving a wireless message and displaying it on a PC
import radio
from microbit import *

radio.on()       # Turn wireless 'on'
radio.config(channel = 9)

while True:
   message_received = radio.receive()
   display.show(str(message_received))
   print("%s" % str(message_received))
```

Example

To put this into context, here's a very simple example of communication between two micro:bit devices. Let's assume that we need to send a text message comprising just 15 bytes of data from one device to another. Listing 4.2 shows the code used for sending the message, while Listing 4.3 shows the code used for receiving the message. Listing 4.4 takes this one step further by not only receiving a message, but also sending it via a serial COM port link to a connected host computer. Note that before a message is received (or when the sending micro:bit is out of range) the receiving micro:bit will just display 'None' as the received text.

Some typical micro:bit wireless applications

Wireless linking provides you with an opportunity to explore a variety of interesting and useful micro:bit applications. To give you some food for thought, Listings 4.5 and 4.6 respectively show the code required to implement the transmitter and receiver of a wireless-linked temperature sensor. This arrangement would be ideal for remotely monitoring the temperature in an infant's bedroom, outhouse or greenhouse. It will display the temperature of the remote sensor in Celsius and it will work reliably at distances of typically up to 10m. Note that the battery life of the remote unit will be greatly extended by commenting out the line indicated in Listing 4.5.

Another potential wireless application is a simple wireless-linked remote controller, as shown in Listings 4.7 and 4.8. This arrangement would be ideal for operating lights or sounding an alarm signal in a remote location. The code in Listing 4.7 loops continuously, sensing the state of the micro:bit's two buttons. If Button A has been operated then the sending micro:bit will display an 'O' before sending the 'on' text string. When the 'on' message is received by the second micro:bit (running Listing 4.8) it will also display an 'O' before taking pin-2 high and connecting power to a load via a suitable relay.

Conversely, if Button B has been operated then the sending micro:bit will display an 'X' before sending the 'off' text string. When the 'off' message is received by the second micro:bit it will also display an 'X' before taking pin-2 low, removing power from the load. The code in Listings 4.7 and 4.8 can form the basis of a variety of different applications. All you need to do is add a suitably rated relay along the lines described earlier in the series.

Listing 4.5 Code for the micro:bit wireless temperature sensor transmitter

```
# Wireless temperature sensor transmitter
import radio
from microbit import *
from microbit import display, button_a, sleep

radio.on()      # Turn wireless 'on'

# Event loop.
while True:
    value = str(temperature())
    display.scroll(value)   # Can comment out
    radio.send(value)
    sleep(2000)
```

Listing 4.6 Code for the micro:bit wireless temperature sensor receiver

```
## Wireless temperature sensor receiver
import radio
from microbit import display, sleep

radio.on()      # Turn wireless 'on'

# Event loop.
while True:
    # Read any incoming messages.
    incoming = radio.receive()
    value = str(incoming)
    display.scroll(value)
    sleep(2000)
```

Listing 4.7 Code for the micro:bit remote control transmitter

```
# Wireless remote control transmitter
import radio
from microbit import display, button_a, button_b, sleep

radio.on()      # Turn wireless 'on'

while True:
    # Button A will be used to turn 'on'
    if button_a.was_pressed():
        radio.send('on')
        display.show('O')
    # Button B will be used to turn 'off'
    if button_b.was_pressed():
        radio.send('off')
        display.show('X')
```

Listing 4.8 Code for the micro:bit remote control receiver

```
# Wireless remote control receiver
from microbit import *
from microbit import display, button_a, button_b
import radio

radio.on()      # Turn wireless 'on'
pin2.write_digital(0) # Start in the off state

while True:
  # Read any incoming messages.
    incoming = radio.receive()
    if incoming == 'on':
        display.show("O")  # Button A was pressed
        pin2.write_digital(1)  # Or insert your own code
    if incoming == 'off':
        display.show("X") # Button B was pressed
        pin2.write_digital(0)  # Or insert your own code
```

Project: A micro:bit wireless-linked tamper alarm

Our practical projects have been designed to provide you with hands-on experience of using the BBC micro:bit. Last month's practical project featured a low-cost analogue temperature sensor and a two-channel relay module to form the basis of a thermostatic controller. This month, we will be describing a useful micro:bit gadget that takes advantage of the micro:bit's radio features to implement a wireless-linked tamper alarm.

Our remote tamper alarm uses two micro:bits: one that act as a sender and the other that serves as a receiver. The sender uses the micro:bit's on-board accelerometer to sense motion in all three axes (x, y and z) and its status is continuously updated with data sent to the receiver using the micro:bit's in-built radio interface.

Coding

The code for the micro:bit wireless-linked tamper alarm is shown in Listings 4.9 and 4.10 for the sending and receiving devices respectively. These two listings should be entered using Mu (see Fig.4.10), saved and then flashed to the respective micro:bits.

What does the code do?

In the sender code (Listing 4.9) we first import the necessary library files before initialising the radio interface and setting it to Channel 3. Next, we obtain the initial 'reference' position of the sending unit by reading the accelerometer position along all three orthogonal axes (*x*, *y* and *z*). This will define the initial resting place of the unit. We then enter the main code loop in which we check for any change, first along the *x*-axis, then the *y*-axis and finally the *z*-axis.

If a change in position is detected along a particular axis then we display an '=' icon using the micro:bit's LED array and send a single '!' text character via the wireless link. If no change in position is detected along a particular axis then we display a '-' icon on the micro:bit's LED array, before sending a '-' character using the wireless link.

In the receiver code (Listing 4.10) we once again import the necessary library files before initialising the radio interface, setting it to Channel 3. Next, we read any incoming messages. If the message is a '!' we know that the device must have been moved along one or more of the three axes. If that's the case then we display a 'sad' image on the LED array and take pin-2 high in order to sound an alarm using a piezoelectric sounder (note that this must be a low-current device that generates a continuous sound when 3.3V is applied to it). If the message is a '-' we can conclude that the device has not been moved and so we display a 'happy' image on the LED array (see Fig.4.11) before taking pin-2 low to disable the piezoelectric sounder. Finally, we check the state of the micro:bit's Button B. If this has been operated then we display a cross on the LED array, disable the alarm by taking pin-2 low, and break out of the main loop. The code can be restarted by simply pressing the micro:bit's Reset button.

Using the wireless-linked tamper alarm

If you receive an occasional error message informing you that the 'Received packet is not a string' this problem can usually be corrected by increasing the delay after attempting to read incoming data from the radio. Increasing `sleep(50)` to `sleep(100)` or `sleep(200)` will usually solve this problem. Note also that, when the alarm has been triggered by motion, it will usually cancel automatically if the sending device is returned to the same position that it was originally placed in. This is a useful feature because anyone engaged in tampering with an item to which the sending micro:bit has been attached will soon realise that the only way to stop the alarm is to replace the item in its original position. If wanted, the sensitivity of the sending micro:bit device can be adjusted by changing the initial value. Increasing this value from 100 to, say, 150 or 200, will reduce the sensitivity of the unit. A value of 25 or 50 will make the unit much more sensitive to movement.

Listing 4.9 Code for the tamper alarm sender

```
# Remote tamper alarm sender
import radio
from microbit import *

# Initialise
radio.on()      # Turn wireless 'on'
radio.config(channel = 3)
sensitivity = 100   # Set sensitivity
# Get initial position
reference_x = accelerometer.get_x()
reference_y = accelerometer.get_y()
reference_z = accelerometer.get_z()
radio.send('-')
sleep(50)
# Main loop
while True:
    # Check for motion along the x-axis
    reading = accelerometer.get_x()
    if reading > reference_x + sensitivity:
        display.show("=")
        radio.send('!')
        sleep(50)
    elif reading < reference_x - sensitivity:
        display.show("=")
        radio.send('!')
        sleep(50)
    else:
        display.show("-")
        radio.send('-')
        sleep(50)
    # Check for motion along the y-axis
    reading = accelerometer.get_y()
    if reading > reference_y + sensitivity:
        display.show("=")
        radio.send('!')
        sleep(50)
    elif reading < reference_y - sensitivity:
        display.show("=")
        radio.send('!')
        sleep(50)
    else:
        display.show("-")
        radio.send('-')
        sleep(50)
    # Check for motion along the z-axis
    reading = accelerometer.get_z()
    if reading > reference_z + sensitivity:
        display.show("=")
        radio.send('!')
        sleep(50)
    elif reading < reference_z - sensitivity:
        display.show("=")
        radio.send('!')
        sleep(50)
    else:
        display.show("-")
        radio.send('-')
        sleep(50)
```

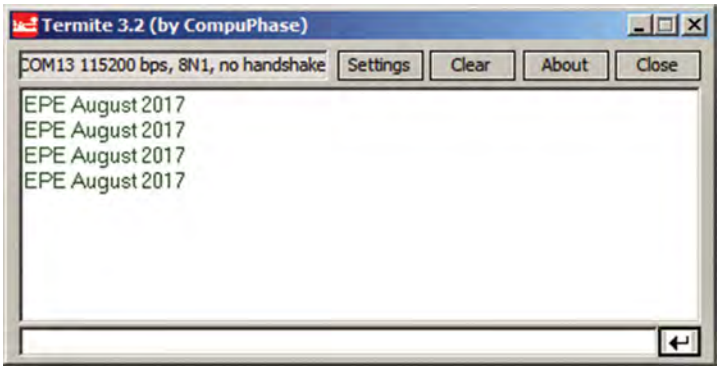


Fig.4.9. The wireless message sent as serial data displayed on a host PC using the Termite terminal application (see Listings 4.2 and 4.4)

Listing 4.10 Code for the tamper alarm receiver

```
# Remote tamper alarm receiver
import radio
from microbit import *
# Initialise
radio.on()      # Turn wireless 'on'
radio.config(channel = 3)
pin2.write_digital(0)    # Start in the off state
# Main loop
while True:
    # Read any incoming messages
    incoming = radio.receive()
    sleep(50)
    if incoming == '!':
        display.show(Image.SAD)   # Motion detected
        pin2.write_digital(1)
    if incoming == '-':
        display.show(Image.HAPPY)# No motion detected
        pin2.write_digital(0)
    if button_b.is_pressed():
        display.show(Image.NO)    # Alarm reset
        pin2.write_digital(0)
        break
```

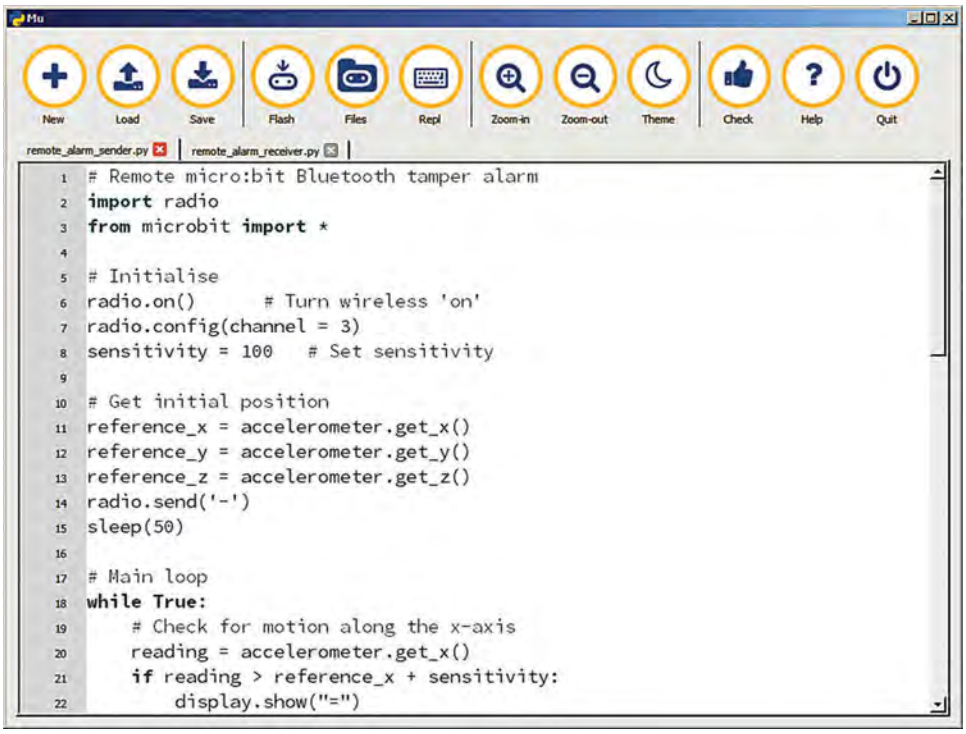


Fig.4.10. Editing the alarm sender code in Mu

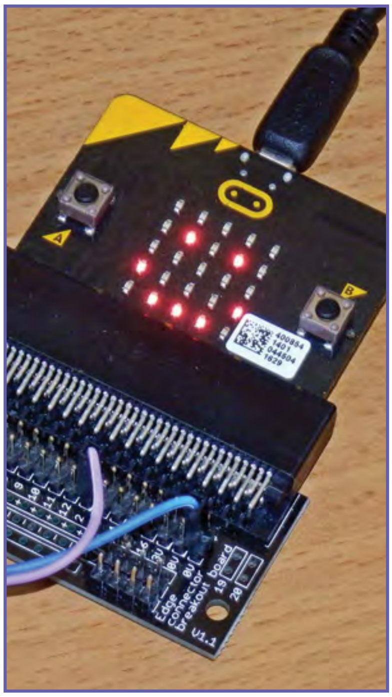


Fig.4.11. The tamper alarm receiver showing a 'happy' icon!

NET WORK

by Alan Winstanley

Garrulous gadgets

AMAZON'S range of network-aware Echo smart devices has stolen the march on Google in the UK, with a strong TV commercial campaign reminding families how an Echo can re-order flour, pizzas, play music or read out the news effortlessly although, less usefully, it cannot yet butter my toast or find the marmalade. The smaller, cheaper Echo Dot seems to be the focus of Amazon's current drive, as Amazon is keen to stick its little cylinders into every room, thereby ensuring that Alexa is always within earshot of its masters.

The Echo ecosystem can also control compatible Internet-of-Things smart appliances. Amazon warns that, 'anyone speaking to Alexa can operate those (connected) products. This includes products such as garage doors, locks and appliances.' Amazon then offers some very basic online recommendations to safeguard such connected devices; eg, turning off the microphone if it's not needed, advice that is a no-brainer anyway – **http://tinyurl.com/ybhflyo6**.

Some owners, untrusting of technology that they fear may be constantly listening to them, keep their devices unplugged unless they are needed. While I could not find any reassurances about Alexa's take on personal privacy spelt out in any online T&Cs, this does not mean to suggest that Echo or any other smart device could be spying surreptitiously on you. Experience of services such as cloud computing and free webmail suggests that most everyday users either don't understand the privacy implications, or they trust the system and waive any concerns in favour of convenience, immediacy and ease of use.

As a sign of what is potentially at risk, a 2014 Wikileaks page (**http://tinyurl.com/zjju36g**) claims that the CIA's 'Weeping Angel' USA/UK workshop was already endeavouring, possibly as nothing more than a proof of concept, to reverse-engineer 2013-era Samsung Smart TVs to create a 'Fake-Off' mode – a TV with built-in camera that seems to be on standby but was in fact wide awake and could presumably be harnessed to spy on you. The technical notes published by Wikileaks illustrated how this TV's Linux-based kernel and associated networking protocols could be re-engineered for potentially illicit purposes. For this reason, some anti-virus software now disables a PC's web camera to prevent unauthorised use – assuming users remember to activate this feature to begin with.

Ultimately, always-on smart networking will integrate completely and seamlessly with all aspects of domestic control, whether at home or work, or on the move. We are not there yet, but future generations will take network 'smartness' totally for granted, just like many of us once treated the new-fangled infra-red remote control as a minor miracle but now treat them as throwaway items (ripe for *EPE* constructional projects!). Smart speakers, 3D cameras and microphones could perhaps be embedded in ceilings or walls as a matter of routine, like any other electrical fitting: intelligent controls and sensors will be omnipresent but go largely unnoticed.

After a late start, Google is working hard to capture its slice of the UK market, starting with the £129 Google Home smart speaker now available from major UK retailers. Although it cannot match Amazon's deep integration with online shopping, Google Home might appeal to more technically-proficient Internet users and unlike Echo it will soon be able to handle multi-user voice recognition too. Meanwhile, Apple, the world's best-known tech brand, has afforded us a tantalising glimpse of its answer to Echo and Google Home, in the shape of a Siri-powered product called HomePod, which claims to analyse a room's acoustics and adapt itself accordingly. An early teaser video depicts a mesh-covered pod being commanded to play favourites; the housing contains an array of whirling coloured lights. Details are scarce and UK buyers will have to wait until December before they can lay their hands on one. More details at: **www.apple.com/uk/homepod/**

The Cortana voice assistant is Microsoft's answer to Siri, Alexa and Google Assistant and is starting to find its way into third-party smart speakers, initially with Harman Kardon's Invoke 360° speaker due later this year. Thanks to Microsoft's involvement, the speaker will also offer Skype VoIP calling. A sneak peek is at: **www.harmankardon.com/invoke.html**. Samsung's voice assistant called Bixby might also emerge as part of a smart speaker in due course.

And now video too

George Orwell described in his novel *1984* how a domestic 'telescreen' spied on his imaginary citizens of the future: 'There was of course no way of knowing whether you were being watched at any given moment...', he wrote, and Orwell described how 'Winston kept his back turned to the telescreen. It was safer; though, as he well knew, even a back can be revealing.' Having found its feet in the smart speaker market, Amazon has debuted its latest smart product, which incorporates a video screen as well. Amazon's Echo Show is a wedge-shaped device featuring a 7-inch colour touchscreen and built-in Dolby stereo speakers. Now Alexa will be able to play Amazon and Youtube videos on-screen or music by voice command, slideshow your favourite photos (stored on Amazon Cloud), or users can simply 'drop in' on other Alexa users and video-chat with them (by prior arrangement, Orwell would be glad to hear).

Alexa learns 'skills' (apps) enabling it to control smart lights or work with other appliances such as video doorbells. Bluetooth enables it to pair with smartphones and, for example, play Apple Music that way. For now, Echo Show is only available in the USA for $229 (or $179 each if you buy two). UK release dates have not been announced.

That's all for this month's *Net Work*. You can email the author at **alan@epemag.net**

Amazon Echo Show is a wedge-shape smart screen with 7-inch LCD and Dolby sound

By Robert Penfold

Raspberry Pi I²C expansion port

THE PREVIOUS *Interface* article covered the basics of SPI and I²C interfacing, and preparing the Raspberry Pi for use with I²C SMBus peripheral devices. Here we move on to a simple I²C expansion port for the Raspberry Pi that provides 16 lines that are individually programmable as digital inputs or outputs. Several of these add-ons can be connected to the I²C bus, making it possible to have over one hundred input/output lines.

MCP23017

An MCP23017 integrated circuit is used as the basis of the expansion port, and this chip is designed specifically for use with an I²C bus. It therefore handles all the encoding and decoding at its end of the system. Python and the Raspberry Pi's operating system handle the same functions at the master end of the system, so data is written to and read from the chip by simply sending and receiving bytes of data. The programmer is not involved with serial encoding and decoding. It operates over a supply voltage range of 2.7 to 5.5V with minimal quiescent-current consumption, and there are no problems in using it with the 3.3V supply output of the Raspberry Pi's GPIO port.

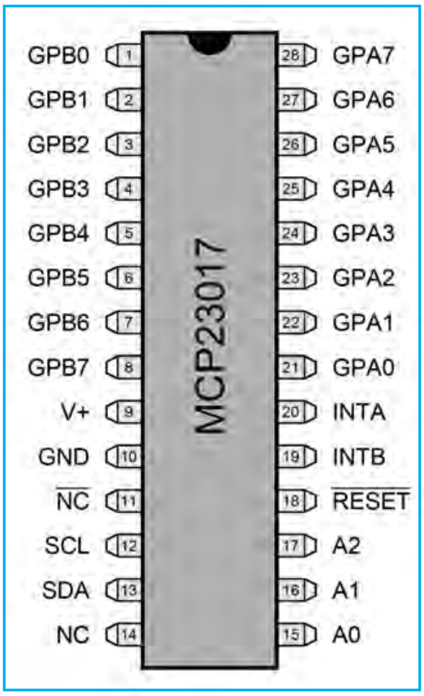


Fig.1. Pinout details for the 28-pin DIL version of the MCP23017. This has two 8-bit ports, with each line individually programmable as an input or an output

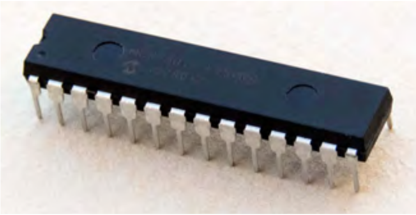


Fig.2. The 28-pin DIL version of the MCP23017. It has the narrower (0.3-inch) row spacing and not the more usual 0.6-inch type

The MCP23017 is available in various surface-mount packages, and also in a standard 28-pin DIL plastic case, which makes it easy to use with a solderless breadboard. Pinout details for the 28-pin DIL version are provided in Fig.1. It uses the narrower version of this package, with 0.3-inch (7.62mm) row spacing, as shown in Fig.2. It should be noted that there is also an MCP23S17 version of the chip. This version is for SPI interfacing, and it is *not* suitable for use with an I²C bus.

GPA0-7 and GPB0-7 are the two 8-bit input/output ports. Due to their programmable nature, these lines can be used for anything from 16 individual lines to a single 16-bit input or output port. A0 to A2 at pins 15 to 17 are the address inputs, and they are used to set the chip's address on the I²C bus. Four bits of the seven-bit address are preset internally, and this restricts the address range to eight addresses from 32 to 40 (20 to 27 hex). No more than eight of these chips can be used on an I²C bus, but the limit of 128 input/output lines that this imposes is unlikely to be of importance in practice.

There is a negative Reset input at pin 18, and this can be pulsed low in order to take the chip back to its default conditions. It has a built-in reset circuit that operates when the chip is powered up, and normally it is unnecessary to supply a reset pulse to pin 18 at switch-on. In most cases, pin 18 can simply be connected to the positive supply rail. Pins 11 and 14 have functions on the MCP23S17 version of the chip, but on the MCP23017 they are dummy pins with no internal connections to them.

Interrupts

INTA and INTB at pins 20 and 19 respectively are two interrupt outputs. They can be set up via a configuration register to operate as active-high, active-low, or open-drain outputs. They can operate individually for their own ports, or in unison so that monitoring one of them will detect an interrupt generated by either port. An interrupt can be generated by an input line of a port changing from its previous state. Interrupts are individually set for each input, so they can be used to monitor anything from one to the full eight inputs per port.

The normal use for interrupts in the current context is to wait for new data to appear on a port. When it appears, an interrupt is generated and the new data is read from the port. This avoids the need for software polling to detect new data, and should give a faster response time. It is a facility that is aimed at a system where everything is on a single board, rather than having an I²C connection to off-board peripheral circuits. However, inputs of the Raspberry Pi's GPIO port can be used as a form of interrupt input, and the interrupt facility of the MCP23017 could be very useful in the current context.

The circuit

The circuit diagram for the Raspberry Pi expansion port is shown in Fig.3. The only component other than the MCP23017 is supply decoupling capacitor C1. A four-line connection to the Raspberry Pi is required, and this carries the clock, data, ground and 3.3V supply lines. The circuit worked reliably when I tried it using the 5V supply at pin 2 of the GPIO port, but the 3.3V supply is the safer option. As the circuit worked fine using the internal reset circuit, the Reset input at pin 18 is simply connected to the positive supply rail.

I also tied the three address inputs (pins 15 to 17) to the positive supply, merely because this was the most convenient way of dealing with them. This places the expansion port at address 40 (27 hex). Any of the eight available addresses can be used, provided conflicts with any other devices on the I²C bus are avoided. Of course, if more than one port is used, each one must have its own address code hardwired to the address inputs. If required, the two interrupt outputs at pins 19 and 20 can be monitored by GPIO inputs, but they are otherwise left unconnected.

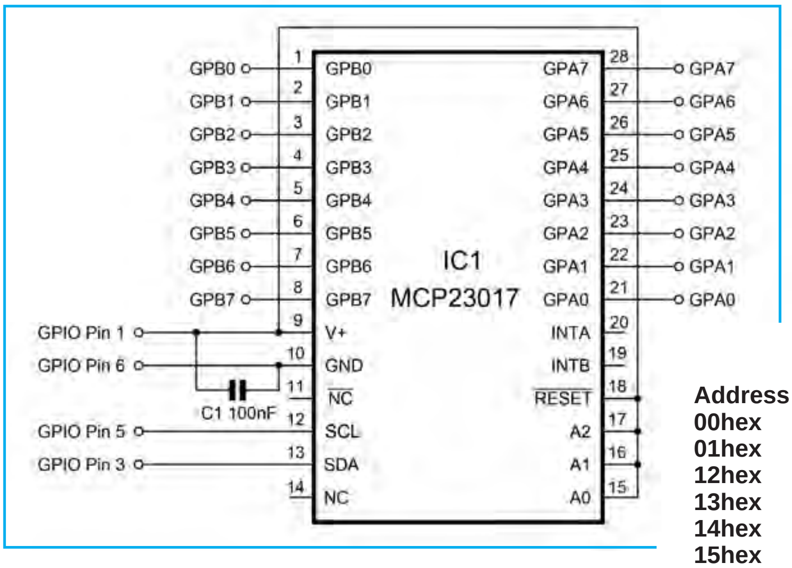


Fig.3. The circuit diagram for the I²C expansion port – only four wires, including the supply lines, are needed to connect it to the Raspberry Pi's GPIO port

Test, testing

Before trying to use the expansion port it is a good idea to check that it has been discovered by the Raspberry Pi's operating system and that it is actually accessible. There is no point in proceeding further until its presence has been detected by the operating system. This line should be entered into a console window:

```
sudo i2cdetect –y 1
```

With an early Raspberry Pi it might be necessary to use this instead:

```
sudo i2cdetect –y 0
```

It should produce something like Fig.4, showing the presence of the expansion port at hex address 27. It will also show entries for any other I²C devices that are present.

Registers

The MCP23017 is a fairly complex device that has a set of eleven registers for each port, plus a control register for both ports. When accessing the device, its address on the I²C bus must be given first, followed by the address of the register being contacted, and then the data for that register if a write operation is being performed. Depending on the state of a bit in the control register, one of two register address maps is selected. With one method, the registers for port A are grouped together at the low addresses, and the port B registers are grouped at the high addresses. By default, the register functions are grouped in pairs. For example, the direction control registers for port A and port B are grouped together at addresses 0 and 1, the bit polarity addresses are at addresses 2 and 3, and so on. The default system is suitable for most purposes, and when reading and writing one byte at a time it does not really matter which type of mapping is used.

Anyone using the MCP23017 really needs to download and study the relevant data sheet, which gives all the ins and outs, including the way in which the interrupt outputs can be used. Here it is only possible to cover the basic use of the ports when reading and writing bytes or words of data. For basic input and output operations it is only necessary to use six of the registers, which are at these addresses by default:

Address	Name	Function
00hex	IODIRA	Input/output direction register, port A
01hex	IODIRB	Input/output direction register, port B
12hex	GPIOA	The pins of port A
13hex	GPIOB	The pins of port B
14hex	OLATA	Output latches for port A
15hex	OLATB	Output latches for port B

By default, all the input/output pins are set as inputs. Accordingly, the ports can be read via the GPIOA and GPIOB registers without the need for any setting up, but it is probably best to do so anyway. Before writing data to a port, the appropriate line or lines must be set as outputs using its direction register. Writing a 0 to a bit of a direction register sets the corresponding input/output pin as an output. As a couple of examples, writing a value of 15 (00001111 binary) to IODIRB, would set GPB4 to GPB7 as outputs, and a value of 0 (00000000 binary) would set the whole port as an output. Data for the port would then be written to the port B output latches at the OLATB register.

Programming

The SMBus module for Python provides six instructions. There are three for writing data to an I²C device, and three for reading from them. Individual bytes, 16-bit words, and blocks of data can be accommodated. However, you can get by with the two that are used to read and write bytes of data. The instruction for writing a byte of data takes this form:

```
smbus.SMBus(1).write_byte_data(Address, Register, Data)
```

Here, `Address` is the I²C bus address of the add-on, which is 27h for the MCP23017 expansion port. `Register` and `Data` are respectively the internal address of the register that is being written to, and the data for that register. The data must be in the form of an integer in the range 0 to 255.

The instruction for reading a byte of data is similar, and takes this form:

```
smbus.SMBus(1).read_byte_data(Address, Register)
```

Again, `Address` is the I²C bus address for the add-on device, and `Register` is the internal address register that is being accessed.

Listing 1 is for a simple Python program that reads port A and prints the returned value on the screen. The first line imports the SMBus module that handles communication with the Raspberry Pi's I²C interface. The next three lines set variables at the values of port A, the port A direction register, and the I²C address of the expansion port. The variables can then be used within instructions, thus avoiding the need to keep checking the actual addresses. This is probably not all that helpful with a small demonstration program, but it makes life much easier with longer programs where several internal registers are being used. The next two instructions set all the port A pins as inputs, and then read the port, placing the returned value in a variable called PINS. This value is then printed on the screen, together with an 'end' message to show that the program has terminated properly.

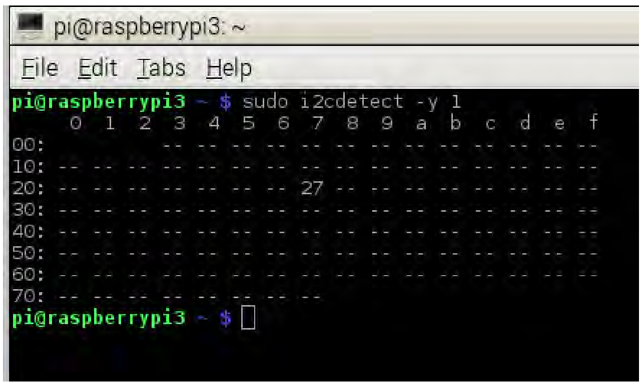


Fig.4. The expansion port is present and correct at hex address 27..

Listing 1

```
import smbus

CHIP_PORTA = 0x12
CHIP_DIRA = 0x00
CHIP_ADDR = 0x27

smbus.SMBus(1).write_byte_data(CHIP_ADDR,
CHIP_DIRA, 255)
PINS = smbus.SMBus(1).read_byte_data(CHIP_
ADDR, CHIP_PORTA)

print (PINS)
print ("end")
```

Listing 2

```
import smbus

bus = smbus.SMBus(1)
CHIP_DIRA = 0x00
CHIP_DIRB = 0x01
CHIP_LATCHB = 0x15
CHIP_PORTA = 0x12
CHIP_ADDR =0x27

bus.write_byte_data(CHIP_ADDR, CHIP_DIRA, 255)
bus.write_byte_data(CHIP_ADDR, CHIP_DIRB, 0)
bus.write_byte_data(CHIP_ADDR, CHIP_LATCHB, 240)
PINS = bus.read_byte_data(CHIP_ADDR, CHIP_PORTA)

print (PINS)
print ("end")
```

Listing 3

```
import smbus

bus = smbus.SMBus(1)
CHIP_DIRA = 0x00
CHIP_LATCHA = 0x14
CHIP_ADDR =0x27

bus.write_word_data(CHIP_ADDR, CHIP_DIRA, 0)
bus.write_word_data(CHIP_ADDR, CHIP_LATCHA, 65280)

print ("end")
```

Listing 2 takes things a step further, and it writes a byte of data to port B in addition to reading port A. Again, variables are set up so that things are more convenient later on. A value of 0 is written to the direction register for port B, setting all eight of its lines as outputs. In this example a value of 240 (11110000 binary) is written to port B, setting GPB0 to GPB3 low, and GPB4 to GPB7 high, but any valid byte value can be used here.

Listing 3 shows how a word can be written to the expansion port. Things operate in much the same way as byte operations, but the data values are16-bits long. Data is sent to and read from the port A registers, but only the least-significant bytes are sent to or read from these. The MCP23017 automatically increments its address counter, and the most significant bytes are sent to or read from the port B registers. In this example a value of 0 is sent to the direction registers, setting both ports as outputs. A value of 65280 (1111111100000000 binary) is sent to the ports, which sets all lines of port A low, and all those of port B high.

PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

Simple PIC Sinewave Generator

WE'RE finally done with the *Beginner's Guide to the PICKit3* and the Low Pin Count Demo Board. For those of you who were following along, I hope it was beneficial and you learned a lot over the last year. I want to finish it all off with a little project that uses a lot of what was learned in the *Guide*. The subjects I want to cover are PWM, button debounce, interrupts, look-up tables and the EEPROM. It's time to make a little noise and what better way than with a PIC and a buzzer!

This month, we're going to start to build a simple sinewave generator using the same PIC16F1829 that we've been using in the *Beginner's Guide*. While we're at it, we may as well try and add a square wave and a triangle wave output as well. By the end of this project, we should be able to hear the difference between a sinewave, square wave and triangle wave from a small buzzer.

Plan of action

As with any project, it's good to have some sort of plan of attack. Starting off with the main features of what we want to achieve in our design, followed by a small breakdown of some of the functions we want to implement and then look at the schematic and components before building the actual board.

It's a good idea to start off with the list of features you want to include in a design. The following list looks at the basic features we want:

- Create a sinewave generator
- Use as much of the PICKit3 Demo Board Tutorials as possible
- Use the PIC16F1829
- Output a generated wave to a buzzer
- Generate a sinewave
- Generate a square wave
- Generate a triangle wave or sawtooth
- Be able to switch between modes
- Show which mode we are currently in using LEDs
- Change frequency of output using a potentiometer
- Use as few components as possible

Showing the mode

While this is quite simple, it also makes it much easier to tell the difference between each mode. There's no point being able to switch between different modes and not know which one we're listening to.

Switching between different modes

A simple momentary button will suffice for mode switching. When we press the button, it will cycle between the various modes we setup in our software.

Programming the device

I intend to use a DIL socket in our design, so we have two options in programming the PIC. We could program it by removing the IC from the DIL socket and using the Low Pin Count Demo Board socket and program it there. However, if you're testing your code and you need to swap it more than two or three times, then it really is a much better idea to use the standard 6-pin programming header (J1 in this design).

Sinewave generator

I've mentioned sinewave, square wave and triangle wave already. What do we mean by these terms? Fig.1 shows these waveforms – each one will sound different, as we'll discover next month when we get it up and running.

There are several ways to generate a sinewave using a PIC. The easiest method is to use a PIC that has a digital-to-analogue converter (DAC). The PIC16F1828 has a single DAC output, which could be used to output all sorts of waveforms. A DAC is the opposite of an ADC input; it converts a digital value into an analogue voltage output. The PIC16F1828 has only a 5-bit DAC with 32 unique voltage levels it can output. Other 8-bit PICs have 8-bit DACs, such as the PIC16F1618, which has 256 voltage levels. 16-bit PICs offer even better resolution in their digital signal controllers – the dsPIC33FJ32GP302 offers 16-bit dual channel DACs, which can be used for full audio synthesis.

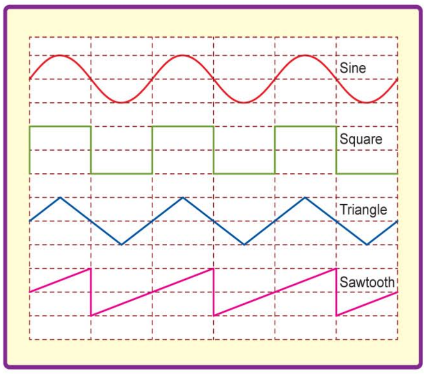


Fig.1. Sine, square, triangle and sawtooth waveform examples

Moving on from using a DAC, we could use Direct Digital Synthesis (DDS), which is a technique for generating an analogue waveform (often sinusoidal) from a time-varying signal in digital form using a DAC. A numerically controlled oscillator (NCO) module operates on the principles of DDS by continually adding a value to an accumulator. When the accumulator periodically overflows, it will produce a transition in the output of the NCO module. This method is used to produce very accurate waveforms.

In this project, we're going to use PWM, which is commonly known as the 'poor man's DAC'. The limitation in using PWM to generate arbitrary waveforms is the lower frequencies. Our low-frequency waveforms won't be 'pretty', but we will gain a deeper understanding of the fundamental building blocks of producing a sinewave using a digital microcontroller. All of the modules mentioned above build upon these blocks for greater frequency range and accuracy. At the end of the day, they all focus around filtering PWM signals.

Generating the square and triangle waveforms

The primary goal is to produce a sinewave with the PIC. The PWM output is already a square wave, but a filter will alter this signal, so we need to be aware of this in our code next month. Generating a triangle or sawtooth waveform will be done in a similar way to creating a sinewave. These will both be secondary functions, based on the sinewave-production technique.

Frequency control

In order to adjust the frequency, we connect a 10kΩ potentiometer into an ADC pin on the PIC. As we adjust the potentiometer, we should be able to adjust the frequency. However, this range will be limited due to the output filter to the buzzer, which has a fixed corner frequency.

Components

Before we take a look at the schematic, here's what we'll need to get started:

Semiconductors
1 × PIC16F1829-I/P (DIL socket type) (IC1)
3 × standard 5mm red LEDs (D2, D3, D4)
1 × standard 5mm green LED (D1)

Passive Components
2 × 330Ω resistors (R5, R6)
1 × 820Ω resistors (R7)
4 × 1kΩ resistors (R1, R2, R3, R4)
2 × 10kΩ resistors (R8, R9)
2 × 68nF ceramic capacitors (C3, C4)
2 × 100nF (C1, C5)
1 × 330nF capacitors (C2)
1 × 10kΩ potentiometer (VR1)

Hardware
1 × momentary SPST button (S1)
1 × 3V piezo buzzer
1 × 20 pin DIL IC socket (2227-30-07 from Multicomp or equivalent) (IC1)
1 × 6-pin header (2213S-06G from Multicomp or equivalent) (J1)
1 × 3-pin header (J2)

Miscellaneous
1 × PICKit3 programmer
1 × multimeter for testing and debug

A quick note on the components – I haven't fully tested all of the software yet, so some of the components in the output filter may be adjusted.

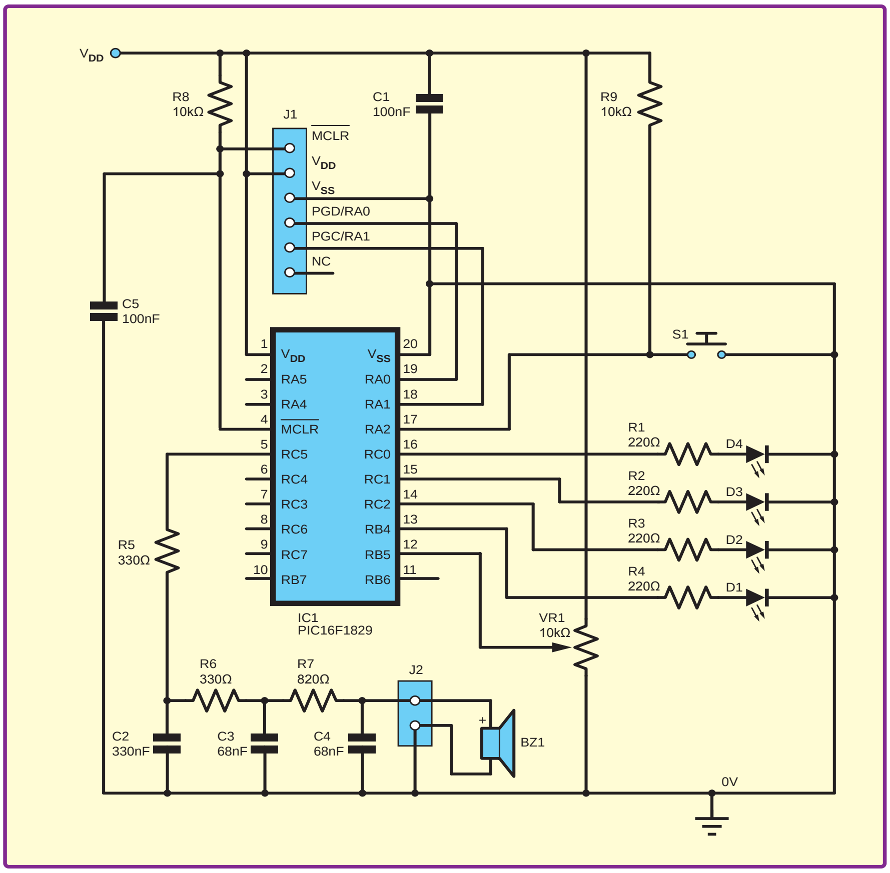


Fig.2. Schematic for the Simple PIC Sinewave Generator *using PIC16F1829*

Circuit details

Examine the schematic in Fig.2. There are 23 components in total. The device will be powered from the PICKit3 programmer, but it can be powered from 2 × AA batteries in a battery holder (BT06092 from Pro-Power).

J1 covers the 6-pin programming header. All of our LEDs are grouped together on similar adjoining pins. We can see the potentiometer VR1 connected to RB5 and our momentary button S1 connected to RA2. One side is connected to V_{DD} and the other side is connected to V_{SS}. When the knob is rotated, we should be able to detect the full voltage range.

R9 is the 10kΩ resistor for the button switch, which ensures RA2 is pulled high, when the button is not pressed, and is pulled low when the button is pressed.

Filter

This is the most important part of the design. I'm using a very basic design to keep component count and design complexity low. As we develop the code next month, we may modify these values to improve our design.

I've mentioned outputting a sinewave using PWM, but how is this really happening? We know the PWM outputs a square wave with a variable period and duty cycle. We need to filter this signal into a sinewave. In order to do this, we need to use an RC (resistor and a capacitor) low-pass filter. This is basically a resistor-capacitor network that allows lower frequencies to pass, while removing higher frequencies. The values of the resistor and capacitor are chosen in order to filter out the higher frequency PWM signal (which will be in the order of 20kHz to 40kHz, or higher) and allow through the 1kHz signal we are trying to produce.

We'll cover where these values come from next month when describing the software and the frequency of the PWM is selected.

Breadboard construction

Once we have all of our components, we should be able to build our board. Fig.3 shows the Veroboard (component side at top and the copper side below). You may need to cut the Veroboard down to size from a larger piece. I recommend running a sharp blade back and forth along a line of holes as it is easier to snap then. It should snap apart easily enough once this is done. Be careful using a blade of any type and always cut away from you.

The orange lines on the underside represent the conductive copper tracks. These need to be cut to separate signals from each other. Large black circles dividing the copper track show the cuts. To make track cuts I recommend using a sharp 2.5mm drill bit and screwing into the board at the hole, not all the way through, just enough to remove

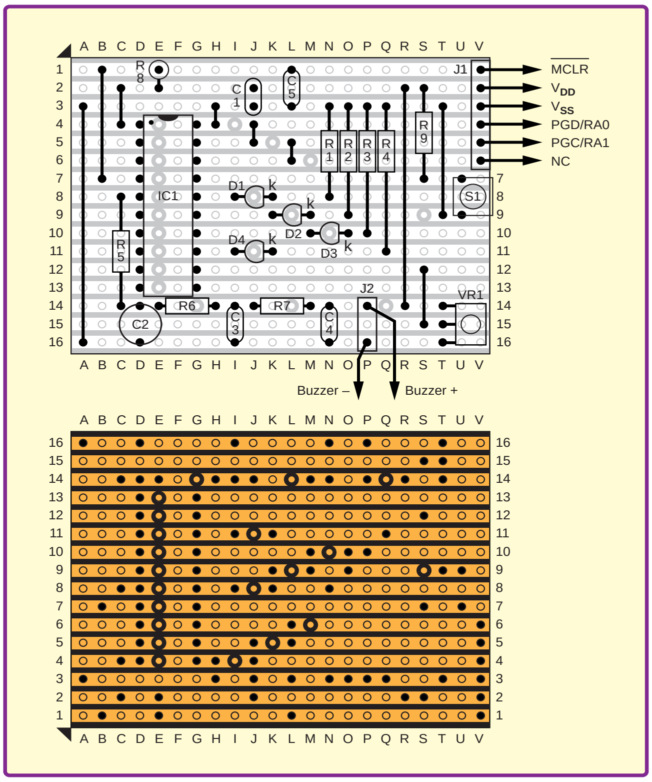


Fig.3. Top and bottom of Veroboard for the Simple PIC Sinewave Generator

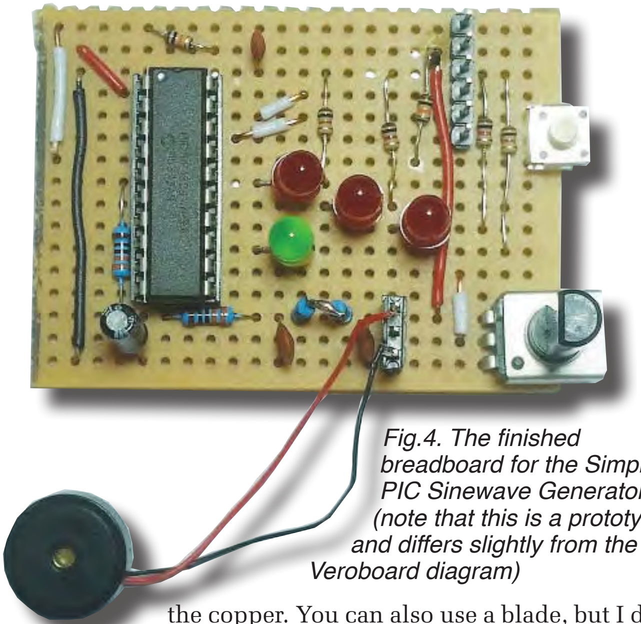


Fig.4. The finished breadboard for the Simple PIC Sinewave Generator (note that this is a prototype and differs slightly from the Veroboard diagram)

the copper. You can also use a blade, but I don't think it looks as nice. Use a multimeter to make sure the two sides of the cut track tracks are now disconnected from each other.

Once all the cuts have been made and holes drilled, we can flip the board over and start placing the components. The top half of Fig.3 shows the component placement and wiring for the board. Compare this to the schematic to place the correct components in the correct place.

A small note on wiring up veroboards for any project, it's much easier to give yourself lots of space and run components and wires perpendicular to the copper tracks. It's also a good idea to avoid crossing wires or components if at all possible.

The finished design should look something like Fig.4. Instead of placing the buzzer straight onto the veroboard, I used a socket header on the board. This means you can connect and disconnect the buzzer, which can be a useful as the buzzer can be annoying when trying to get things working.

Future improvements

I wanted to keep this sinewave generator as simple as possible. There are numerous improvements that can be made to increase the accuracy and shape of the wave. We could go into self-calibration, 2nd and 3rd harmonic distortion effects, as well as finding total harmonic distortion (THD), but I want to focus on the fundamentals first and getting something working before explaining complicated maths, simulations and oscilloscope measurements.

Some possible improvements we may include:

- Use a 20MHz external crystal and 2 × 22pF capacitors to increase accuracy of output; the PIC's internal oscillator used isn't that accurate
- Add a series inductor to the filter at RB5. This will help smooth the output of the PWM into the buzzer
- Adding a relay to swap between the PWM output on RB5 to another PWM pin to get a better square wave output with a greater frequency range
- As mentioned earlier, use a PIC with a DAC and an NCO module for a better frequency range (0Hz up to 500kHz)

Next month

We've looked at the hardware build of the *Simple PIC Sinewave Generator* – next month, we will take a look at the software to control this hardware. This will include PWM, button debounce, interrupts, look-up tables and the EEPROM.

Not all of Mike's technology tinkering and discussion makes it to print.

You can follow the rest of it on Twitter at *@MikePOKeeffe*, up on *EPE Chat Zone* as *mikepokeeffe* and from his blog at *mikepokeeffe.blogspot.com*

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Further high-frequency PCB design

LAST MONTH we looked at how some aspects of transmission line theory informed high-frequency circuit board design. This followed on from a general introduction to transmission line ideas. To recap briefly, transmission line theory enables us to understand (and hence take into consideration when designing) the behaviour of electrical interconnections (PCB traces, cables) when the time taken for a signal to travel the length of the connection is comparable with the timing of the signal itself.

A key concept from transmission line theory is the requirement to match the transmission line to the output impedance of a signal source, and to the impedance of the load at the other end of the line. If this is not done, signal reflections occur, which may degrade circuit performance. The characteristic impedance (Z_0) of a transmission line is expressed in ohms (but the line does not act as a resistor) and is most commonly encountered in the specification of coaxial cables (eg, 50Ω coax). Z_0 depends on the geometry of the connection and its signal return path, and the dielectric constant of the surrounding material. For a given type of circuit board, some of the geometry is fixed (board and copper thickness), as is the dielectric constant (typically 4.2 to 4.9 for commonly used FR4), so the designer must control the characteristic impedance of a trace by setting its width, and possibly the separation gap from adjacent ground connections.

We saw last month that there are several standard geometries for PCB traces, with names such as 'microstrip' and 'coplanar waveguide', for which the transmission line theory and mathematics have been well investigated. As a result, simple-to-use online calculation tools can be used – for example, the width required for a PCB trace to achieve a required characteristic impedance. This allows RF boards to be designed correctly, at low cost, at least for moderate frequencies and performance levels. Of course, in the most demanding cases, professional designers may use advanced tools and high-performance board materials.

Quarter-wavelength transmission line

In previous discussions we have only thought about the length of a transmission line in terms of the signal delay (eg, how long a pulse will take to travel down the line), or in terms of rules of thumb – for example, we should consider transmission line effects if the connection length is 1/20 to 1/10 of a wavelength or more (around 1cm at 1GHz). However, interesting things happen when the line length is an exact fraction of a wavelength, with a quarter wavelength (λ/4) being of particular importance. This month, we will looks at aplications of this type of line, as they are widely used in high-frequency design. We'll also look at two other related issues that are important to understand when developing high-frequency boards – the effect of parasitics and the need for decoupling capacitors.

The wavelength (λ) of an electromagnetic wave on a transmission line is given by $\lambda = v/f$, where v is the speed of the wave and f is the frequency. The speed of the wave depends on the dielectric constant of the surrounding insulation (board material) and is a fraction of the speed of light in a vacuum, given by $F_v = 1/\sqrt{\varepsilon_r}$ (F_v is the velocity factor). For standard PCBs, built using FR4 (with $\varepsilon_r \approx 4.2$ to 4.9) the velocity factor is about 0.5. For a 1.0GHz signal on a transmission line on such a board, the wavelength is about 15cm and a quarter wavelength is around 3.5cm, so a quarter-wavelength transmission line will certainly fit on a reasonably sized PCB from hundreds of MHz up.

Quarter-wave transformer

A quarter-wavelength transmission line is regarded as an electronic component – it behaves like an impedance transformer and can

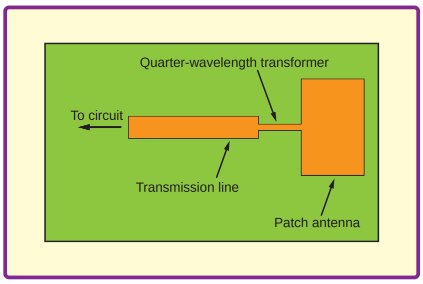

Fig.1. Illustrative PCB layout (top view) showing a patch antenna matched to a circuit via a quarter-wavelength impedance transformer (not scaled for a specific design)

therefore be used for purposes such as matching. Any quarter-wavelength transmission line can be used in this way – that is, it can be implemented using a PCB trace, or length of coax. Quarter-wave transformers (QWTs) are commonly used in radio systems to match transmitters to antennae, but can also be used in filters and other circuit applications. A quarter-wavelength transmission line on a PCB looks just like any other trace – except it has a very specific length and width. At very high frequencies, many electronic components can be created by using the correct geometry of conductors on a circuit board, rather than requiring conventional parts to be soldered for every component used. This can seem quite strange if previously you have only encountered low-frequency design.

An example use of a QWT is shown in Fig.1 – the transmission line, which conveys the signal, will be matched to the active circuitry, at say 50Ω, but if the impedance of the antenna is different (eg, 200Ω) there would be a mismatch if the antenna was connected directly to the transmission line. This can be solved using a matching transformer, as shown in the PCB layout of Fig.1. Note that there is a ground plane under this layout, which is part of the patch antenna, microstrip QWT and transmission line.

QWT operation

Having seen an example of its use we will now look at the operation of the QWT in more detail. Fig.2 shows a quarter-wavelength transmission line driven from a sinewave source with the load open circuit. The graph shows the voltage of the out-going wave along the transmission line a quarter of a cycle after the positive peak in the sinewave left the source – a quarter of the sinewave fits along the line, so the positive peak has just reached the end. This can only happen at one frequency, where the delay of the line from end to end is equal to one quarter of the cycle. Sinewaves 'fitting' on transmission lines are similar to the waves on a guitar string, or in an organ pipe. It is a form of resonance.

For the situation in Fig.2, assume the source is matched to the line. When the wave first switches on the line will appear as a resistance (equal to R_S

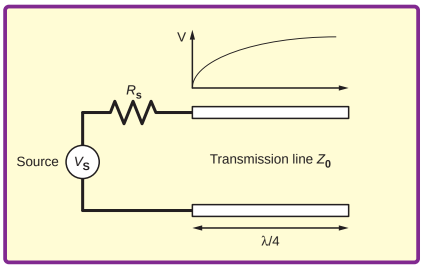

Fig.2. Quarter-wavelength transmission line with an open circuit load

as the line is matched to the source), forming a potential divider, so a wave of amplitude $V_S/2$ will travel down the line. From our discussion two months ago we know that an open-circuit load will reflect the wave with a reflection coefficient of +1. The +1 reflection will double the voltage at the load to V_S as the reflection occurs, so the peak will be at V_S at the open end. The reflected positive peak will arrive back at the source another quarter of a cycle later, at which point the source will be exactly at the negative peak. The waves will cancel and the voltage at the source end of the line will be zero – as if the line was a short circuit at the source end. The voltage at the open end of the line will oscillate with amplitude V_S, but the source end of the line voltage will be constantly zero (except during the first half cycle after source switch-on). Thus, a quarter-wavelength transmission line with an open-circuit load looks like a short circuit to the source. This 'inverting' effect of the quarter-wavelength transmission line is due to the half-cycle (180° phase) round-trip time for the wave travelling from the source to the load and back again.

Similar arguments can be made about a quarter-wavelength line with a short circuit at the load. In this case, the first $V_S/2$ peak arriving will reflect with coefficient –1, giving 0V at the load end (it has to be 0V, it is a short circuit). The reflected $-V_S/2$ peak will travel back, arriving, as before, exactly at the time the source is at its negative peak, reinforcing the source voltage to $-V_S$. Thus, after the first half cycle the signal amplitude at the source end of the line will be V_S, as it would be for an open circuit. So a short circuit load at the end of a quarter-wavelength transmission line looks like an open circuit to the source.

The open/short-circuit transformations just described are extreme cases. In general, a quarter-wavelength transmission line, with characteristic impedance Z_0 connected to a load of impedance Z_L will present an input impedance to the source given by:

$$Z_{in} = \frac{Z_0^2}{Z_L}$$

If we have a load of Z_L and source impedance of Z_S, which are not matched (as in the patch antenna example above) then we can use a QWT to match the source to the load – if the QWT's Z_{in} is set up to equal Z_S. Note that either or both of the source and load could be any suitable circuitry, including another transmission line. Rearranging the above equation gives the required characteristic impedance of the QWT to achieve a match between source and load:

$$Z_0 = \sqrt{Z_S Z_L}$$

So, for the patch antenna example, if the connecting line impedance is 50Ω and the antenna's is 200Ω then the QWT characteristic impedance would need to be 100Ω. This matching only works at one frequency, but more sophisticated circuits, for example using cascaded quarter-wavelength transmission lines, can overcome this.

Wilkinson splitter

In basic low-frequency circuit design, if you need to connect the output of one circuit to two inputs, say from the output of one op amp to the inputs of two other op amps, then you might simply wire it up without much thought. In this, and other similar situations, there is no need to worry about matching – typically a low-impedance source drives a high impedance load and adding another load makes little difference. However, in situations where transmission line effects come into play life is not so simple. For example, consider the situation in Fig.3, where R_S, Z_0 and R_L are matched, and imagine that we need to add another load equal to R_L. If we simply connect the new load via another transmission line, as shown in Fig.4, we cannot achieve matching. If the lines match the load, then their parallel connection at the source will not match. If the parallel line impedances together match the source, then the line impedances will not match the load.

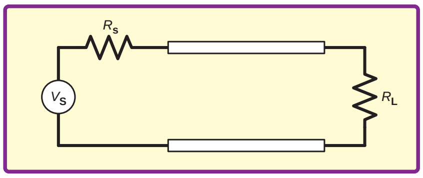

Fig.3. Matched connection from source to load via a transmission line

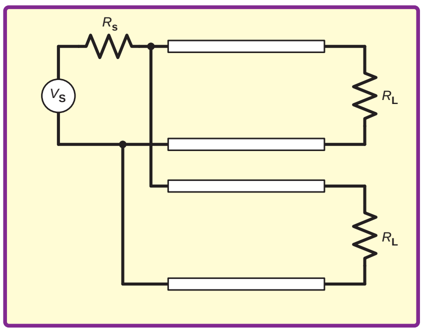

Fig.4. Attempting to add another load to the circuit in Fig.3 like this will cause matching problems

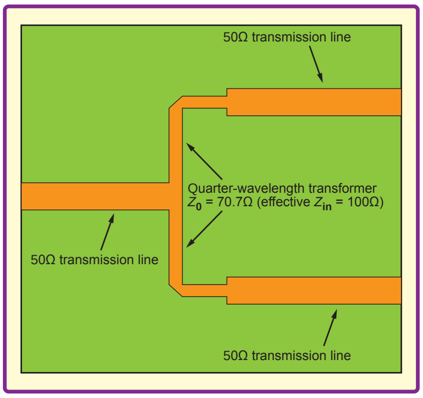

Fig.5. Illustrative PCB layout of two-way power splitter using two quarter-wavelength transformers (not to exact scale)

To match the source with two (equal) parallel connections their input impedance has to each be equal to $2R_S$, so that the parallel combination equals R_S. Hence, for R_S = 50Ω we need two connections with Z_{in} = 100Ω. However, these also have to be individually matched to their 50Ω loads. We can use two QWTs with Z_{in} = 100Ω and Z_L = 50Ω, for which we need Z_0 = 70.7Ω. A possible PCB layout for such an arrangement is shown in Fig.5. Note the mitred corners at the bends, which we discussed last month. Other layouts, with curved QWT lines are also used. Power splitters are commonly required in high-frequency design and their theory was developed in the late 1950s by Ernest Wilkinson. Often, a resistor of value twice the impedance of the I/O lines is connected between the split signals (a circuit known as the Wilkinson splitter).

Parasitic effects

Transmission line matching is not the only issue that has to be considered in high-frequency board design. At high frequencies, parasitic effects may cause significant problems if the design does not take them into account and is not set up to minimise their effects. Parasitics are non-ideal electrical properties (resistance, inductance and capacitance) of electronic components, PCB traces and other structures used in the physical implementation of the circuit. Although the need to consider parasitic effects is by no means exclusive to RF circuits (eg, the resistance of wiring for high currents) they are often a concern in high-frequency design. Although parasitic effects are often a problem, it is also worth noting that the inherent inductance and capacitance of PCB traces can be exploited to achieve required component values in some situations.

In terms of PCB wiring, a long trace will have inductance and capacitance to ground planes, and any traces running in parallel will have capacitance between them. It is not just traces that have parasitics; vias (connections between layers – plated through holes) are imperfect electrical connections and have both inductance and capacitance, with typical values being around 1nH and 0.5pF. As with PCB transmission lines, online calculators are available to calculate via parasitics (eg, the via inductance calculator from Reference Designer at: **http://referencedesigner.com/rfcal/cal_13.php**

Component parasitics are also an important concern in high-frequency circuits. For example, a capacitor has some series parasitic inductance (due to its leads, terminals or electrodes), so it will form a series-resonant LC circuit. Thus, a capacitor has a self-resonant frequency, which will depend on the structure of the capacitor and the dielectric material used. At the self-resonant frequency, an ideal series LC circuit behaves as a short circuit. A real capacitor will not be a perfect short at this self-resonant frequency because it also has parasitic resistance (again in series); this is called the 'equivalent series resistance' (ESR). For frequencies above the series resonance the capacitor will behave like an inductor (ie, its impedance will increase with frequency), but unlike an actual inductor component it will not conduct at DC (the capacitor is still physically an open circuit). This behaviour is sometimes referred to as a 'DC blocking inductor'.

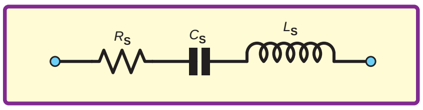

Fig.6. Commonly used equivalent circuit model of a capacitor with series inductance and resistance

If a capacitor behaves as a series RLC circuit then we can draw a schematic to represent this (see Fig.6), which is known as an 'equivalent circuit model'. The model can be used in calculations and simulations. The RLC series model may be too simple to represent what happens in some real situations. In such cases, a more complex model can be used, for example that in Fig.7, which is for a high-frequency ceramic capacitor. Here, there are both parallel and series LC combinations and so more than one resonant frequency – the series resonant frequency (SRF) and parallel resonant frequency (PRF). In reality, there may be multiple resonant frequencies. It is also worth noting that the abbreviation SRF is also used for 'self-resonant frequency', which may cause some confusion.

The capacitor equivalent circuit in Fig.7 is more complex than it may seem at first glance because the component values are frequency dependent. For example, the parallel resistor (R_P) is not the insulation resistance at DC, but is needed to make the model accurate at high frequencies. We discussed related issues in *Circuit Surgery* in the September 2016 article on chip capacitors and the February 2016 article on ferrite bead inductors.

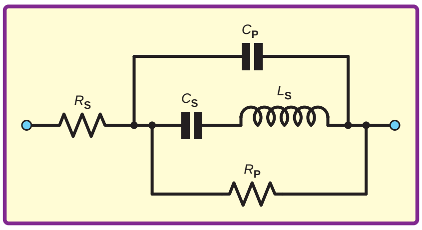

Fig.7. Example of a more complex equivalent circuit model of a capacitor than Fig.6. This is for high-frequency chip capacitors and features additional parallel components. The component values in the model are frequency dependent (based on a model from Johanson Technology Inc)

Decoupling capacitors

It is common for ICs to require power-supply-decoupling capacitors to ensure good quality power delivery to their power connections (pins). For high-frequency circuits these capacitors are often essential for good operation. Device datasheets often specify decoupling capacitor requirements and these should always be followed. The decoupling capacitors remove noise from the power lines and prevent it from entering the signal path. To do this, the capacitors must effectively short the supply at the relevant frequencies, but they will only be effective up to the self-resonant frequency. For this reason, low-value decoupling capacitors (with higher self-resonant frequencies) are often required in high-frequency circuits. However, low-value capacitors are less effective against lower frequency noise, so often more than one capacitor, with different values, are used in parallel to decouple supplies.

Although accurate modelling of real components and PCB layout at high frequencies may be difficult, such analysis is needed in high-performance systems. However, we can infer some rules of good design based on our understanding of the situation, but which do not require detailed individual calculations. This includes, for example, the choice, placement and wiring of decoupling capacitors. The smallest value decoupling capacitors need to be placed very close to the individual power pins of an IC with minimal trace lengths involved in their connection. This is to minimise wiring inductance, which will add to the capacitor's own series inductance. Typically, these capacitors will be surface-mount components connected to a ground plane using a via. In such cases, the vias must be close to the capacitor and each capacitor should have its own via. Examples of good and poor high-frequency layout based on this argument are shown in Fig.8. The capacitors used need to be types suitable for high-frequency decoupling.

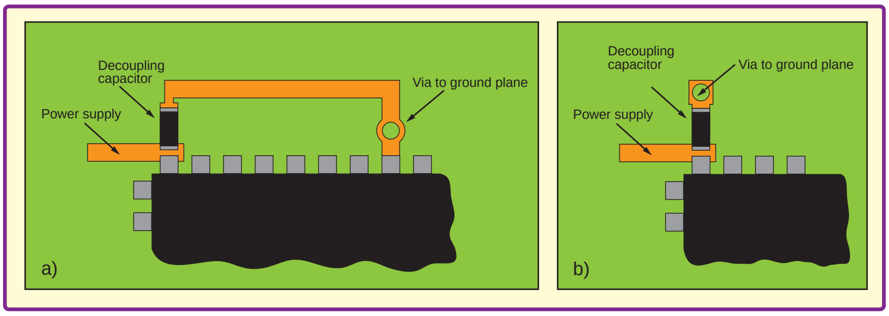

Fig.8. Example of considering PCB parasitics in layout. a) Poor layout because there is a relatively long trace connecting the decoupling capacitor to the ground plane and the via has shared use; b) better layout with short traces from both IC pin and ground to the capacitor, and the via is used solely by the decoupling capacitor

AUDIO OUT

By Jake Rothman

Looming problems – Part 2

Last month, I discussed the lost art of lacing wiring looms. I will now finish this topic by looking at a variety of looming-related techniques to help you make the best of a neat wiring job.

Other techniques

Occasionally, I find 'lacing' with spiral wrap (Fig.12). This was once thought a great idea, but is bulky and heavy and is now mainly confined to office 'cable tidy' kits. Hellerman Neoprene rubber binding sleeves are also useful for small cable bunches and to provide a strain-relief/insulation for wires on tags (see Fig.13a). Although it has been known to provide cover for bad soldering. Fig.13b shows a multiway switch where sleeves have been used in conjunction with lacing to tidy up what is often a wiring nightmare. The sleeves are slid on using Hellerine lubricant (a castor oil mixture which sets) using a sleeve expander tool (Fig.14). These sleeves have now been partly superseded by heat-shrink. I prefer my operatives to use clear heat-shrink so that I can see the soldered joint.

Fixing the loom

Stranded wire looms are floppy, so it is important to fix them down every few inches. Don't use sticky pads, as they fall off after a few years (Fig.15) and are a mark of amateur construction. Use proper screw down hardware such as the 'P' clips illustrated in Fig.16.

Valve heater wiring

This is a special case and warrants an article itself. Because valve heater wiring usually carries AC, it is not included in the loom. It's also best to run the heater wiring close to the chassis for screening, so it is usually laid down first. Placing it along the corner of a metal chassis is also effective. Here, I actually recommend solid-core wire for this job because rigidity is required and it only has to go short distances from one valve holder to the next. To minimise hum, the wire must be twisted. Use two different colours when twisting to keep track of the phase. (In this age of cheap regulated power supplies, DC should be used for low-level valves.)

Fig.12. Spiral-wrap, a bit bulky.

Fig.13. (top) Rubber binding sleeves (right) – easy to put on with lubricant (left); b) a multi-way rotary switch – the wireman's nightmare. Sometimes the wire to the wiper fouls the rotating arm.

Fig.14. Sleeve expander

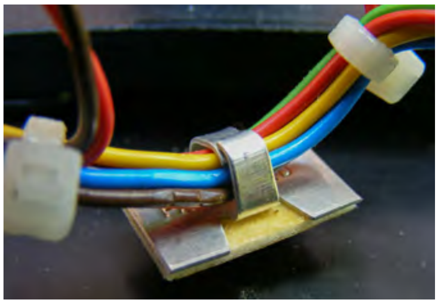

Fig.15. Self-adhesive clips are only temporary and must be avoided.

Termination and tool-lust

There is no point making a nice loom unless it is terminated properly to the tag or PCB terminals. There should be no broken or loose strands protruding from the insulation (Fig.17). Wire strippers with a 'V' shaped notch are banned in safety-critical work because of this. I use a wire stripper by Miller (formerly AB Engineering) called the MK1/FD (from **grovesales.co.uk**), which I've had since 1984 and found nothing better. It has a set of self-adjusting teeth within an inner jaw and a second jaw for clamping the wire (Fig.18). A cheaper stripper, the Miller PS-2 is available from **canford.co.uk**. After stripping, the insulation is pulled near to the end. The insulation is then twisted, which provides a good grip for a straight tight twist and avoids finger contaminants. This is the military way, shown in Fig.19. Just pulling the insulation off, then loosely twisting the strands gives a rough twist.

The next step is tinning the conductor. Attempting to solder stranded wire without tinning may well cause failures. The key here is to obtain proper fluxing to ensure complete impregnation and no lumps. The old trick of applying the solder to the wire,

Fig.16. 'P'-clips – the professional way.

Fig.17. Broken/loose strands can easily cause shorts.

not the iron, is necessary to ensure this. Of course solder has to be placed under the bit at first to establish thermal transmission. Don't let the solder wick up the wire under the insulation. It should stop a half-conductor thickness before it otherwise the insulation will melt and deform. The weak point is always where the insulation stops and the tinned section/joint begins. A maximum distance for this of about 1mm is suggested. Cut the wire to length with side cutters. The best are the Lindstrom 8140. These steps are illustrated in Fig.20.

A loop is the best shape for soldering to terminals, and this is formed with round-nosed pliers (Fig.21). I like the CK Tools T3771D (Rapid 93-1270) shown in Fig.22. (Flat-nosed types nick the wire with their sharp corners.) This is then hooked onto the terminal. Note the direction of the wrap relative to the

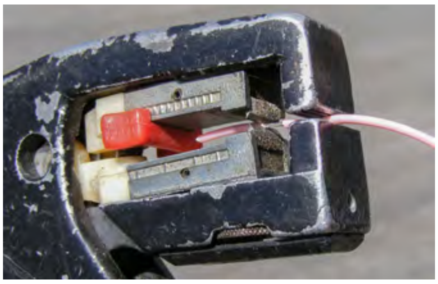

Fig.18. The Miller wire stripper, which is my favourite for stranded hook-up wire.

Fig.19. Twist the wire by turning the insulation. It gives a straighter result with no contamination.

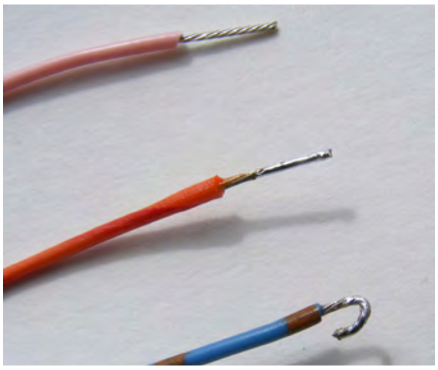

Fig.20. Tinning twisted wire: (top) wire ready for tinning; (middle) tinned wire, insulation melt-back evident; (lower) loop ready for attachment

Fig.21. Forming a loop of tinned stranded wire using round-nosed pliers.

Fig.22. CK round-nosed pliers suitable for fine 7/0.2 cables attached to Veropins.

wire position. The wire should hook round and not unwind if pulled, as shown in Fig.23. Don't wrap it tightly as it will be difficult to remove. For neat soldering, heat the tag before the wire because it has the biggest thermal mass and the risk of melting a wire's insulation is reduced.

If you are in design mode and you know that you may well want to unsolder the joint then just tin the terminal, heat it and place the tinned wire vertically against it, holding it until it sets. This is surprisingly strong with stranded wire and very easy to

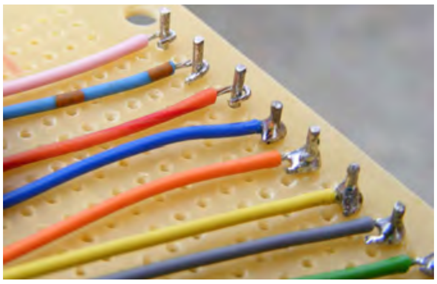

Fig.23. Soldering harness wires to Veropins

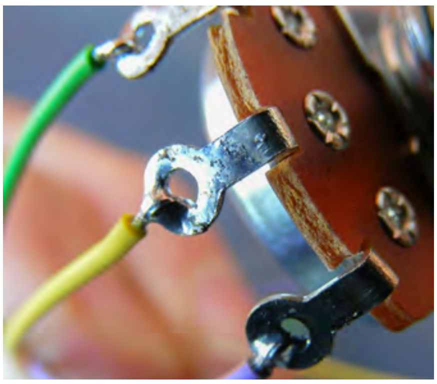

Fig.24. Soldering to tag on pot. Leaving a hole is not a problem and can be used to attach more wires.

Fig.25. For screened wire, the braid conductor is normally the thickest, so it should be the shortest for strength.

Fig.26. Clean dirty tags before tinning with a glass-fibre bush.

unsolder. When soldering tags, such as on pots, it is not necessary to fill the hole completely with solder as is commonly believed (Fig.24). It's easier to add extra connections later if there is a hole. With screened wire, it's best to make the braid the shortest connection, since it is generally thicker and stronger than the inner conductor (Fig.25).

You should clean oxidised tags (Fig.26), a fibre-glass brush works wonders (Rapid order code 49-0595).

Controversially, if making equipment for yourself, prototyping or learning, then use leaded solder. It has much better wetting ability and much longer service life. Just wash your hands before eating those salt and vinegar crisps. I get my leaded solder for £15.00 from Mouser, order code 738-13288. It comes from the US (which hasn't banned it yet) in imperial half-pound rolls.

It's a sign of the times, all too often when I fix up someone's project I have to redo the wiring before I look at the PCBs. I do enjoy examining the mechanical quality of some old equipment such as Tektronix oscilloscopes.

Resources

A great place to learn about soldering is Alan Winstanley's *The Basic Soldering Guide*. Pace Worldwide have some fantastic videos on soldering technique. There is also an excellent book called *Quality Hand Soldering and Circuit Board Repair* by H Ted Smith. *Nasa standard 8739* is well worth a look, as is aeronautical literature, such as the *Federal Aviation Authority advisory circular* AC 43.13-1B, Chapter 11, Aircraft Electrical Systems pages 1-190

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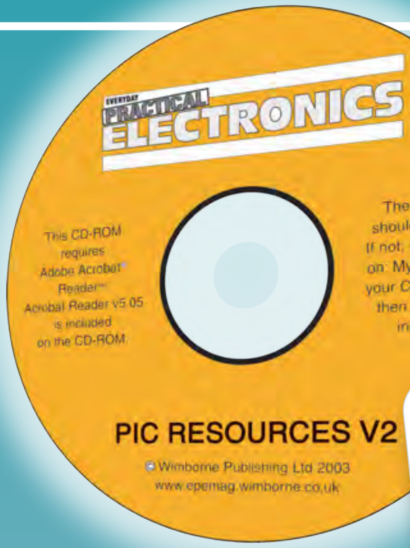

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Max's Cool Beans

By Max The Magnificent

Precious memory

In my previous column (*EPE*, August 2017), we talked about how computer memory used to be tremendously expensive, which meant we had to learn to use very little of it. We also talked about how I used to write programs for a GenRad 2225 printed circuit board tester, and how a linear feedback shift register (LFSR) could be used to compress thousands of bits of test data into a single 16-bit 'signature.'

Another type of data we had to compress was that of text, including letters, numbers, punctuation and other special symbols. In this case, GenRad used a variation of the Radix-50 format that was originally created by Digital Equipment Corporation (DEC). The advantage of the Radix-50 format is that it can encode three characters in a 16-bit word, as opposed to standard ASCII which can store only two.

Plentiful memory

These days, of course, computer memory is cheap and plentiful. Thus, for most applications – especially those that run on larger systems like desktop, notepad, and tablet computers – we really aren't too concerned about how much memory we are using.

In some cases, however, such as Internet of Things (IoT) devices based on teeny-tiny microcontrollers, we may run into strict memory limitations, in which case the tricks and techniques we are talking about here – or your own custom variations thereof – may prove to be jolly efficacious.

What do we want to do?

For the purposes of these discussions, we will derive our own flavor of the Radix-50 format. Before we do so, however, let's first agree on what we want to do. Ideally, we want some way to encode the uppercase alpha characters 'A' to 'Z', the lowercase alpha characters 'a' to 'z', the numeric characters '0' to '9', the space character ' ', and all of the regular punctuation characters. In the case of the well-known ASCII code, we require seven bits to store 32 control characters and 96 printing characters, as illustrated in Fig.1.

MSBs	LSBs															
	0000	0001	0010	0011	0100	0101	0110	0111	1000	1001	1010	1011	1100	1101	1110	1111
000	NUL	SOH	STX	ETX	EOT	ENQ	ACK	BEL	BS	HT	LF	VT	FF	CR	SO	SI
001	DLE	DC1	DC2	DC3	DC4	NAK	SYN	ETB	CAN	EM	SUB	ESC	FS	GS	RS	US
010	Space	!	"	#	$	%	&	'	(	)	*	+	,	-	.	/
011	0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
100	@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
101	P	Q	R	S	T	U	V	W	X	Y	Z	[	\	]	^	_
110	`	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
111	p	q	r	s	t	u	v	w	x	y	z	{	|	}	~	DEL

Fig.1. The 128 standard ASCII characters and codes

Note that the acronym 'MSB(s)' stands for 'most-significant bit(s) and 'LSB(s)' stands for 'least-significant bit(s),' so the code for 'A' would be 100 0001 in binary or 65 in decimal.

Since ASCII requires 7 bits to store each character, this means that two such characters require 14 bits, so we can store only two characters in a 16-bit word with two bits left over. Another way of looking at this is that 16 bits can store 2^16 = 65,536 different combinations of 0s and 1s, but we are using only 2^14 = 16,384 of these patterns. In turn, this means we are using only 16,384/65,536 = 0.25, or 25% of the available patterns, which means we are wasting 75% of our memory bits. Generally speaking, this is not considered to be a good thing to do.

Remember octal?

For reasons that will soon become apparent, we are going to be working with a 40-character encoding scheme. We might think of this as being a Radix-40 scheme, but earlier we said that we were going to derive our own flavor of DEC's Radix-50 format. What gives? Well, DEC's format was conceived at a time when computer designers and users commonly employed the octal (Base-8) number system, and Radix-50 in octal is equivalent to Radix-40 in decimal (5 × 8 = 4 × 10).

So, if we can represent only 40 characters, what characters should these be? Well, my first choice would be the uppercase alpha characters 'A' to 'Z', the numbers '0' to '9', and a space character as illustrated in Fig.2.

As we see, we require six bits to encode our 40 characters. Of course, 2^6 = 64 different combinations of 0s and 1s, but we're using only 40 of these possibilities (we aren't using the 101, 110, and 111 MSB values).

At a first glance, you might think we've made things worse, not the least that we are now able to represent less than half of the 96 ASCII printing characters. We do have three 'spare' codes, but these aren't sufficient to represent any useful subset of punctuation symbols. Observe that I've annotated two of these codes, 011 011_2 and 011 100_2, as 'Su' and 'Ss', respectively; we will return to consider these little scamps shortly.

Now, since we require 6 bits to store each character, this means that two such characters require 12 bits. As for ASCII, we can still store only two such characters in a 16-bit word, but now we have four bits left over. This means we are using only 2^12 = 4,096 of our 65,536 possible patterns of 0s and 1s, which means we're wasting 93.75% of our memory.

Can this get any worserer?

I hate to tell you, but things get worse when we consider that we're only actually utilising 40 patterns out of the 64 that can be represented by each 6-bit field. This is because we can now store only 40 × 40 = 1,600 different character combinations in our 16-bit word, and 1,600/65,536 = 0.024 = 2.4% utilisation, which means we're really wasting 97.6% of our precious memory. Eeek!

But fear not, my friends, because things are about to get a whole lot better. Suppose we want to encode the character string 'HEY', where 'H' = 001 000_2 (8_{10}), 'E' = 000 101_2 (5_{10}), and 'Y' = 011 001_2 (25_{10}). We could achieve this using ('H' × 40^2) + ('E' × 40^1) + ('Y' × 40^0); that is, (8 × 40^2) + (5 × 40^1) + (25 × 40^0). Of course 40^2 = 40 × 40 = 1,600; 40^1 = 40; and 40^0 = 1; which gives us (8 × 1,600) + (5 × 40) + (25 × 1) = 13,025.

Another way of performing this calculation is to take the first character ('H') and multiply it by 40, add the second character and multiply the result by 40, and then add the third character; that is, ((('H' × 40) + 'E') × 40) + 'Y' = (((8 × 40) + 5) × 40) + 25 = 13,025.

A minor detour

As an aside, if you are dealing with a really teeny-tiny microcontroller that doesn't have a hardware multiplier, then a short cut for multiplying a value X by 40 is to first multiply it by 4 to generate Y, and then multiply Y by 10. In turn, 10Y is the same as saying 8Y + 2Y. The point is that when working with the binary values stored inside the computer, multiplying a value by 2, 4, or 8 is the same as shifting it 1, 2, or 3 bits to the left, respectively. Thus, we've reduced our clock-cycle-intensive multiplication by 40 to a couple of shift and add operations, but I digress...

MSBs	LSBs							
	000	001	010	011	100	101	110	111
000	Space	A	B	C	D	E	F	G
001	H	I	J	K	L	M	N	O
010	P	Q	R	S	T	U	V	W
011	X	Y	Z	Su↑	Ss↕		0	1
100	2	3	4	5	6	7	8	9

Fig.2. First pass at a Radix-40 code

MSBs	LSBs							
	000	001	010	011	100	101	110	111
000	Space	a	b	c	d	e	f	g
001	h	i	j	k	l	m	n	o
010	p	q	r	s	t	u	v	w
011	x	y	z	Sd↓	Ss↕		+	-
100	.	,	;	:	'	"	?	!

Fig.3. Enhancing our Radix-40 code

MSBs	LSBs							
	000	001	010	011	100	101	110	111
000	#	$	%	&	@	*	(	)
001	[	]	{	}	/	\	|	=
010	<	>	~	^				
011								
100								

Fig.4. A third set of less frequently used characters

When we eventually wish to take our 16-bit value of 13,025 and extract the characters, which will appear in reverse order, we do so as follows. The first step is 13,025 % 40 = 25, where % is the modulus operator that returns the remainder from an integer division, and 25 is our code for the letter 'Y'. Next, we subtract this code from our total and divide the result by 40; that is, (13,025 – 25) / 40 = 325.

Now we repeat the modulus operation: 325 % 40 = 5, where 5 is our code for the letter 'E'. Once again, we subtract this code from the total and divide the result by 40; that is (325 – 5) / 40 = 8, which is, of course, our code for the letter 'H'. (You may be wondering why we didn't perform a final modulus operation, but 8 % 40 = 8, so this would be superfluous.)

Radix-40 triumphs

The end result of all this is that we can now store 3-character strings in 16-bit words, where these strings can range from '   ' (three spaces) to '999'. Since our code for a space is 000 0000_2 (0_{10}) and our code for a '9' is 100 111_2 (39), this means we end up using values of 0 through (((39 × 40) + 39) × 40) + 39 = 63,999. Another way of looking at this is that we can now store 40 × 40 × 40 = 64,000 different character combinations in our 16-bit word, and 64,000/65,536 = 0.977 = 97.7% utilisation, which should bring smiles to our faces.

All of the above explains why we decided to use a Radix-40 character set. If we used Radix-39 or lower, we would be wasting space, while Radix-41 or higher wouldn't allow us to store 3-character strings in our 16-bit word.

This looks shifty

Sad to relate, we are still left with the problem that we can currently only represent the uppercase letters 'A' to 'Z', the numbers '0' to '9', and the space character with our current coding scheme.

Well, do you remember the code we annotated as 'Su' ('Shift up')? The idea here is that, by default, we start off using our original character set. When we see a Su code (011 011_2), we swap over to using the alternative character set illustrated in Fig.3. This gives us access to the lowercase characters and some of the commonly used punctuation characters.

Observe that we are now showing code 011 011_2 as having an 'Sd' ('Shift down') annotation. The idea is that we will continue to use this new set of characters until we see an Sd code, at which time we will return to using our original set.

Observe that we decided to use code 000 000_2 to represent a space in both of our character sets. This saves us having to switch back and forth between characters sets if we have sentences formed from words comprising only uppercase or lowercase letters.

What about code (011 100_2) which we've annotated as 'Ss' ('Shift special')? Well, when we see this little scamp, we can use it as a control to say that the following code will represent a member of a third set of less-frequently required symbols as illustrated in Fig.4.

As you can see, I actually ran out of symbols I wanted to represent, but I'm sure we could think of something to use the remaining codes for if we wished. The reason we can use all forty code possibilities in this set is that, as soon as we've accessed this character, we will automatically swap back to whichever character set we were using before we saw the Ss code.

In closing, I'm not suggesting that you should use the techniques shown here for anything in particular, but I think you may find that the underlying principles may come in handy one day. Until next time, have a good one!

Any comments or questions? – please feel free to send me an email at: **max@CliveMaxfield.com**

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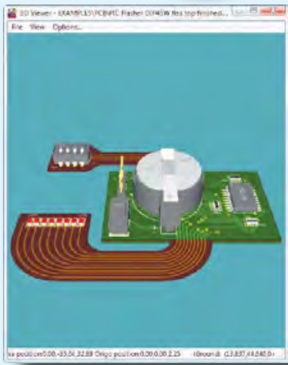

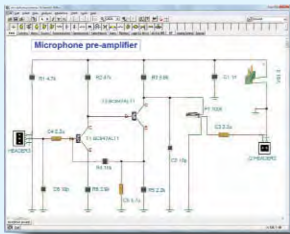

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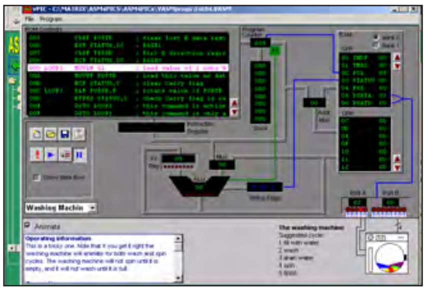

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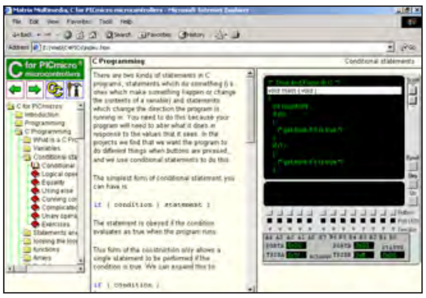

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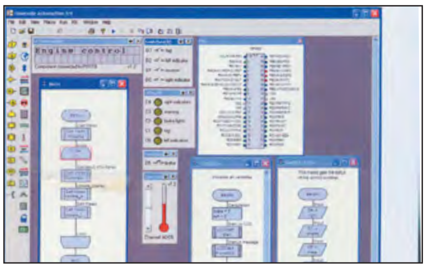

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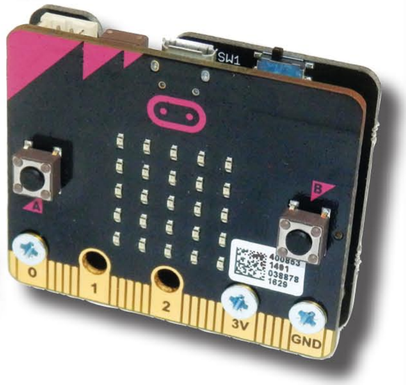

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FOR A FULL DESCRIPTION OF THESE BOOKS AND CD-ROMS SEE THE SHOP ON OUR WEBSITE

www.epemag.com

All prices include UK postage

GETTING STARTED WITH THE BBC MICRO:BIT
Mike Tooley

Not just an educational resource for teaching youngsters coding, the BBC micro:bit is a tiny low cost, low-profile ARM-based single-board computer. The board measures 43mm × 52mm but despite its diminutive footprint it has all the features of s fully fledged microcontroller together with s simple LED matrix display, two buttons, an accelerometer and a magnetometer.

Mike Tooley's book will show you how the micro:bit can be used in a wide range of applications from simple domestic gadgets to more complex control systems such as those used for lighting, central heating and security applications. Using Microsoft Code Blocks, the book provides a progressive introduction to coding as well as interfacing with sensors and transducers.

Each chapter concludes with a simple practical project that puts into practice what the reader has learned. The featured projects include an electronic direction finder, frost alarm, resction tester, battery checker, thermostatic controller and a passive infrared (PIR) security alarm.

No previous coding experience is assumed, making this book ideal for complete beginners as well as those with some previous knowledge. Self-test questions are provided at the end of each chapter together with answers at the end of the book. So whatever your starting point, this book will take you further along the road to developing and coding your own real-world applications.

108 Pages | **Order code BBC MBIT** | **£7.99**

THEORY AND REFERENCE

PRACTICAL ELECTRONICS HANDBOOK – 6th Edition. Ian Sinclair
440 pages | **Order code NE21** | **£33.99**

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MICROPROCESSORS

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– LEARNING TO FLY THE PIC24 Lucio Di Jasio
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David W. Smith
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Mike James
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Books are normally sent within seven days of receipt of order, but please allow 28 days for delivery – more for overseas orders. *Please check price and availability (see latest issue of* Everyday Practical Electronics*) before ordering from old lists.*

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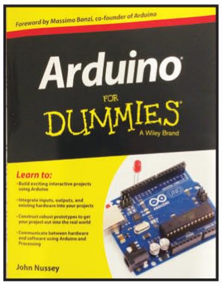
Teach-In 2016
Exploring the Arduino



ARDUINO FOR DUMMIES
John Nussey

Arduino is no ordinary circuit board. Whether you're an artist, a designer, a programmer, or a hobbyist, Arduino lets you learn about and play with electronics. You'll discover how to build a variety of circuits that can sense or control real-world objects, prototype your own product, and even create interactive artwork. This handy guide is exactly what you need to build your own Arduino project – what you make is up to you!

- Learn by doing – start building circuits and programming your Arduino with a few easy examples – right away!
- Easy does it – work through Arduino sketches line by line, and learn how they work and how to write your own.
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- Kitted out – discover new and interesting hardware to turn your Arduino into anything from a mobile phone to a Geiger counter.
- Become an Arduino savant – find out about functions, arrays, libraries, shields and other tools that let you take your Arduino project to the next level
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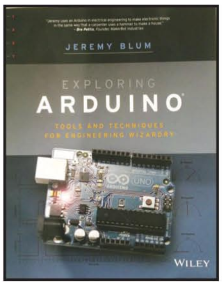

EXPLORING ARDUINO
Jeremy Blum

Arduino can take you anywhere. This book is the roadmap.

Exploring Arduino shows how to use the world's most popular microcontroller to create cool, practical, artistic and educational projects. Through lessons in electrical engineering, programming and human-computer interaction this book walks you through specific, increasingly complex projects, all the while providing best practices that you can apply to your own projects once you've mastered these. You'll acquire valuable skills – and have a whole lot of fun.

• Explore the features of several commonly used Arduino boards • Use the Arduino to control very simple tasks or complex electronics • Learn principles of system design, programming and electrical engineering • Discover code snippet, best practices and system schematics you can apply to your original projects • Master skills you can use for engineering endeavours in other fields and with different platforms

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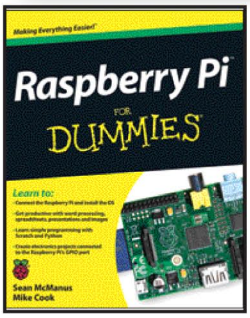
RASPBERRY PI



RASPBERRY Pi FOR DUMMIES
Sean McManus and Mike Cook

Write games, compose and play music, even explore electronics – it's easy as Pi! The Raspberry Pi offers a plateful of opportunities, and this great resource guides you step-by-step, from downloading, copying, and installing the software to learning about Linux and finding cool new programs for work, photo editing, and music. You'll discover how to write your own Raspberry Pi programs, create fun games, and much more! Open this book and find: What you can do with Python; Ways to use the Raspberry Pi as a productivity tool; How to surf the web and manage files; Secrets of Sonic Pi music programming; A guide to creating animations and arcade games; Fun electronic games you can build; How to build a 3D maze in Minecraft; How to play music and videos on your Raspberry Pi.

400 Pages | Order code RPiDUM01 | £17.99

RASPBERRY Pi MANUAL: A practical guide to the revolutionary small computer
176 pages | Order code H001 | £17.99

RASPBERRY Pi USER-GUIDE – Third Edition
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ELECTRONICS TEACH-IN 5

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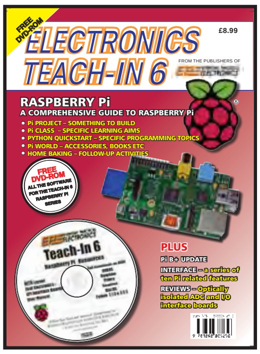
ELECTRONICS TEACH-IN 6



ELECTRONICS TEACH-IN 6 – A COMPREHENSIVE GUIDE TO RASPBERRY Pi
Mike & Richard Tooley

FREE CD-ROM

Teach-In 6 contains an exciting series of articles that provides a complete introduction to the Raspberry Pi, the low cost computer that has taken the education and computing world by storm.

This latest book in our Teach-In series will appeal to electronic enthusiasts and computer buffs wanting to get to grips with the Raspberry Pi.

Anyone considering what to do with their Pi, or maybe they have an idea for a project but don't know how to turn it into reality, will find Teach-In 6 invaluable. It covers: Programming, Hardware, Communications, Pi Projects, Pi Class, Python Quickstart, Pi World, Home Baking etc.

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THE BASIC SOLDERING GUIDE HANDBOOK

LEARN TO SOLDER SUCCESSFULLY!
ALAN WINSTANLEY

The No.1 resource to learn all the basic aspects of electronics soldering by hand.

With more than 80 high quality colour photographs, this book explains the correct choice of soldering irons, solder, fluxes and tools. The techniques of how to solder and desolder electronic components are then explained in a clear, friendly and non-technical fashion so you'll be soldering successfully in next to no time! The book also includes sections on Reflow Soldering and Desoldering Techniques, Potential Hazards and Useful Resources. Plus a Troubleshooting Guide.

Also ideal for those approaching electronics from other industries, the Basic Soldering Guide Handbook is the best resource of its type, and thanks to its excellent colour photography and crystal clear text, the art of soldering can now be learned by everyone!

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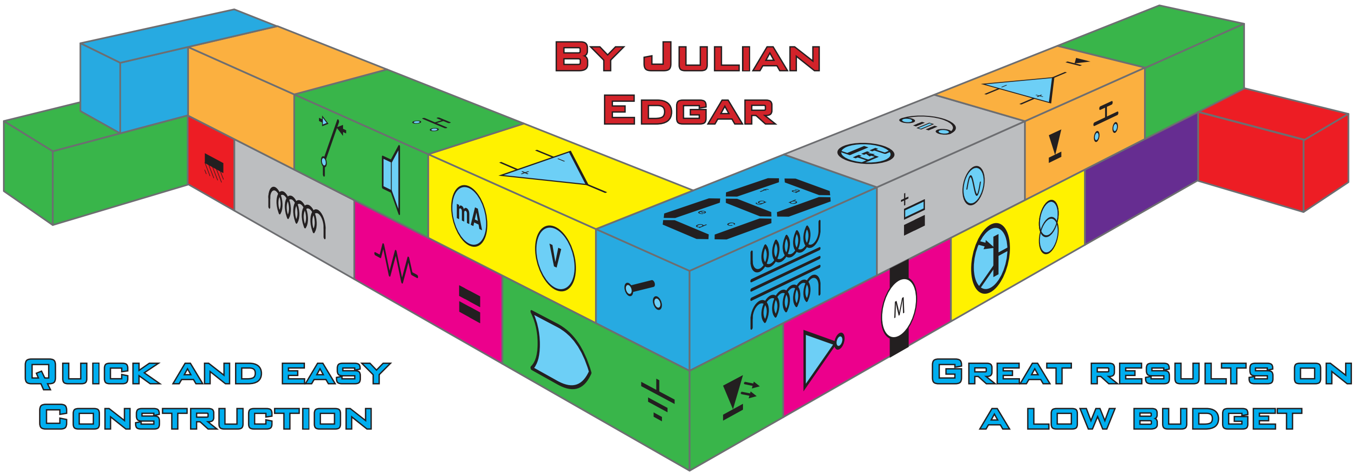
Electronic Building Blocks



By Julian Edgar

Quick and easy construction

Great results on a low budget

Solar LED Lighting Control Module

Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be... FAST! They represent the best value we can find in today's electronics marketplace!

Here's a very smart module that allows you to easily set up a solar-powered LED lighting system.

In our house we have a corridor that's darker than we'd like. A skylight is the obvious answer, but I've long thought about using an LED light powered by a solar panel. But you really need some constant-current electronics between the solar panel and LED, otherwise the LED output will vary widely with panel output. Plus, of course, at night it won't work at all – so then you need to add a storage battery. Hmm, then it would be good to use a device that best matches the battery load to the panel – gee, it's all getting complicated!

This tiny and cheap module is a superb controller for a solar-powered LED lighting system. It is configurable for different battery types and can automatically turn on the LED lighting as it gets dark. But that's just the start of what it can achieve!

Compact controller

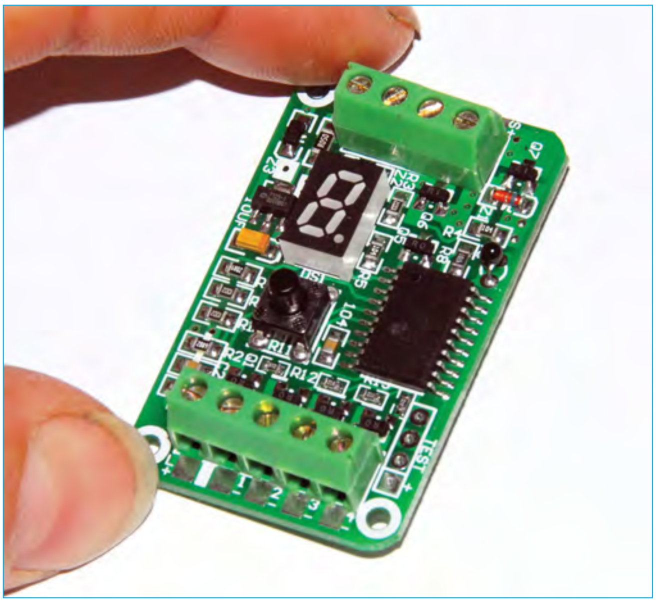
And then along comes the tiny module that's the subject of this month's column. Called the '3A 6V 12V PWM Solar Panel Light Controller Battery Charge Regulator Intelligent', it's available from www.banggood.com for under £7, delivered. What this module can achieve for the price is quite amazing – more on that in a minute. But before that, here's the bad news.

First, the module has so many functions, all controlled by just one on-board press button and indicated by just one 7-segment display (plus decimal point), that setting up the system can be quite a challenge. (And, while the instructions are unusually good for a Chinese-sourced cheap module, they still need careful reading.) Second, the enclosure is not waterproof, and so if you're intending to use the module outside (for example, to operate garden lighting), it will need to be mounted in a waterproof box. But in terms of the negatives – they're about it!

What can it handle?

So what is the module's capability? The largest solar panel that can be used is 40W with a peak open-circuit voltage of 23V. The module can drive LED lights (equipped with suitable dropping resistors for the battery voltage being used) with a maximum lighting load of 36W at 12V. Batteries that can be used include 12V lead-acid

The module being used to control a shed door light. Shown is a 10W panel and a single 1W LED. Inside the shed is the control module and a 4.2Ah SLA battery. This system has sufficient power that three or four of these 1W LEDs could be used.



Programming of the board is via a single pushbutton for battery type, the level of darkness at which the LED lighting turns on, the intensity of the LED lighting - and other functions. The status of the system (eg, whether the battery is charging) is indicated by illuminated segments on the digital display.

and a variety of lithium-ion and nickel-metal hydride designs. Nominal battery voltages can vary from 6V to 12V.

In testing, I used a 10W solar panel, a 12V 4.2Ah sealed lead-acid battery, and a few 1W LEDs. Incidentally, the solar panel and SLA battery were obtained for nothing – both had been thrown away by others before I salvaged them! (And that's one of the advantages of using this module – you can mix and match with what you already have.)

Programmable

Now, if you're wondering how such a wide range of batteries can be used with the module, here's its first excellent function. The module is programmable for the battery type that you are using, with no less than nine different battery types and combinations available for selection. For each battery type, a provided table shows the charging and discharging voltage parameters that the module then adopts.

You can also decide how you want to control the LED lighting that you're powering. For example, you can specify that the LED lighting turns on only at night – or is on all the time (good for that dark corridor of mine). You can also specify how many hours the lighting stays on when it gets dark – from 1 to 15 hours. The degree of darkness required before the lighting output is activated is also adjustable in nine levels. Last, to reduce energy consumption, you have PWM control over the LED lighting intensity – from 10 per cent to 100 per cent in 10 per cent increments.

When set up and operating, the 7-segment LED display has the following indications, shown by means of steady or flashing bars:

- Solar panel working
- Solar panel output low
- Battery charging
- Battery level sufficient
- Battery level low
- Output (eg, LED lighting) on
- Output over-current or short-circuit

The battery is protected against over-discharge, and the solar panel output is optimised by MPPT matching of the panel to the battery.

There is also further logic built in: for example, the solar panel needs to 'see' darkness for 20 seconds before the LED lighting output switches on – this is presumably so that the shadows of passing birds and the like don't trigger the light.

Set up

Connections are very easy – the solar panel and battery at one end, the LED lighting at the other.

I think that this module is a stunner. A lot of work has gone into programming its micro and as a result, its functionality is very high. It's also a product that not only can control LED lighting, but also be used wherever a battery needs to be charged by a small solar panel. Take the time to read the instructions and master the user programming, and you won't be disappointed!

Next time

In my next column I'll be looking at a high-current battery charger. Using a mix of new and salvaged parts, this car and truck battery charger has some serious grunt!

PCB SERVICE

CHECK US OUT ON THE WEB

Basic printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are drilled and roller tinned, but all holes are a standard size. They are not silk-screened, nor do they have solder resist. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. **NOTE: PCBs from the July 2013 issue with eight digit codes** have silk screen overlays and, where applicable, are double-sided, plated through-hole, with solder masks, they are similar to the photos in the relevent project articles.

All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail.

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Compact 8-Digit Frequency Meter	04105161	£12.88

*** See NOTE left regarding PCBs with eight digit codes ***

Please check price and availability in the latest issue.
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Boards can only be supplied on a payment with order basis.

Back numbers or photocopies of articles are available if required – see the Back Issues page for details. WE DO NOT SUPPLY KITS OR COMPONENTS FOR OUR PROJECTS.

EPE SOFTWARE

Where available, software programs for *EPE* Projects can be downloaded free from the Library on our website, accessible via our home page at: **www.epemag.com**

PCB MASTERS

PCB masters for boards published from the March '06 issue onwards are available in PDF format free to subscribers – email **fay.kearn@wimborne.co.uk** stating which masters you would like.

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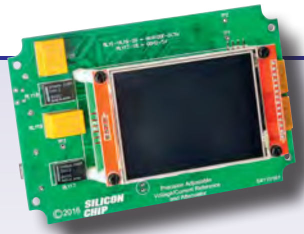
Next Month

OCTOBER '17 ISSUE ON SALE 7 SEPTEMBER 2017



Precision Voltage & Current Reference with Touchscreen Control – Part 1

This new design lets you produce any voltage from 0-37V with 0.1% or better accuracy, plus you have all the convenience of a touch-screen interface. Plus, it can act as a precision current source or sink from 1mA to several amps (with up to 2.5W continuous dissipation) and is largely self-calibrating. It can also be used as a precision AC signal or DC voltage attenuator/divider.

Micromite Plus Explore 100 – Part 2

We have introduced the *Explore 100* module, described its features and gave the circuit details. Part 2 this month gives the full assembly details, describes the display mounting and explains the setting-up, testing and fault-finding procedures. We also show you how to configure the touchscreen and configure the unit for use as a self-contained computer.

Currawong upgrade – a new transformer

Since the original *Currawong Amplifier* was published at the end of 2015, it has created quite a deal of interest and those who have built it have been most enthusiastic. However, it had a complicated power supply employing two transformers. Here's a much simplified circuit using a single power transformer, which also saves on the overall cost.

Teach-In 2018 – Part 1

Yes, you read that right, '*Teach-in 2018*'! The October issue sees the start of a brand new *Teach-In* series from Mike Tooley – full details revealed next month!

PLUS!

All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *Electronic Building Blocks*, *PIC n' Mix* and *Net Work*

Content may be subject to change

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