

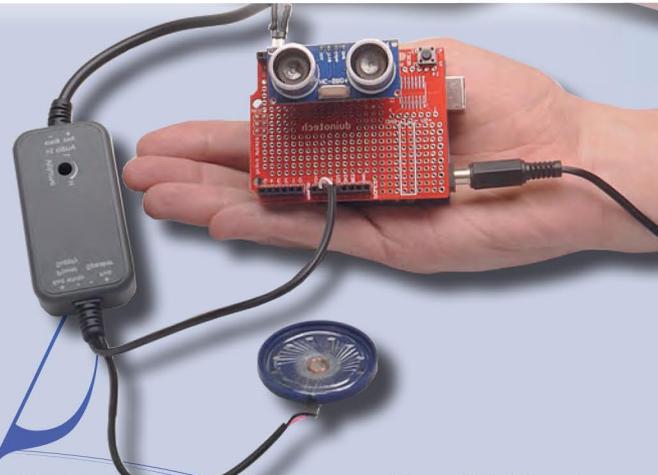
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(inc. LEDs, TVSs etc)**

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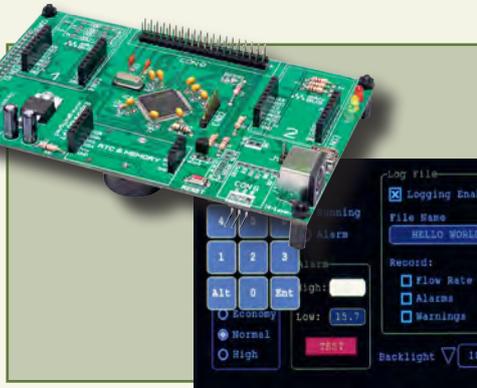
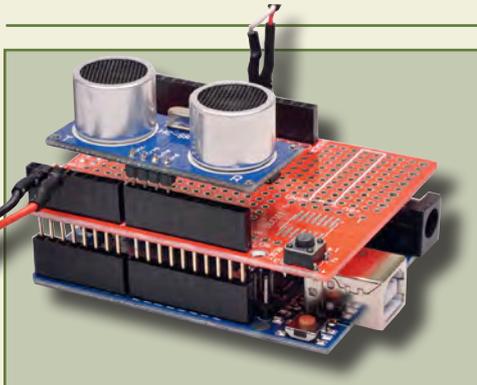
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Our January 2018 issue will be published on Thursday 7 December 2017, see page 72 for details.

Everyday Practical Electronics, December 2017

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Kit Order Code: K8055N - ~~£39.95~~ **£22.74**
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Kit Order Code: 8157KT - ~~£44.95~~
 Assembled Order Code: AS8157 - ~~£49.96~~



Computer Temperature Data Logger

Serial port 4-ch temperature data logger. °C/°F. Continuously log up to 4 sensors located 200m+ from board. Choice of free software applications downloads for storing/using data. PCB just 45x45mm. Powered by PC. Includes one DS18S20 sensor.

Kit Order Code: 3145KT - ~~£19.95~~ **£16.97**
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Kit Order Code: 3179KT - ~~£17.95~~
 Assembled Order Code: AS3179 - ~~£24.95~~



Many items are available in kit form (KT suffix) or pre-assembled and ready for use (AS prefix)

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 Kit Order Code: 3166KT - ~~£19.95~~
 Assembled Order Code: AS3166 - ~~£25.95~~



8-Ch Serial Port Isolated I/O Relay Module

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 Kit Order Code: 3108KT - ~~£74.95~~
 Assembled Order Code: AS3108 - ~~£89.95~~



Infrared RC 12-Channel Relay Board

Control 12 onboard relays with included infrared remote control unit. Toggle or momentary. 15m+ indoor range. 112 x 122mm. Supply: 12Vdc/500mA
 Kit Order Code: 3142KT - ~~£64.96~~ **£59.96**
 Assembled Order Code: AS3142 - ~~£69.96~~



Temperature Monitor & Relay Controller

Computer serial port temperature monitor & relay controller. Accepts up to four Dallas DS18S20 / DS18B20 digital thermometer sensors (1 included). Four relay outputs are independent of the sensors giving flexibility to setup the linkage any way you choose. Commands for reading temperature / controlling relays are simple text strings sent using a simple terminal or coms program (e.g. HyperTerminal) or our free Windows application. Supply: 12Vdc.
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 Assembled Order Code: AS3190 - ~~£59.95~~



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 Kit Order Code: 8191KT - ~~£29.95~~
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Code: WFS210 - **£79.20 inc VAT & Free UK Delivery**



PC-Scope 1 Channel 32MS/s With Adapter

0Hz to 12MHz digital storage oscilloscope, using a computer and its monitor to display waveforms. All standard oscilloscope functions are available in the free Windows program supplied. Its operation is just like a normal oscilloscope. Connection is through the computer's parallel port, the scope is completely optically isolated from the computer port. Supplied with one insulated probe x1/x10.

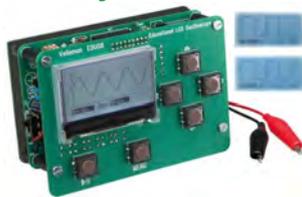
Code: PCS100A - **£124.91 inc VAT & Free UK Delivery**



LCD Oscilloscope Self-Assembly Kit

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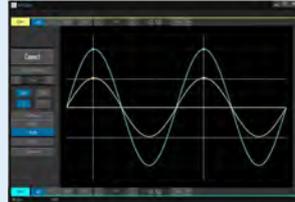
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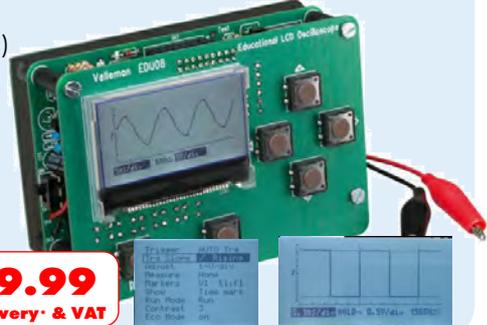
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EPE EVERYDAY PRACTICAL ELECTRONICS

Coming up... 2018!

Another year, another 12 issues! For the editorial team 2017 is now 'over', and by the time you read this we will be well on our way to producing the January 2018 issue. I hope 2017 brought you many happy hours of *EPE* reading, project building, circuit designing and component soldering. Just like last year, I'd like to thank our trusty band of regular contributors – so, in no particular order, a rousing *EPE* 'three cheers' for Alan Winstanley, Mike and Richard Tooley, Ian Bell, Mark Nelson, Mike O'Keeffe, Clive 'Max' Maxfield, Robert Penfold, Julian Edgar and Jake Rothman. Plus, I'd like to offer an extra special 'thank you' to the now-retired Robert Penfold, who contributed so much to *EPE* over not merely years, but decades.

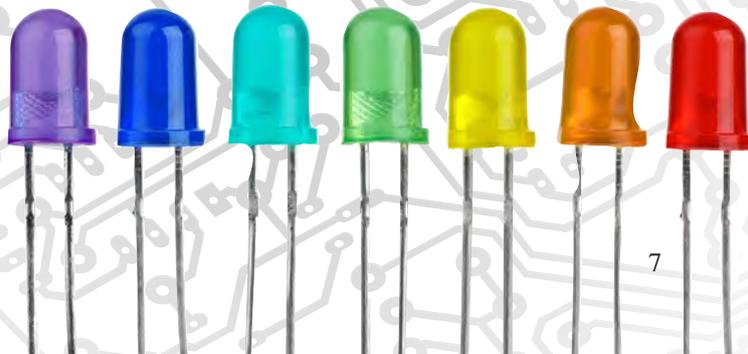
So, what do we have planned for the *EPE* readership in 2018? Naturally, Mike Tooley will continue with *Teach-In 2018*, and I'm sure it will continue to be a special must-read for electronics enthusiasts of all types – from the very latest converts to seasoned old hands. Looking at our project list, for audio fans, I can see a superb power amplifier design, a rather interesting graphic equaliser and an usual three-way speaker crossover, plus there'll be the usual monthly helping of unique insight into analogue electronics from Jake Rothman in his *Audio Out* column. If you are a microcontroller enthusiast then there are projects for the Arduino and Micromite, and of course your regular dose of *PIC n' Mix* fun. And... I could go on and on, but I don't want to reveal all our surprises, so I'll mention just one more item, in fact a regular item, which will be a new series starting in the January issue: cheap, but powerful electronic modules from Asia. Lots to look forward to!

Extra special Christmas present?

If you are lost for ideas when facing the inevitable 'What would you like for Christmas?' interrogation from your nearest and dearest, then why not suggest a subscription to your favourite magazine. It doesn't matter whether you choose paper or online, as a subscriber you can be sure that you won't miss out.

From all of us at *EPE*, thank you for your support during 2017, and have a memorable 2018!

Mick



NEWS

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



High noon for HDR showdown in Berlin – report by Barry Fox

To Berlin again in early September for another IFA – which this year had become a swamp of drones, fitness wearables, connected fridges, big and clumsy virtual reality headsets, smart toothbrushes and bigger 4K screens.

(US Patent 9 635 377 – <http://bit.ly/2yD9DO0>). Instead of upscaling or ‘stretching’ a conventional SDR (standard dynamic range) signal to simulate HDR, Samsung’s ‘High Dynamic Range Image Processing Device and Method’ relies on

The optional data includes histograms, showing the lowest, highest and most frequent pixel information, and sharpness information. The data is sent in packets stored inside a 10-bit base layer signal for backwards compatibility.

HDR10+ vs Dolby Vision

The move into cloud-based voice control looks likely to be a lot more fruitful for the future (especially for audio streaming and in-car entertainment) as was the foundation of a new consortium of Samsung, Panasonic and 20th Century Fox, which is clearly intending to cut Dolby’s proprietary HDR (high dynamic range) system Dolby Vision off at the knees – and end the current, crippling HDR standards battle.

The consortium is promoting and licensing Samsung’s new HDR10+ system, which uses metadata to control all aspects of picture quality on a frame-by-frame basis (like Dolby Vision) but (unlike Dolby Vision) the HDR10+ metadata takes up very little extra bandwidth and (unlike Dolby Vision) the Samsung system is available to any hardware manufacturer or content producer under a royalty-free licence scheme.

Samsung, Panasonic and Fox have been secretive over how exactly HDR10+ works, but as is so often the case, their recently published patents tell all.

Low-bandwidth solution

The lynch pin is a patent granted to Samsung Electronics in April 2017



SAMSUNG



Panasonic



additional information or metadata to describe each scene or frame.

The metadata is of two types, ‘compulsory’ and ‘optional’. Compulsory data includes information on the maximum and minimum brightness for each scene or frame, backlight peak brightness for each scene or frame, colour gamut and temperature, and gamma and contrast.

Look-up table solution

A new HDR10+ capable TV will have look-up tables stored in its software, which hold details of the set’s display capabilities. So the metadata can squeeze the best results available from each individual set, regardless of the brightness of its display. HDR10+ uses Bezier transfer curves which smoothly convert digits to light – without having to switch between gamma and log transfer functions as is necessary for the BBC Hybrid Log Gamma broadcast HDR system to work without metadata.

To minimise the amount of metadata needed, and so use up as little transmission or storage space as possible, HDR10+ only codes changes in the picture parameters. So if there is no change between picture frames, or even between scenes, no data – even compulsory data – is needed.

In this way, claims Samsung’s patent, only around 20 bytes of data are required for each frame, and at 60Hz a bandwidth of only 10kbps is needed for the metadata. In practice, metadata will often only be needed for scene changes, so the data overhead may be as low as 1kbps. By contrast, the Dolby Vision metadata adds up to 20% of the normal TV signal.

High noon for HDR showdown in Berlin – continued

Samsung also has several more recent applications which are still pending. These include United States Patent Application 20160381363 (<http://bit.ly/2gS4aJG>), for 'HDR Tone Mapping Methods with Scene Adaptive Paramaterized Tone Map Function'. This deals with the Bezier transfer curves on which HDR10+ relies.

Patent filings from Panasonic (such as US 20170251245 – <http://bit.ly/2znIfRd> and 20170251244 – <http://bit.ly/2inFT1G>) reveal what Panasonic has brought to the HDR10+ table – ways and means of decoding the signal and metadata, and managing the way it flows to the TV set. This is done by HDMI connection with HDCP (High-bandwidth Digital Content Protection) copy protection.

Trademark resolution

The HDR10+ consortium announcement explains why Samsung has

been so keen to register a trademark for the word 'HDR10+'; it will strengthen licence control. But it does not explain why Samsung tried also to land grab rights on the word 'HDR10', which is already widely used in the industry to describe the basic HDR system, which is part of the Blu-ray standard. Most likely, Samsung's lawyers were briefed to protect the word 'HDR10+', ahead of the new system announcement, and got carried away trying to collar all words similar to 'HDR10+'.

The good news, though, is that shortly before IFA, Samsung finally dropped all claims to the industry word 'HDR10'.

So, hopefully, the world of TV can now move forward into a new age of improved pictures with future-proof sets that automatically self-adjust to all the royalty-free HDR systems, HDR10, HDR10+ and HLG.

Arduino boards support IoT connectivity

Arduino has unveiled the new Arduino MKR WAN 1300 (LoRa) and the Arduino MKR GSM 1400, two new boards that are designed to offer a practical and cost-effective solution for developers, makers and enterprises, enabling them to quickly add connectivity to their projects and ease the development of battery-powered IoT edge applications.

The MKR WAN 1300 delivers LoRa low-power WAN connectivity, and the MKR GSM 1400 adds global 2G/3G communications capability.

Offering 32-bit computational power, the MKR WAN 1300 is based around the Murata LoRa low-power connectivity module and the Atmel SAM D21 microcontroller, which integrates the 32-bit low-power ARM Cortex-M0+ processor, 256KB Flash memory and 32KB SRAM.

Like the MKR WAN 1300, the Arduino MKR GSM 1400 is based on the ARM Cortex-M0+ based SAM D21, but integrates the u-blox module to deliver global 3G communications.

New PV cell technology

A recent report from the Society of Chemical Industry in London has highlighted the potential of a new kind of solar PV (photovoltaic) cell based on non-silicon materials.

Silicon solar cells have long been the standard for the solar renewable energy sector, with almost 90% of PV cells globally containing silicon. However, research in the last decade has produced an alternative to silicon-based PV cells that could challenge their position on the market. Made from readily available materials such as ammonia and iron, perovskite solar cells are highly efficient and inexpensive. As silicon solar cells struggle to reach 20% in power conversion efficiency, the National Renewable Energy Laboratory, US, has revealed data predicting 50% efficiency for perovskites.

Occurring naturally, perovskites are inherently light absorbing, making them the ideal candidate for PV cells, as well as being light-weight, flexible, and semi-transparent. Perovskites are popular with solar power researchers and engineers as they can absorb a wider range of wavelengths of light, increasing their capacity to convert sunlight into electricity.

Researchers still have obstacles to overcome, including toxicity and UV-based degradation, but the future is starting to look bright for these new PV materials.

Midlands roads to be UK autonomous vehicle testbed



Roads in Coventry and Birmingham are set to become a world-class UK testbed for developing the next generation connected and autonomous (CAV) of vehicles, thanks to a new £25m programme of investment being led by the Warwick Manufacturing Group (WMG) at the University of Warwick.

The pioneering venture, undertaken by a consortium of research and industry partners, will make UK roads ready for CAVs by developing wireless networks, analysing how vehicles behave in real urban environments and involving the public in their evaluations.

The UK Central CAV Testbed will be based on 80km of urban roads in Coventry and Birmingham, creating a world-leading connected infrastructure and eco-system, and positioning the Midlands as a centre for cutting-edge automotive and communication technologies.

Professor Paul Jennings, an expert in CAV technology from WMG, is leading the project. He commented: "The Midlands has a proud heritage of pioneering vehicle development, and I am delighted to be part of the next era – bringing CAVs onto the road and allowing all of us to reap the benefits as soon as possible."

The control room for the testbed will be located within the National Automotive Innovation Centre (NAIC) – a unique centre which will provide a critical mass of research capability, combining automotive expertise nationally and internationally.

The development and deployment of CAVs is driven by the need to reduce traffic congestion and accidents on our roads, and will provide significant societal benefits, as well as business opportunities for the automotive, communications, infrastructure and transport sectors in the UK.

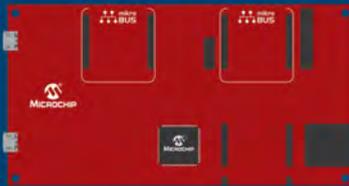
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Winter mixture

No, we're not talking about traditional boiled sweets, but you might find something warming in this month's selection, along with something that might make you shiver! Why not find out what's in the bag?

DO YOU HAVE A QUIET SMILE

when you read about heavy goods vehicles getting stuck down six-foot wide country lanes after blindly following GPS directions without engaging brain? I suppose you could call this bad luck or avoidable misadventure. But back in August, the news media were reporting something far more sinister: the intentional and malicious misdirection of GPS navigation systems by forces unknown. *New Scientist* magazine made the remarkable suggestion that Russia may be testing a new system for spoofing GPS. This development, it continued, could lead to a new form of electronic warfare available to all manner of users, from rogue nation states to petty criminals.

Lost at sea... er, land

This speculation followed an incident report filed by the US Maritime Administration stating the master of a ship navigating the Black Sea discovered his location to be more than 32km inland – according to GPS. He checked that navigation equipment was working correctly and then contacted more than 20 other ships nearby, all of whose GPS equipment located them at the same inland position.

GPS spoofing

Although the magazine article suggested this incident was the first documented use of GPS misdirection, the reporter appears not to have consulted Wikipedia. There (and in numerous other web reports) it is stated that the downing of a Lockheed RQ-170 drone in north-eastern Iran six years ago was the result of GPS spoofing. A proof-of-concept attack was successfully performed in June, 2013, when the luxury yacht 'White Rose' was misdirected with spoofed GPS signals from Monaco to the island of Rhodes by Todd Humphreys and a group of aerospace engineering students from the University of Texas.

The possibility of GPS spoofing attacks was predicted as early as 2004 and discussed subsequently in the GPS community. A favoured technique is to start by broadcasting signals synchronised with the genuine

signals observed by the targeted receiver. The power of the counterfeit signals is then gradually increased, making the victim unable to detect the genuine signals. This was the method used by Humphreys from the University of Texas when his team hijacked the 'White Rose' and he says that any reasonably competent hacker could build a GPS spoofer.

Weaponising GPS

Many guided bombs, missiles and drones rely on GPS navigation, meaning that transmitting false signals could render it impossible for weapons guided by GPS to reach their targets. Consequently, GPS spoofing can be used as a cyberweapon and is a very serious threat if carried out by a state operator, according to Humphreys. 'It affects safety-of-life operations over a large area, and in congested waters with poor weather, such as the English Channel, it would likely cause great confusion and probably collisions,' he told *New Scientist*.

Economy drive

Plummeting... I think that's a fair way of describing the cost of data storage for computers, whether we're discussing USB memory sticks or, for example, 4TB hard drives. In fact the only commodity that isn't yet as 'cheap as chips' (and it should be, considering it's just a big package of memory chips) is the solid-state drive or SSD. Sure, these treasures are a lot cheaper than they were, say, a year ago, but spinners (conventional hard drives with rotating magnetic platters) remain significantly easier on the pocket, especially if you don't have an endless budget for IT.

Is there a cheaper alternative? Yes, there is and it uses home-grown materials that you already have at home: deoxyribonucleic acid. You probably know it as DNA and already have more than you need in your body. And it works fine: scientists in the US funded by the National Institutes of Health have managed to encode a primitive movie using DNA in living cells. What's more, they have also played it back in their ingenious 'molecular recorder'. This, they say, may make it possible one day

to see read-outs, for example, of the changing internal states of neurons as they develop.

This notion, comments biologist James MacDonald, is not as crazy as it sounds. After all, DNA already is an incredible storage device and cellular DNA contains all the information needed for an organism to function, stored in a microscopic package. Nevertheless, it won't be a simple process. DNA does not perform its processes anywhere close to the speeds present in an electronic processor, while large-scale synthesis of appropriate molecules is slow and expensive. A method of attaching a USB connector has not yet been determined either.

Happy 80th birthday!

I guess just about every reader is familiar with Radiospares, once the universal go-to supplier of electronic components and still a major force to be reckoned with in its current incarnation under the RS Components banner. Back in the day, when its policy was trade customers only, I remember the dodges which people had to resort to in order to buy goods from their trade-only counters – slapping down a shopping list on my employer's letterhead and saying my boss needs these parts urgently and paying with money allegedly from the firm's petty cash account.

But did you know that Radiospares was founded 80 years ago at a lock-up garage in north-west London? As well as its birthday, it's celebrating a number of notable firsts, such as the fact that it was the first electronics and maintenance company to have an own-label range. Another first from 1937 – it was the first distributor to offer free next-day delivery. The rebranding operation, from Radiospares to RS Components, took place in 1971, even if not all customers have come to terms with this yet. In 1994, RS was the first electronics distributor to introduce a CD-ROM version of its monster catalogue, while in 1998 RS became the first distributor to launch a transactional website, followed by a mobile version in 2007 (its YouTube channel came a year later). Pretty impressive all round, I would say.

BUILD YOURSELF A DIGITAL THEREMIN using Arduino

By BAO SMITH

We have described quite a number of Theremins over the years, but this is something new: an Arduino-based Theremin with hand sensing via an acoustic distance sensor.

THE THEREMIN was one of the very first electronic musical instruments, and the first to be played without physical contact.

It was patented by the Russian inventor Lev Termen in 1928 and is played by waving your hands near two metal plates or antennas. The proximity of your hands is used to alter pitch and volume, and it has been used many times in movies and by pop bands.

Part of the appeal comes from its ethereal sound, and you can see why if you take a look at a few videos of it being played. To find them, just do a Google search for "Theremin".

This Arduino version of a Theremin was devised by the technical staff at Jaycar Electronics and instead of using analogue circuitry to sense hand proximity, it uses a standard Arduino shield and an ultrasonic sensor module, to sense your hand movement.

It only varies the pitch and is quite effective at that, but volume can only be varied by using the volume control on a small amplifier module.

Jaycar sells the parts for this *Arduino Theremin* – an Arduino Uno (XC-4410, based on an ATmega328P microcontroller); an Arduino prototyping shield (XC-4482); an ultrasonic sensor (XC-4422); an amplifier module (AA-0373) and a 40mm plastic cone loudspeaker (AS-3004).

Putting this project together is quite simple but you will need a PC that can run the Arduino IDE, which can be found at: www.arduino.cc/en/Main/Software

Jaycar has posted instructions to build this Theremin at: www.jaycar.com.au/diy-ultrasonic-theremin

We suggest you have a good look at those instructions but we have taken a slightly different approach here, which you may prefer.

Putting it together

The prototyping shield can be plugged on top of the Uno board first. Next, you connect the amplifier module to the speaker and then to the prototyping board.

Jaycar recommends removing the PCB from the amplifier module,

extracting all leads from it and mounting it on the prototyping shield using wire soldered to the underside of the PCB.

This would be advisable if you want to add an external volume control, which can be easily manipulated while you are playing the instrument.

As supplied, the module comes with a tiny preset volume potentiometer on the PCB and that is a bit tricky to adjust. However, it's much easier to leave the amplifier in its case and just wire it up to the board. The reason we did this is to let us easily swap around components on the board, making adjustments easier, and it allows us to reuse each part for different projects.

Step by step

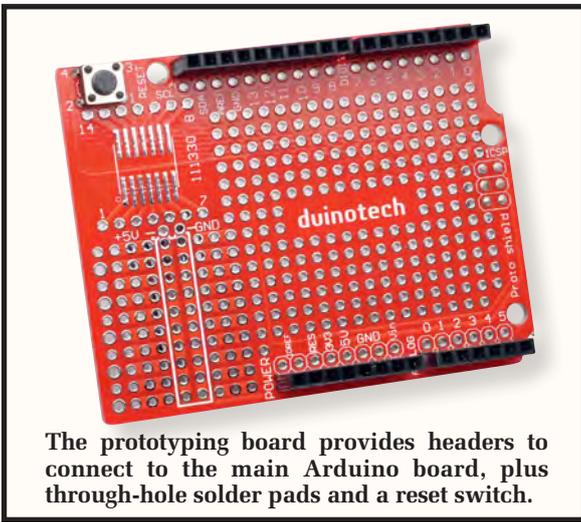
Step 1: solder the speaker positive (pink) and negative (black) leads from the amplifier module to the speaker's terminals (either way around).

Step 2: make the connections to power the amplifier module. We soldered the

The mono amplifier module doesn't come with a knob for volume control, but you can easily add one yourself.



In this amplifier module, the leads were soldered and glued to the PCB, making removal quite difficult.



The prototyping board provides headers to connect to the main Arduino board, plus through-hole solder pads and a reset switch.



Step 1: the Speaker lead from the amplifier module needs to be soldered to the underside of the speaker. It doesn't matter which leads go to which solder pad.

red and black supply leads to a 2-pin male header that can then be plugged directly into the 5V and GND pins on the prototyping shield, which are indicated on the silkscreen printing.

Step 3: solder the red and black input leads of the amplifier module to a 2-pin right-angle header and then plug it into pin 2 (for the black wire) and pin 3 (for the red wire) on the opposite side of the prototyping shield from the power supply connection.

Step 4: make sure the prototyping shield is correctly plugged into the Uno board.

Step 5: straighten the pins on the ultrasonic sensor and plug it into the prototyping board header next to the amplifier audio input leads. Its four pins are labelled V_{CC}, Trig, Echo

and GND. These are plugged into the DIGITAL shield pins with V_{CC} to pin 8, Trig to pin 9, Echo to pin 10 and GND to pin 11. These are default pin locations set by the software, but you could modify the software to change them, as explained later in this article.

All the above connections are listed in the table entitled *Lead connections* later in this article, so refer to that if you're unsure.

With all parts connected, the next step is loading the software on the ATmega328P chip via the Arduino IDE. The original software can be found at: www.jaycar.com.au/diy-ultrasonic-theremin#sketchfiles

There are two files: **Ultrasonic_Theremin.ino** and **sample.c** and these should be downloaded to a folder on your PC named 'Ultrasonic_Theremin'. The Arduino must be connected to your

computer using a USB Type-A to Type-B cable (as commonly used for printers) so that the software can be loaded onto it.

Steps 6 and 7: once the Arduino IDE has been installed, open **Ultrasonic_Theremin.ino** and on the menu bar, go to **Tools** and check that the board is set to 'Arduino/Genuine Uno' and that **Port** is 'COMX (Arduino/Genuine Uno)', where X is whatever port number it has been assigned to on your PC. If your board does not show up in this list, you may need to manually install the drivers for it. Instructions on how to do this can be found at: www.arduino.cc/en/Guide/ArduinoUno

The Arduino uses Virtual COM Port (VCP) drivers to emulate a COM port over a serial connection.

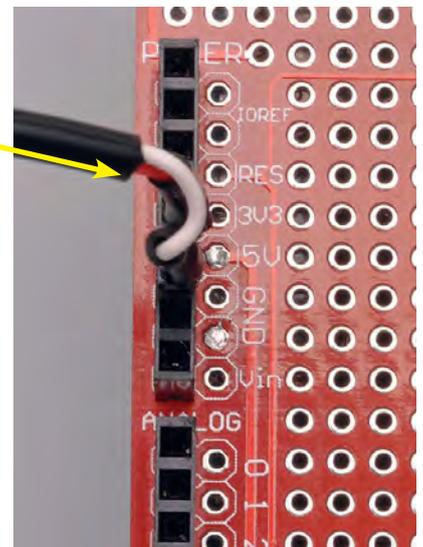
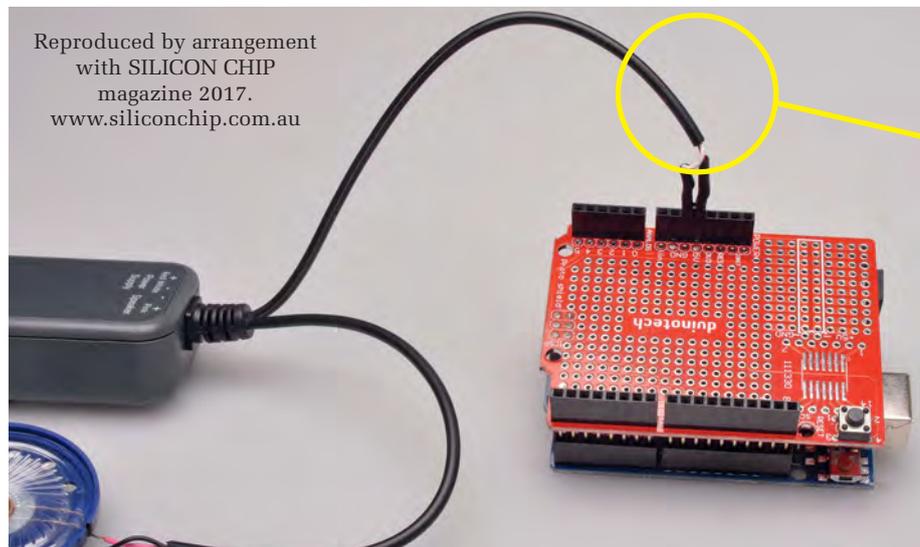
Step 8: if everything is in working order, on the menu bar go to **Sketch** → **Upload**. This will compile and upload the software onto the Arduino. The device can then be tested by holding your hand over the ultrasonic sensor. It should produce a sound with a pitch which increases as your hand gets closer to the sensor and conversely, lowers as your hand moves away from the sensor.

If you don't get any sound, check that the amplifier is wired to the

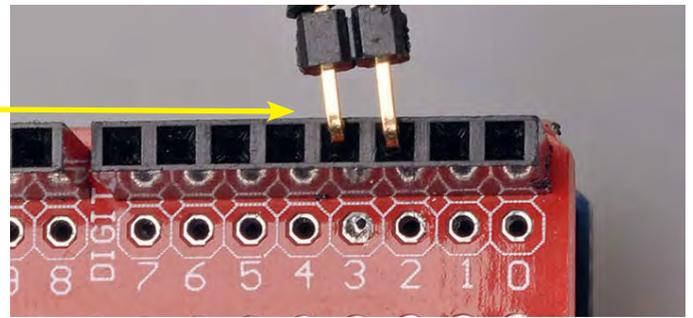
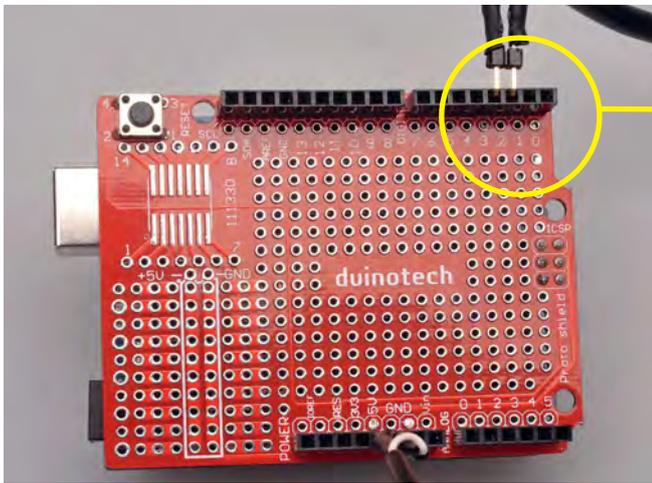
You may want to solder a two-pin (or two one-pin) header(s) to the input and power leads from the amplifier. Keep in mind for the amplifier Audio In, right-angle header(s) need to be used if connecting to the female header. This is needed for clearance from the sensor module.



Step 2: the Power Supply positive lead (red) from the amplifier goes to the 5V connection on the prototyping board. The negative lead (white) can then go to either of the two GND connections nearby. We've used a two-pin male header and added heatshrink tubing over the solder joints to provide greater strength.



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Step 3: the amplifier Audio In positive lead (red) needs to be plugged into DIGITAL pin 3. The negative lead (black) is not needed and so can go to any unused pin. Here we have the negative lead plugged into pin 2 directly next to the positive lead, but you can choose what works most comfortably for yourself.

correct pins on the prototyping shield and that the compilation and uploading proceeded with no errors, which would be displayed at the bottom of the Arduino IDE window.

Besides communication issues, the most likely problem would be if the two provided files are not in the same directory.

Once the software has been uploaded to the device, rather than plugging it into your PC, it can be powered via a 7-12V DC power supply or battery, via the DC barrel socket located next to the USB connector.

Making some improvements

Once you have it running, you will probably find that the Theremin sound is not particularly good and not like the Theremins that you will have seen on videos on YouTube.

With that in mind, we modified the software to give a more realistic Theremin sound, more like that which could be produced by one of our previous Theremins.

The important change is the addition of a sinewave look-up table which is substantially smaller (256

bytes compared to 16 kilobytes) than playing back a larger digital sample at a varying rate to control the pitch. This is especially important when considering that memory on the micro is quite sparse, at 31.5KB of usable Flash and 2KB of SRAM.

This version of the software is available on the *EPE* website. Download the two files which are labelled **SC_Ultrasonic_Theremin.ino** and **SC_sample.c**. They should unzip into a suitably named directory ('SC_Ultrasonic_Theremin'). You then upload them to the Uno using the same procedure as described above. We hope you find the resultant sound more satisfying.

One of the advantages of using an Arduino to build this Theremin is that you can easily modify the software if you want to. For example, you could change the linearity of the pitch control or change the waveform. If you do want to modify the software, it would be a good idea to familiarise yourself with a programming language like C or Java. However, even inexperienced readers may have some luck making simple changes. For example, at the top of

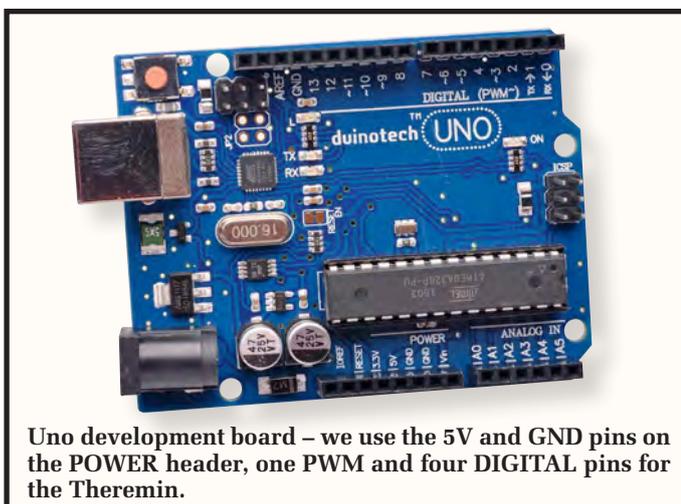
the .ino file, some macros are defined which allow you to easily change certain properties of the Theremin:

- **MAX_DIST** sets the maximum distance for the range sensor, with a value of 5700 approximately equal to 1m. The sensor has an effective range of 2-400cm, although in practice it will barely work beyond 3m, which gives MAX_DIST at most being $300\text{cm} \div 0.0175\text{cm}/\mu\text{s} \approx 17000 (\mu\text{s})$. Note that $0.0175\text{cm}/\mu\text{s}$ is half the speed of sound at 25°C and 100kPa.
- **FREQ** sets the default playback frequency for the sample. Generally, anything within 22050 ± 5000 (ie, half the sampling rate of a CD) sounds best, but depending on the sample used, your results may vary.
- **UVCC**, **UTRIG** etc define the pin location for the ultrasonic sensor. These can be changed if you want to move the sensor to a different location on the board.

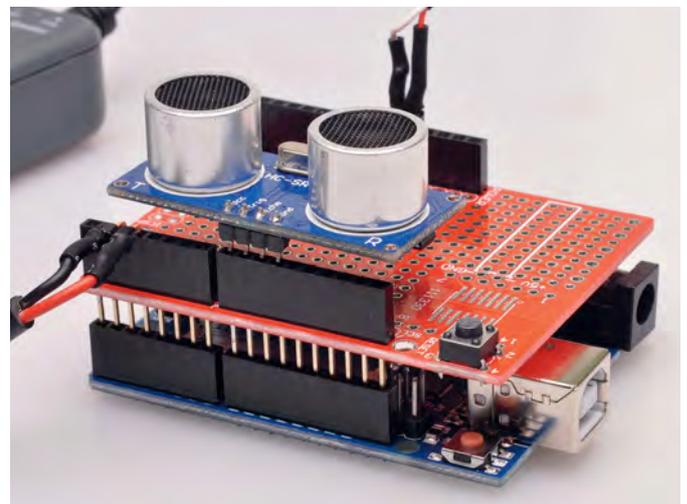
Also, there are four different samples you can use with the Theremin (in *sample.c*): sine, piano, theremin and sine256. The first three can be easily selected by changing the name referenced on line 67 of the .ino file, ie:

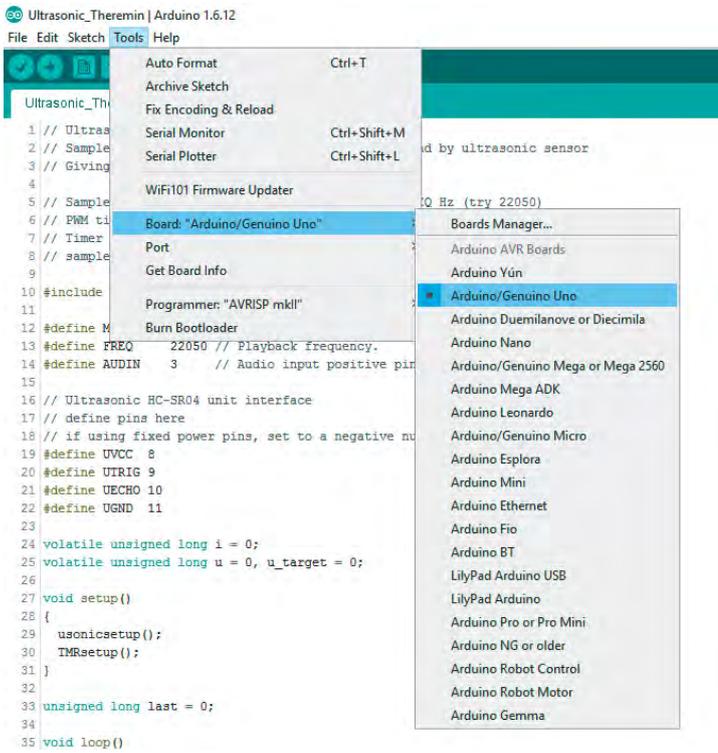
Step 4: if you haven't already done it, now is the time to plug the proto shield into the Uno board. The orientation is simple as both reset switches should be in the same location.

Step 5: the ultrasonic sensor needs to have its pins straightened and then it can be plugged into the female header with V_{CC} on DIGITAL pin 8 and Trig on pin 9.



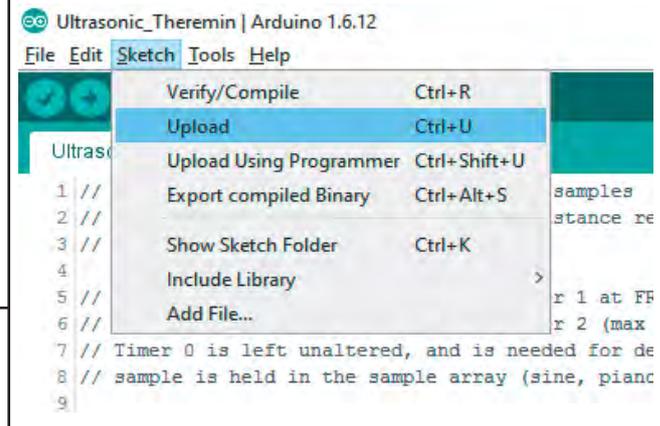
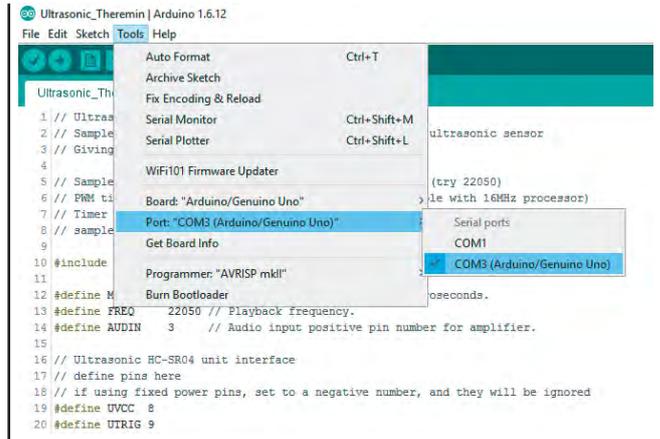
Uno development board – we use the 5V and GND pins on the POWER header, one PWM and four DIGITAL pins for the Theremin.





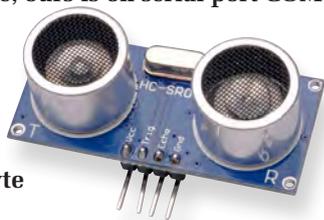
Step 6: (above): check that the Board type selected is 'Arduino/Genuino Uno' in the Arduino IDE before uploading the software to the board.

Step 7: (upper right): While the Uno is plugged into the computer, check that Port is correctly set to the one that the device is connected to. In this case, ours is on serial port COM3.



Step 8: using the Arduino IDE, upload the software onto the board. Assuming there have been no changes, it should compile and run correctly.

The HC-SR04 ultrasonic sensor



OCR2B = pgm_read_byte (&theremin[i >> 18]);

Here, you can change 'theremin' to 'piano' or 'sine'. If you want to use sine256 instead you need to comment out this line (by prefixing it with two slashes, ie, '//'), and uncomment the one above.

Without difficult changes you cannot use the other PWM-enabled pins for the amplifier audio in. Since any DIGITAL pin that the amplifier audio input is on needs to be matched with corresponding OCR register settings, if the pin location is changed the OCR referenced in the code needs to be changed too. For example, by default we use the OCR2 (pins 3 and 11) register which is an 8-bit register, while the

other 8-bit register OCR0 (on pins 5 and 6) could also be used. However, OCR1 (pins 9 and 10) is a 16-bit register making working with them quite different.

If you know what you're doing you can alter this, otherwise it's best not to. You can find the pin mapping for the chip here: <https://www.arduino.cc/en/Hacking/PinMapping168> and the ATmega328P documentation here: <http://bit.ly/2yAS4uY>

Where to get it

All the components for the kit can be purchased from Jaycar. The speaker and amplifier module can easily be substituted to obtain more power and better bass and that should make it considerably more satisfying to play.

Finally, for a detailed Arduino installation guide, see: www.arduino.cc/en/Guide/HomePage

Soon, we hope to publish details on how to add a second ultrasonic module to control the volume of the Theremin. This will be accompanied with changes to the software.

Parts List

Ultrasonic Theremin Project Kit

- 1 Uno Main Board (Jaycar XC4410)
- 1 Arduino Prototyping Shield (Jaycar XC4482)
- 1 Ultrasonic Sensor Module (Jaycar XC4442)
- 1 Mono Amplifier Module
- 1 8Ω 1/4W 40MM Speaker

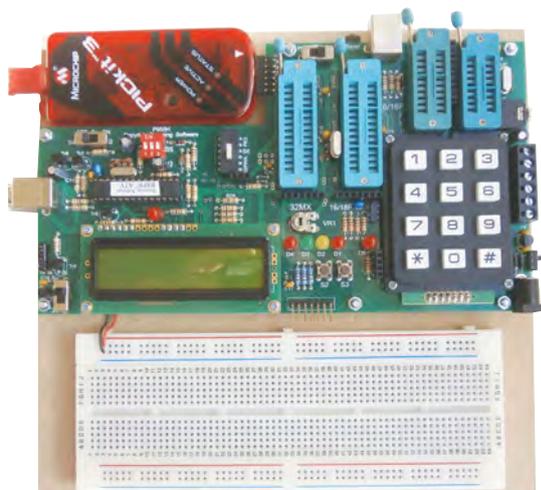
Additional items

- 1 USB Type-B to Type-A male-male connector (e.g, printer cable)
- 1 7-12V DC plugpack (if you want to run it without USB)
- 1 2-pin male header
- 1 2-pin male right-angle header

Table 1: Lead connections

Component	Lead	To Header/Part	To Pin
Amp Power Supply (4-12V)	+ (red)	POWER	5V
	- (white)	POWER	GND
Speaker	± (pink/white)	Mono speaker	
Amplifier Audio Input	+ (red)	DIGITAL	3
	- (black)		any unused
Ultrasonic Sensor	Vcc	DIGITAL	8
	Trig		9
	Echo		10
	GND		11

Brain Training by Peter Brunning



When I was young electronics was full of creative energy. Everything we needed had to be built using fundamental electronic components. Now the youngsters have ready built modules which perform feats which in the early days I could only dream about. But what a difference. Now they walk around with an iphone in their hand and a permanent downward angle to their gaze.

If our tasks are made too easy we loose the ability to create fundamentally original solutions but we cannot avoid the reality of modern life. Computers are here to stay and when used correctly they are the most exciting way to train our brains. We are well past the days of learning to programme our own simple home computer so we must find an alternative very latest technology system which can generate that same level of creative energy. The microcontroller fulfills this requirement in every way. A microcontroller is a complete computer on a chip but unlike the home computer the simple versions of the microcontroller are still used and are in great demand. So there we have it!

The Brunning Software P955H PIC Training Course

Imagine giving a Thomas Hardy book to a child who has just learnt to read. The child cannot understand the book so we create a new language to avoid the complications. How absurd! So why do it with computer languages? The correct technique is to avoid the complications not to rewrite the language.

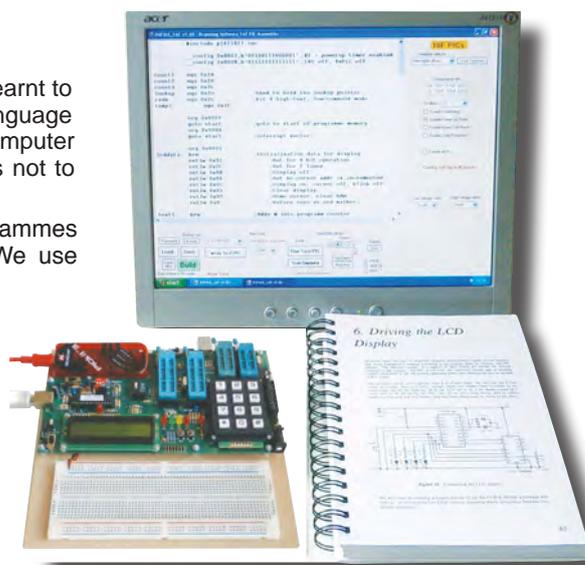
The first book teaches absolute beginners to write PIC programmes using assembler which is the natural language of the PIC. We use a relatively simple 8 bit PIC, simple programming techniques, and inspire the reader with immediate success. In the space of 24 experiments two projects and 56 exercises we work through from absolute beginner to experienced engineer level. The second book introduces the C programming language for 8 bit PICs in very simple terms. The third book teaches Visual C# programming for the PC so that we can create PC programmes to control PIC circuits.

In the fourth book we learn to programme 32 bit MX PICs using fundamental C instructions. This is quite straight forward to start with as most of the code is the same as already used with 8 bit PICs. Then life gets more complex as we delve into serial communication with the final task being to create an audio oscilloscope with advanced triggering and adjustable scan rate.

The complete P955H training course is £254 including P955H training circuit, 4 books (240 × 170mm 1200 pages total), 6 PIC microcontrollers, PIC assembler and programme text on CD, 2 USB to PC leads, pack of components, and carriage to a UK address. To programme 32 bit PICs you will need to plug on a PICKit3 which you need to buy from Microchip, Farnell or RS for £43.

Prices start from £170 for the P955H training circuit with books 1 and 2 (624 pages total), 2 PIC microcontrollers, PIC assembler and programme text on CD, USB to PC lead and carriage to a UK address. PICKit3 is not needed for this options. See website for full details..

Web site:- www.brunningssoftware.co.uk



Mail order address:

Brunning Software

138 The Street, Little Clacton, Clacton-on-sea,
Essex, CO16 9LS. Tel 01255 862308

EXCLUSIVE OFFER

Win a Microchip MPLAB ICD 4 In-circuit Debugger

EVERYDAY PRACTICAL ELECTRONICS is offering its readers the chance to win a Microchip MPLAB ICD 4 In-Circuit Debugger (DV164045). The new MPLAB ICD 4 introduces a faster processor and increased RAM to deliver up to twice the speed of ICD 3 for in-circuit debugging of PIC microcontrollers and dsPIC digital signal controllers. The MPLAB ICD 4 also introduces a wider target voltage range and an optional 1A of current via an external power supply.

For maximum flexibility, MPLAB ICD 4 features a selectable pull-up/pull-down option to the target interface and programmable adjustment of debugging speed for greater productivity. The MPLAB ICD 4's significant improvement in speed is accomplished through a 32-bit MCU running at 300MHz. Faster processing, together with an increased buffer memory of 2MB, results in a product that is up to twice as fast as its predecessor.

Microchip's MPLAB ICD 4 is easy to use and supports many PIC microcontrollers and dsPIC digital signal controllers in Microchip's portfolio through the MPLAB X Integrated Development Environment (IDE). This simplifies the design process for customers when they choose to migrate from one PIC MCU to another to meet the needs of their application.

The MPLAB ICD 4 connects to the PC using a high-speed USB 2.0 interface and is connected to the target with a debugging connector which is also compatible with the MPLAB ICD 3 or MPLAB REAL ICE™ In-Circuit Emulator systems. The MPLAB ICD 4 also works with JTAG interfaces.

Faster and more flexible real-time in-circuit debugging • Supports many PIC microcontrollers and dsPIC DSCs • x2 faster than ICD 3 • Reduced wait time improves debugging productivity • Simplifies migration between PIC MCUs.



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CLOSING DATE

The closing date for this offer is 31 December 2017.

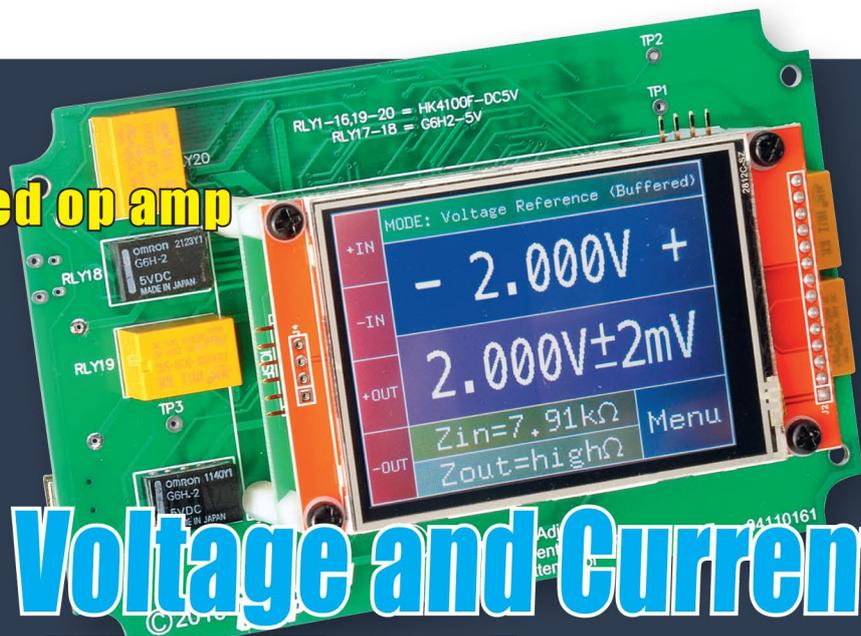
August 2017 ISSUE WINNER

Mr Keith Hudson from Cotec Technology Ltd,
Guisborough, North Yorkshire

He won a Microchip PIC32MK1024GP
Development Kit, valued at £93.00

Uses a
chopper-stabilised op amp

Part 2: By
Nicholas Vinen



Precision Voltage and Current Reference With Touchscreen Control

We introduced this instrument with its comprehensive touchscreen control in the October issue. It is a first for us in that it is a test instrument with no physical switches or knobs to control its functions; everything is done via the touchscreen. In this second and final article, we give the construction details and provide all the testing and operation instructions.

VIRTUALLY ALL the components are mounted on a single PCB coded 04110161 and measuring 140 × 85mm. Fig.3 shows how the components are fitted on both sides of the board. All the SMDs are mounted on one side, while the through-hole components and the LCD Backpack module go on the other side. The only off-board components are the four insulated banana sockets. The PCB assembly and all four banana sockets are mounted on the lid, with short lengths of stiff wire joining the sockets to the board.

Start by fitting the SMDs. The only slightly tricky parts are voltage reference REF1 and the USB socket (micro or mini, depending on which you have decided to fit). These have the most closely spaced pins. However, there are only a few pins on each and the other components have much more generous spacing, making them quite easy to solder.

Start with REF1. Use a magnifying glass and a good light to identify the pin 1 dot on top of its package and place it on the PCB near its pads, with pin 1

closest to the adjacent board edge. Place a little solder on one of its corner pads, then heat that solder while sliding the part into place. Check that all its leads are over their associated pads; if not, reheat the solder joint and gently nudge it into place.

Alternatively, having tinned one of the pads, you can carefully line up the IC and then press down gently on it while heating the solder on that pad to let it 'sink in'. Either way, you should now have the part tacked down and properly aligned with all of its pads. You can then proceed to solder the remaining pins. This is easiest if you first apply a little flux paste to the pins.

Don't worry if you bridge any of the pins with solder; simply add a little flux paste and use solder wick to remove the excess solder. When finished, refresh the solder joint on the pin you first used to tack the part down, either by adding a little flux and heating it (the preferred method) or by adding some fresh solder.

Clean off any flux residue using flux cleaner or alcohol (eg, methylated

spirits or isopropyl alcohol) and carefully check all six leads to ensure that they have proper fillets and no bridges. Assuming you're happy with that, move on to solder the remaining ICs (IC1-IC6 and REG1) using a similar technique. If you can't locate a pin 1 dot or divot on any of these, check for a bevelled edge; pin 1 is on that side.

Discrete semiconductors

Next, move on to the smaller discrete semiconductors, ie, D1-D4, Q2, Q3, ZD1 and ZD2. Do note that with the exception of D1, these are all in essentially identical packages, so don't get them mixed up. All you need to do is tack down one pin as above, check the placement and then solder the remaining pin(s).

Now move on to the resistors and capacitors, using a similar technique. None of them are polarised. The resistors are labelled with their value in a shortened code (eg, 22kΩ = 223 or 2202) however, you may need a magnifier to read them. SMD ceramic capacitors are not labelled. Note that

the three 10 μ F capacitors may be larger than the others and the pads provided are more widely spaced to suit. The 0.1 Ω resistor is larger again but a similar technique can be used, although you might need to hold the iron on the joint a bit longer to produce a good joint.

The smaller inductor (L2) can be fitted in the same manner as the resistors and capacitors. And while a similar technique is required for L1, its much larger thermal inertia presents some challenges. Be sure to spread a little flux paste on both pads before starting. Also, when you slide the part onto the pad with the molten solder, you will find it solidifies as the inductor heats up and it will be several seconds before you can finally move the part into its correct location.

Last, when applying solder to the second pad, you will need to heat it for a few seconds before a good solder joint will form.

Now fit MOSFET Q1. Start by spreading a thin smear of flux paste on the large pad, then add solder to one of the smaller solder pads and slide the part into place, as with the other components. After that, solder the other two small pins before turning your attention to the large tab. As with L1, it will take a few seconds to heat up the part and PCB so that they are hot enough for the solder to flow properly and form a good joint.

The final SMD part to fit is either CON1a or CON1b (one of the USB sockets). **Normally, both would not be fitted, as plugging them both into two different USB sockets would potentially damage one or both of the power supplies.**

Decide which one you want to use, then solder one of its mounting lugs to the board, using a similar technique as before. Make sure all the small pins are properly aligned over the pads before soldering the other mounting lugs and finally, the pins themselves.

You will probably need to apply flux and some solder wick to remove any bridges which form, as the pins are closely spaced. We've elongated the pads for both connectors to make this easier.

Assembling the BackPack

If you haven't already done so, you will need to assemble the *Micromite LCD BackPack*, as described in the May 2017 issue. This is a pretty quick job as it only involves a dozen or so through-hole components. Note that this project is not designed to use the *Micromite Plus LCD BackPack* (described this month); it requires multiple 5V-tolerant pins, which is one of the few incompatibilities between

Parts List

- | | | | | | | | | | | | | | | | | | |
|---|--|-----------------|---------------|----------------|-----------------|----------------|-----------------|----------------|---------------|----------------------|----------------|----------------|----------------|-----------------|---------------|---------------------------|--------------|
| <ul style="list-style-type: none"> 1 PCB, available from the <i>EPE PCB Service</i>, coded 04110161, 140 x 85mm 1 Micromite LCD BackPack module 1 UB1 jiffy box (157 x 95 x 53mm) 1 black laser-cut lid to suit jiffy box (optional) 2 red panel-mount binding posts/banana sockets (IN+,OUT+) 2 black panel-mount binding posts/banana sockets (IN-, OUT-) 3 0.9mm PCB pins (TP1-TP3) (optional) 1 47μH 6x6mm SMD inductor (L1) 1 220μH 3.2x2.6mm/1210 SMD inductor (L2) 18 HK4100F-DC5V-SHG SPDT relays (RLY1-16,RLY19,RLY20) 2 G6H2-5V DPDT relays (RLY17,RLY18) 1 SMD mini USB type B connector (CON1a) and/or 1 SMD micro USB type B connector (CON1b) 1 18-pin low-profile female header (or cut down 40-pin dual-wipe DIL socket) (CON2) 1 18-pin female header (or cut down 20+ pin female header) (CON2) 1 200mm length 0.7mm diameter tinned copper wire (or four component lead off-cuts) 4 M3 x 25mm machine screws 4 M3 x 15mm nylon tapped spacers 4 3mm ID 6mm OD 1mm thick Nylon washers <p>Semiconductors</p> <ul style="list-style-type: none"> 4 TPIC6C595 8-channel SPI relay drivers, SOIC-16 (IC1-IC4) 1 ADA4522-4ARZ quad precision op amp, SOIC-14 (IC5) 1 LM358, SOIC-8 (IC6) | <ul style="list-style-type: none"> 1 MAX6071-2.5 precision 2.5V reference, SOT-23-6 (REF1) 1 CS5173 boost regulator, SOIC-8 (REG1) 1 BSP030 N-channel Mosfet, SOT-223 (Q1) 2 BC846 NPN transistors, SOT-23 (Q2,Q3) 1 5.6V SOT-23 zener diode (ZD1) 1 39V SOT-23 zener diode (ZD2) 1 DB2W60400L 60V 2A Schottky diode (D1) 3 BAT54S dual serial Schottky diodes (D2-D4) <p>Capacitors
(2012/0805 X7R 50V unless stated)</p> <ul style="list-style-type: none"> 3 10μF 50V X5R 3216/1206 4 4.7μF 6.3V X5R 1 1μF 16V X7R 9 100nF 1 10nF 2 47pF 50V C0G/NP0 <p>Resistors
(0805 1% unless stated)</p> <table border="0"> <tr> <td>2 270kΩ</td> <td>1 3kΩ</td> </tr> <tr> <td>2 47kΩ</td> <td>2 2.2kΩ</td> </tr> <tr> <td>3 30kΩ</td> <td>1 1.5kΩ</td> </tr> <tr> <td>1 22kΩ</td> <td>6 1kΩ</td> </tr> <tr> <td>51 12kΩ 0.1%</td> <td>1 750Ω</td> </tr> <tr> <td>4 10kΩ</td> <td>3 100Ω</td> </tr> <tr> <td>1 4.7kΩ</td> <td>2 47Ω</td> </tr> <tr> <td>1 0.1Ω 1% 3W 2512</td> <td>1 0Ω</td> </tr> </table> <p>A short form kit is available from the SILICON CHIP online shop (www.siliconchip.com.au) which includes everything except for the BackPack kit (available separately), box, tinned copper wire and optional PCB pins.</p> | 2 270k Ω | 1 3k Ω | 2 47k Ω | 2 2.2k Ω | 3 30k Ω | 1 1.5k Ω | 1 22k Ω | 6 1k Ω | 51 12k Ω 0.1% | 1 750 Ω | 4 10k Ω | 3 100 Ω | 1 4.7k Ω | 2 47 Ω | 1 0.1 Ω 1% 3W 2512 | 1 0 Ω |
| 2 270k Ω | 1 3k Ω | | | | | | | | | | | | | | | | |
| 2 47k Ω | 2 2.2k Ω | | | | | | | | | | | | | | | | |
| 3 30k Ω | 1 1.5k Ω | | | | | | | | | | | | | | | | |
| 1 22k Ω | 6 1k Ω | | | | | | | | | | | | | | | | |
| 51 12k Ω 0.1% | 1 750 Ω | | | | | | | | | | | | | | | | |
| 4 10k Ω | 3 100 Ω | | | | | | | | | | | | | | | | |
| 1 4.7k Ω | 2 47 Ω | | | | | | | | | | | | | | | | |
| 1 0.1 Ω 1% 3W 2512 | 1 0 Ω | | | | | | | | | | | | | | | | |

the two. So for now, you will need to stick with the regular *LCD BackPack*.

Note that the *BackPack* is available as a complete kit from micromite.org

One small change that we suggest you make while building the *LCD BackPack* is to use a right-angle header for CON1 (power and console), with the pins projecting out the side of the module, as shown in our photos. That makes it easier to supply power for testing and also provides access to the serial console, should you need it.

Once you've assembled the *BackPack* PCB, mount the LCD touchscreen in place. If you have purchased a kit which already has the correct software loaded, then you can test it by applying 5V power to the board and check that the display comes up correctly. The software should detect that the main board is not attached and display a message

indicating this. You can now test the touch function by touching that message to dismiss it.

If you don't have a pre-programmed chip, there are two ways to program it. First, you can download the HEX file for this project from the *EPE* website and load it onto your PIC32 using a PICkit 3 and Microchip's MPLAB X IPE (Integrated Programming Environment). You can then plug the chip in and proceed as per above. However, you do need a PICkit 3 to do this, plugged into the ICSP header on the *BackPack* board.

Alternatively, if you have a PIC32 programmed with MMBasic (or you can program one), you can then plug this into the *LCD BackPack*, power it up, connect it to your PC using a USB/serial converter (as described in the May 2017 issue) and then set it up using the free MMChat software.

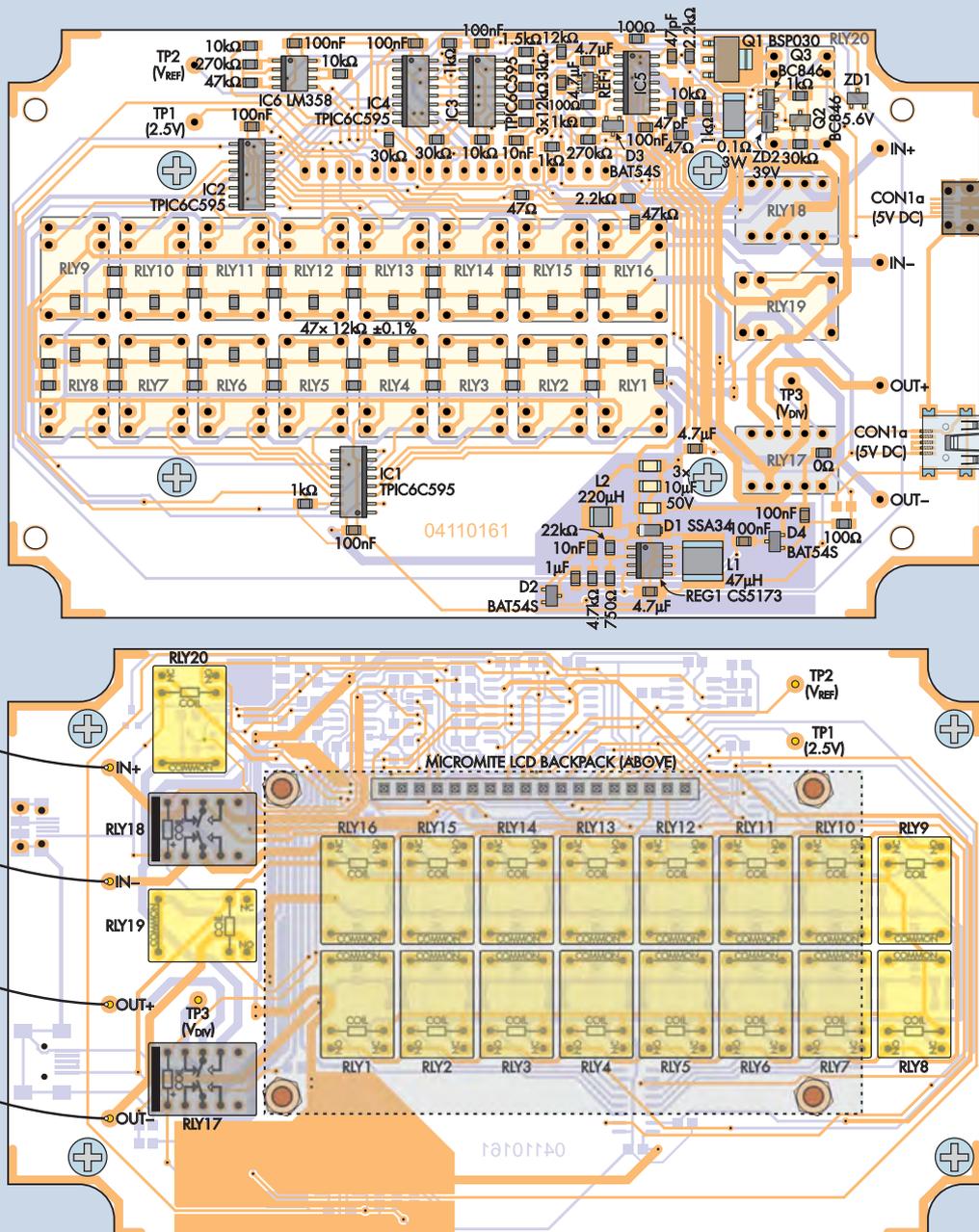


Fig.3: the parts layout diagrams for both sides of the main *Voltage/Current Reference* PCB. All SMD components go on one side of the board, as shown at top, while the relays and *LCD Backpack* are mounted on the other side. Only one of the USB power input connectors, CON1a and CON1b, should be fitted. Note that the 18-pin female header that the *LCD Backpack* is plugged into actually consists of two stacked headers (see text).

To get it going, you will need to set up the TFT and touch interfaces (also described in the May 2017 issue), then download the BASIC source code for this project from the *EPE* website and upload it to the Micromite chip, as detailed in the panel on the penultimate page.

Through-hole parts

Now flip the board over and fit CON2. This is an 18-pin low-profile female header which can be cut from a 36-pin (or larger) DIL socket. 40-pin sockets are probably the most common part which can be used.

Carefully separate one of the pin strips from the rest of the socket

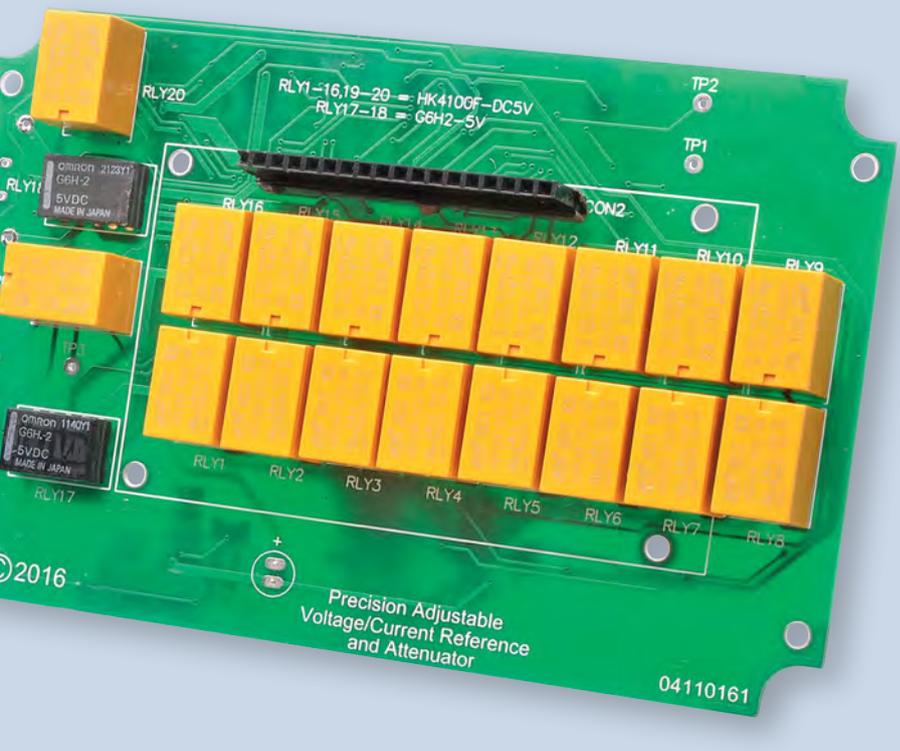
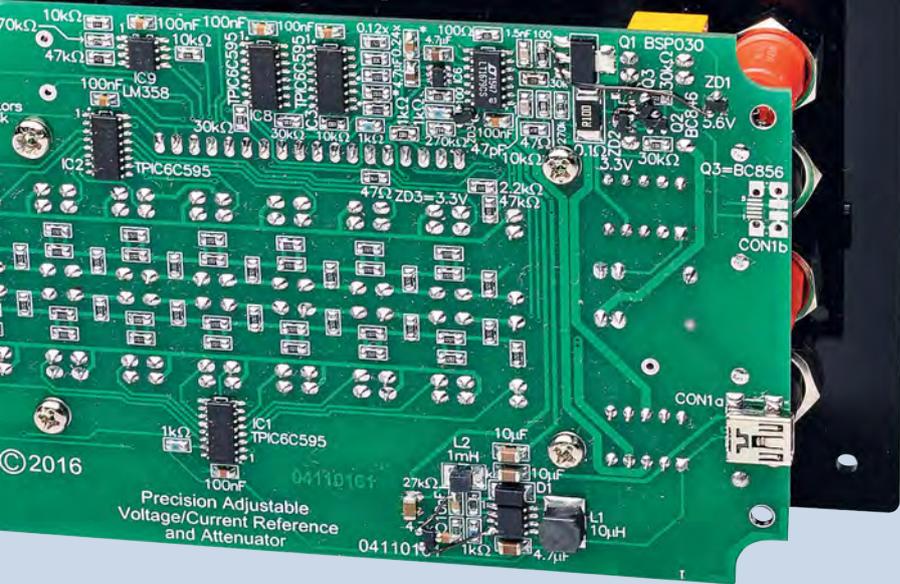
by cutting the plastic cross-braces with a side cutter. Trim off any large projections and cut off any excess pins so that you are left with 18 (be careful not to cut the 18th pin or you may have to throw it away and start again).

Now, feed the four M3 × 25mm machine screws through the *BackPack* mounting holes on the main PCB (heads on the SMD component side) and place one of the 1mm-thick nylon washers over each screw shaft. Screw a 15mm tapped spacer over each shaft until it is almost tight.

Next, detach the TFT module from the *BackPack* PCB and unscrew the four tapped spacers. That done, plug the full-height 18-pin female header

into the low-profile header you made earlier (from the DIL socket) and plug that assembly onto the 18-pin male header on the underside of the *BackPack* PCB. Push it all the way home.

Now place the *BackPack* PCB over the four screw shafts sticking out of the tapped spacers and lower it down so that the pins of the female header go through the holes in the corresponding pads on the main board. That done, screw the 9mm tapped spacers removed from the *BackPack* earlier on top of the remaining shafts in order to hold the *BackPack* PCB in place while you solder the female header to the SMD-component side of the main board.



nylon spacers using the 6mm machine screws supplied with the *BackPack* kit. Don't lose the four extra nylon washers or longer screws supplied with that kit as you will need them to attach the whole assembly to the lid.

Testing

You can do some testing before proceeding to fit the unit into the case. It's a good idea to check that the unit's current drain is within the normal range when it's first powered up. A current-limited power supply is handy to have, but not strictly necessary. You can use any 5V supply capable of delivering at least 500mA, connected in series with a DMM set to measure amps.

It's easiest to make the supply connections to CON1 on the LCD *BackPack* module. Be careful that you make the connections properly, especially since there is no reverse polarity protection; check the labels on the *BackPack* PCB. The current drain should be around 50-200mA, depending on the setting of the backlight trimpot. If you get a reading much higher than this, switch off immediately because that suggests you have a short circuit or an incorrectly placed component somewhere on the board.

If you have an excessive current drain, you can troubleshoot further by unplugging the *BackPack* and briefly connecting a current-limited 5V supply across pins 1 and 2 of RLY17, with +5V to pin 1; pin 1 can be identified as having a square pad and pin 2 is adjacent. Without the *BackPack* attached, only a few milliamps should flow. Much more suggests that there is either a short circuit somewhere on the board (eg, due to bridged pins), an IC has been soldered with the incorrect orientation or one of the other parts is incorrectly installed.

On the other hand, if the current is too low then that also suggests that there is a problem, possibly with the micro-controller programming or soldering, or its bypass capacitors. Proceed with troubleshooting the *BackPack* module as per the instructions in the May 2017 issue.

Now is a good time to check that you have very close to 2.5V between TP1 and a convenient ground point, such as the shell of the USB connector. You should also find virtually the same voltage at TP2 at this point.

Once the micro has been programmed and the software is running, you should be able to further verify the operation of the unit. On power-up, you should be greeted with the initial screen shown in Fig.4. Touch the voltage display below the top bar and on the keyboard which appears (Fig.6), press '2' and

Make sure it's sitting flat on the PCB before doing so. Now that the header has been soldered to the board, remove the *BackPack* PCB and its mounting screws and spacers and keep them until later.

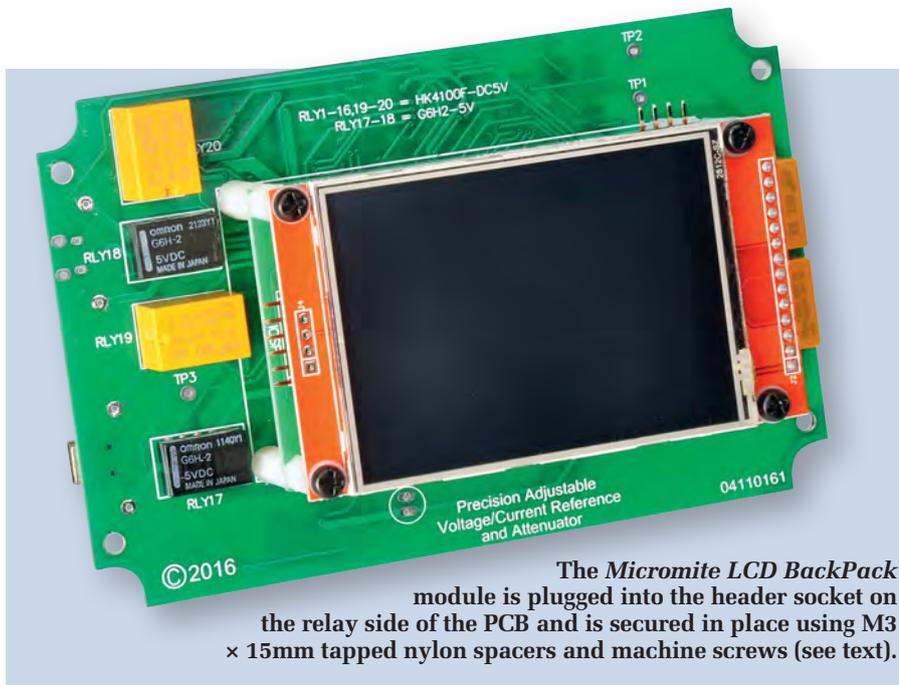
Remaining on-board parts

Basically, the only components left to fit to the PCB are the 20 relays. The two G6H2 DPDT relays must be soldered with their pin 1 markings towards the nearest edge of the board, as shown in Fig.3. Make sure they are pushed down fully onto the board before soldering the pins. It's a good idea to solder two diagonally opposite pins and then check the relay is sitting flat before soldering the remaining pins.

The orientation of each of the 18 HK4100F relays is obvious, as they can only be inserted one way. Again, make sure they are pushed fully into the PCB before soldering.

Now you can re-attach the *BackPack* PCB, as you did before. Make sure that all the screws and spacers are done up tightly. But before plugging the TFT module back into the *BackPack* PCB, trim the 14 solder joints adjacent to the LCD screen as short as possible using sharp side-cutters so that they won't interfere with the lid later (these joints are for the 14-pin header which was supplied pre-soldered to the module).

You can now plug the TFT module into the *BackPack* and attach it to the



The *Micromite LCD Backpack* module is plugged into the header socket on the relay side of the PCB and is secured in place using M3 × 15mm tapped nylon spacers and machine screws (see text).

then 'V'. Then press the line which reads 'Zout=highΩ' at the bottom of the screen.

You should get the display shown in Fig.7 and immediately upon pressing at the bottom of the screen, you should hear the relays click and the current drain will jump as the coils are energised. Now connect a voltmeter between the OUT+ and OUT- terminals at the left side of the board and you should measure very close to 2V. That verifies that the reference, divider ladder and relay drivers are all working properly.

You can now test the boost regulator and PGA by again touching the voltage setting just below the top bar and this time entering '4V'. As soon as you've pressed the 'V' button, the boost regulator will be enabled and the 5V current drain should jump again. Assuming all is well, you can measure 4V between OUT+ and OUT- and 5V (ie, Vref) between TP2 and ground. If you can access L2, you should be able to measure the voltage on either side of it, relative to ground, at around 39V. This is the output of the boost regulator.

If you don't get 4V at OUT+ or you find the unit locks up or draws an excessive amount of current, you may have a problem with REG1 or one of its associated components. **But note that there is quite a large initial spike in the current drawn from the 5V supply when it starts up, so if you are powering the unit from a computer USB port, it may well detect this as a fault and shut the port down. So it's best to power the unit from a 5V charger or bench supply.**

Assuming it's all working so far, it's worthwhile doing one final check before putting the unit in its case, and that is to test the operation in current reference mode. To do this, touch the top of the screen and select 'Current

Reference', then press the box below this and enter '10mA', then press on 'Zout= off' at the bottom of the screen to turn it on (Fig.8).

It's then just a matter of connecting an ammeter set to milliamps mode between the output of your 5V supply and the OUT+ terminal. You should get a reading close to 10mA±0.1mA (plus the tolerance of your ammeter). Basically, if the reading is between 9.5mA and 10.5mA then chances are everything is working correctly.

Case preparation

The case requires 10 holes in total: one in the side for the USB power supply socket, one rectangular cut-out in the lid for the touchscreen, four 3mm holes in the lid for mounting the whole assembly and four larger holes in the lid for the insulated banana input/output sockets.

We're not going to go into detail here because by far the simplest and neatest approach is to purchase a laser-cut panel from SILICON CHIP to replace the existing case lid. These are made from 3mm black acrylic with a matte surface on the top side and the holes are all neat and accurately cut. The panel is sized to fit exactly on a standard UB1 jiffy box and uses the same mounting holes for attachment.

Also, the four banana socket holes in the laser-cut lid are profiled for a snug fit and to prevent accidental rotation of the sockets. The only disadvantage compared to the lid supplied with the case is that the corner screw mounting holes are not recessed, so the screw heads will project slightly above the lid. Also, you may need to use longer self-tapping screws than those supplied with the case (depending on the manufacturer). Still, we think this is the easiest approach that most constructors will adopt.

If you still want to cut the holes in the lid yourself, download the drilling template PDF from the *EPE* website and use this as a guide.

Once you have prepared the lid (or obtained the laser-cut version), attach the completed PCB assembly to its underside with 1mm-thick nylon washers between the top of the TFT module PCB and the back side of the lid. Attach the module to the lid using M3 × 8-9mm machine screws (ideally, black). Make sure that the touchscreen surface is flush with the top of the lid and that it hasn't caught on any plastic burrs or projections.

Now remove the retaining nuts from the four insulated banana sockets, push the sockets through from the top side of the lid and then re-attach the nuts on the other side. Do them up tightly. Make sure that the red and black sockets are in the correct locations – if in doubt, refer to the photos in this article.

Next, feed short lengths of tinned copper wire through the banana socket tabs and bend them over to go through their corresponding pads on the PCB. Solder these wires at both ends to complete the electrical assembly.

Final assembly

The only additional hole is the USB socket access hole, on the side of the case. This cut-out should be approximately rectangular in shape (12mm wide, 6mm high), with its upper edge positioned 32mm down from the top edge of the box. Its exact location depends on which USB socket you have fitted.

The easiest approach is to download the drilling template from the *EPE* website, cut out the side panel, attach it to the side of the UB1 jiffy box case and then drill a series of small holes around the inside of the appropriate cut-out. Knock out the centre plastic section and file it into a rounded rectangle shape, then clean off any swarf and plastic pieces and drop the PCB assembly down into the case temporarily to make sure the USB socket lines up with the hole.

Using it

There are four basic ways to use the unit: (1) as a divider/attenuator, (2) as a voltage reference, (3) as a current reference or (4) as a resistance reference (albeit with a rather limited range).

The first step, once the unit is up and running, is to select the mode and that's done by touching the line right at the top of the screen. A list of six available modes appears and you select the one you want by pressing on it (see Fig.5). The two extra modes allow you to enable or disable the

output buffering in the attenuation and voltage reference modes. Normally you'll want to enable the buffering to reduce the chance of output loading affecting the accuracy of the unit, however, you need to use unbuffered mode for input voltages outside the range of 0-38V (up to $\pm 60V$).

Having selected the mode, the next step is to set the required parameter by pressing on the display area just below the top mode bar and then using the keypad which appears. Taking each mode in turn, this parameter is:

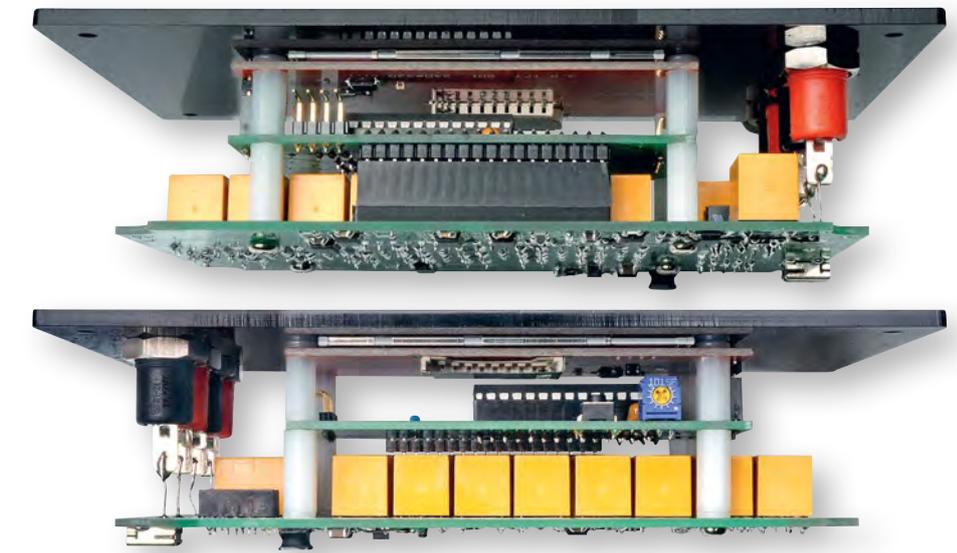
- **Divider/attenuator mode:** the attenuation factor between zero (100% attenuation) and one (no attenuation). There are a number of different ways to set this. You can enter a decimal number between zero and one, or you can enter a fraction like '1/2' or '2/3' (decimals are allowed in both the top and bottom parts), or you can enter a divider ratio such as '3:1' which operates like a resistive divider. In this case, it would operate similarly to a 3k Ω /1k Ω divider in that it is equivalent to a ratio of '1/4' or '0.25'.

You can also enter a value in decibels (including decimal places), in which case, the attenuation factor will be calculated based on that. For example, entering 20dB is equivalent to entering '1/10' or '0.1' (see Fig.9).

- **Voltage reference mode:** the desired output voltage, entered in either V or mV. The range is either 0-37V or 0-37000mV. You can also enter a fraction such as '2/3V'.

- **Current reference mode:** the desired current to sink/source, in either A or mA. The range is either 0-5A or 0-5000mA. You can also enter a fraction such as '1/20A'.

- **Resistance reference mode:** the desired resistance, between 3.5k Ω and 114k Ω . Enter the value desired, in either k Ω or Ω , but note that the actual resistance you get (which will be displayed on the screen later; see Fig.10) may not be exactly what you



These two views show how the *Micromite LCD Backpack* module and the *Voltage/Current Reference* relay PCB are stacked together with the front panel.

have entered. For values in the range 4-12k Ω , chances are you will get the exact value you entered or very close (off by maybe one ohm). For 3.5-4k Ω and 12-18k Ω , expect a value within a few ohms of the target. Above 18k Ω , the error increases to around $\pm 10\Omega$ at 22k Ω , $\pm 50\Omega$ at 33k Ω and up to 1k Ω or more, above 55k Ω .

Having entered your desired parameter, the actual output that you will get will be shown just below it. This display is most helpful in divider/attenuator mode as you can see the entered value (which may be in decibels or a fraction), along with the equivalent decimal value below. However, in all modes, the tolerance figure may be helpful.

Towards the bottom of the screen, the approximate input and output impedances are shown. The output resistance is fixed and depends on the mode; it is normally either 0 Ω (ie, a buffered output) or 2.4k Ω (the ladder output resistance). Note that initially, this will show 'high Ω ' or 'output off', indicating that the output is not yet switched on and you will need to press on this area to activate the output.

The input resistance also depends on the mode as well as the current parameter setting (ie, attenuation, output voltage, etc). It ranges from 3.5k Ω to 114k Ω , ie, the same range as available in resistance reference mode. This means that if you're using the unit to attenuate an external signal, depending on the attenuation factor, it may need to drive a load as low as 3.5k Ω . But you can always enter the required ratio and then check what the actual input impedance will be before proceeding.

Note that most of the time, it's the reference voltage generator driving the ladder, so the input impedance is only really important in attenuator mode.

While the unit is running, note also that on the left side of the screen, the inputs and outputs connections are shown so that you can always refer to these while wiring it up. Also note that the current mode and parameters are stored in non-volatile memory and will be restored when the unit is powered back up. However, it will always power up with the output disabled.

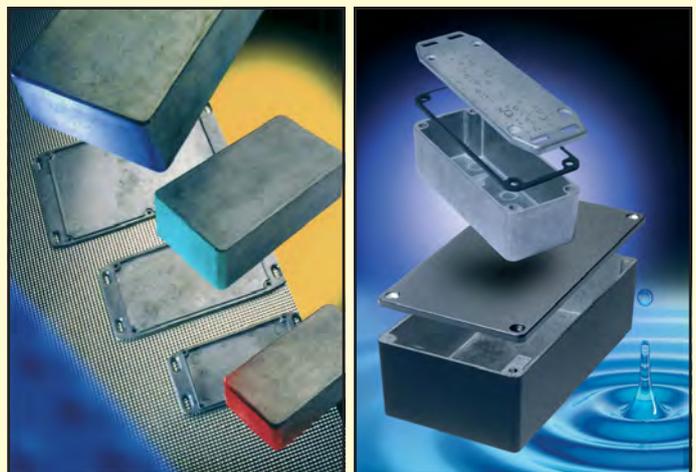


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Uploading the BASIC code to the BackPack

The simplest approach here is to purchase a pre-programmed PIC or, if starting with a blank PIC, flash it with the supplied HEX file which includes MMBasic along with all our code. Alternatively, if you are starting with a regular LCD BackPack kit or you want to modify the software, here's how you load the BASIC code.

First, program your PIC32 with the MMBasic 5.2 firmware and establish a serial console connection using a USB-serial adaptor. You will need to set up the display and touch panel as detailed in the May 2017 article on the LCD BackPack. Note that the BackPack (and, if attached, the main board) are powered from the PC during this process.

Then you need to load **VoltRefLibrary.bas** into the Micromite, which contains the fonts. Having downloaded this from the SILICON CHIP website, grab a copy of Jim Hiley's Windows/Linux 'MMEdit' program. It is freeware and available from www.c-com.com.au/MMedit.htm. For Windows, download the setup file called MMEdit.exe and run it. It will work on any Windows version since XP.

Run MMEdit and open the BASIC file mentioned above. Next, ensure the 'Auto crunch on load' option in the Advanced menu is selected and set up the COM port to communicate with the Micromite by selecting the 'New . . .' option under the Connect menu. You can then click the 'Load and run current code' button, right-most in the toolbar under the menu (with the icon that looks like a blue stick figure running while holding a torch). You should get a progress dialog and the upload will take around 30 seconds.

If it fails, close this window and re-check the COM port settings; make sure you don't have the port open in another program.

Once the upload is complete, the MMChat console window should automatically appear. You can then execute the 'LIBRARY SAVE' command (note: if you have previously done this, you will need to run 'LIBRARY DELETE' first). After a brief delay, it should display the MMBasic prompt (>). You can verify that the code was saved by issuing a 'MEMORY' command, which should yield a response like:

```
> memory
```

```
Flash:
```

```
0K (0%) Program (0 lines)
```

```
14K (24%) Library
```

```
46K (76%) Free
```

Now open the file **VoltRefLibrary.bas** file (which is supplied in the same ZIP as the BASIC file loaded earlier) and, again ensuring that the 'Auto crunch on load' option is enabled, upload that to the PIC32. The MMChat window should appear once this is complete. You can then type in 'OPTION AUTORUN ON', press enter, then execute the 'RUN' command to start the program. Now unplug the USB lead and proceed with the remainder of construction/set-up.

Making connections

Connections are made as follows, depending on the mode:

- **Divider/attenuator:** the signal source is connected between IN+ and IN-, and the output is available between OUT+ and OUT-. An external connection between IN- and OUT- is required for correct operation.
- **Voltage reference:** IN+ and IN- are not connected internally. The reference voltage is available between the OUT+ and OUT- terminals.
- **Current reference:** either connect OUT+ to your external positive supply rail and use OUT- as a current source, or connect OUT- to your external ground and use OUT+ as a current sink.
- **Resistance reference:** the resistance shown is available between the IN+ and IN- terminals. OUT+ and OUT- are not used.

Calibration

Automatic calibration primarily involves sensing the value of the resistors in the

Programmable Gain Amplifier, used to provide reference voltages above 2.5V. This is not done automatically when the unit is first powered up, as it would complicate testing the unit.

So once the unit is working properly, or if you want to re-calibrate the unit later, simply press the 'Menu' button in the lower-right corner, which gives the screen shown in Fig. 11. Then press the 'Calibration' button, followed by the 'Auto. Cal' button.

The relays will click for a few seconds and you should then see new values for the PGA resistors appear, as shown in Fig. 12. Press 'Back' to exit this screen.

To manually calibrate any value on this screen, simply touch that value (ie, Vref, Rshunt, Rval or one of the PGA resistors) and enter the measured value, or cancel to go back to the calibration screen. You can then use the 'Back' button to return to normal operation.

Vref calibration is not necessary and you only need to change Rval if you've

used a precision resistor value other than 12k Ω to build the unit.

The one manual calibration you will probably want to perform will be to set a more accurate value for Rshunt. If you've purchased a kit from SILICON CHIP, simply enter the value we supply along with the shunt resistor. Otherwise, you will need a high-precision ohmmeter to measure the shunt value and then enter that.

External voltage reference

The simplest way to use the unit with an external voltage reference is to set it to divider mode and then select the desired output voltage by entering a fraction. For example, say the external reference is 4.096V and you want to get an output of 2.5V. You could achieve this by simply entering an attenuation ratio of '2.5/4.096'.

Note that when the unit is used as an unbuffered divider, the IN+, IN-, OUT+ and OUT- terminals are completely isolated from the rest of the circuitry, and the maximum applied voltage between IN+ and IN- can range from -60V to +60V. However, when using it as a buffered divider, OUT- is necessarily connected to circuit ground and since normally OUT- and IN- are joined externally, by extension IN- is also. This should not normally matter since the unit's supply will normally be floating, but it's worth keeping in mind.

When operated as a resistance reference, the inputs and outputs are also fully isolated, whereas in both voltage reference and current reference mode, OUT- is connected internally to ground.

Other features

In current reference mode, the current, voltage and temperature of the controlling MOSFET (Q1) is continuously monitored (or in the case of temperature, estimated) and the temperature is shown on-screen, where the input impedance is normally shown (see Fig. 8).

As explained in Part 1 (October issue), should any of these parameters exceed the normal limits, the output relay will immediately switch off and a message indicating the reason for disconnection will be displayed. You can simply press on this message to dismiss it (see Fig. 13) and then switch the output back on again.

When using the unit as a buffered voltage reference or divider, the output will also switch off if the output voltage is pulled outside its normal range by the load, although this would be a rare situation. This is to protect the op amps from being damaged by

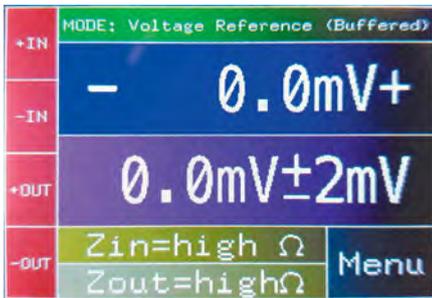


Fig.4: assuming everything is working properly, this is what should appear on the LCD when the unit is first powered up.

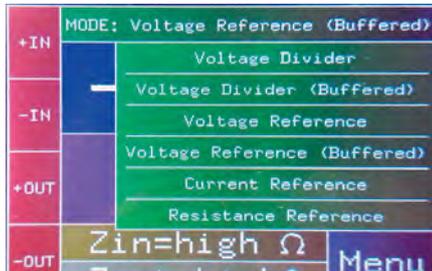


Fig.5: after touching the bar at the very top of the screen, you can select from the six different modes that are shown here.



Fig.6: when you touch a value that can be changed, a keyboard like this appears. The keyboard layout changes to suit the value being entered.

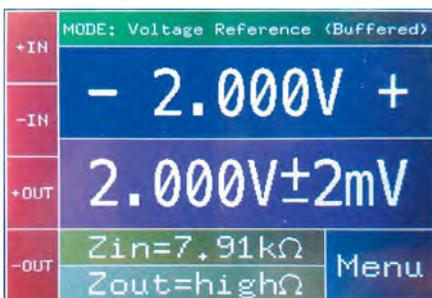


Fig.7: the unit has now been set as a 2V voltage reference with buffered output, but the output has not been switched on yet, as shown at bottom.

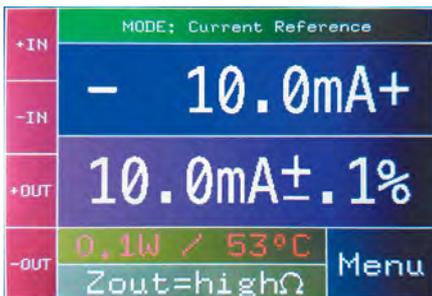


Fig.8: it is now operating as a 10mA current reference and the output is on. Note the always-present terminal labels at the left side of the screen.

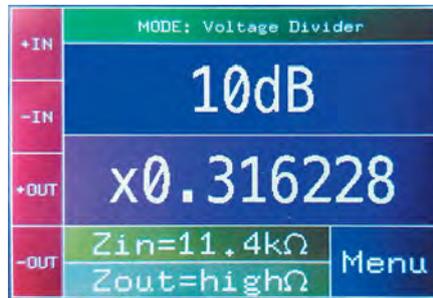


Fig.9: in divider mode, the division ratio can be entered in multiple ways; in this case, in decibels (dB). The attenuation factor is shown below.



Fig.10: the resistance reference mode is somewhat limited; the selected resistance is shown at the top while the actual resistance is shown below.

a back-fed voltage and similarly, an on-screen message will appear if this happens to explain why the output has been disconnected.

Pulse test mode

Normally, once the output of the unit has been switched on, it stays on until you switch it off. But there may be situations where you want to feed the output of the unit to its load only for a brief period. This is especially useful if using the unit as a current source or sink above 100mA to prevent it from overheating, for example, while load testing a power supply, but it can be applied to any mode.

In this case, you can set an output on-time from 10ms to one minute. You switch the output on manually and it

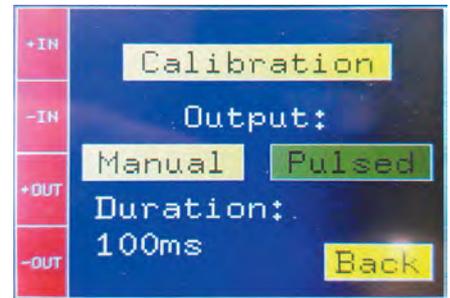


Fig.11: the set-up menu which provides access to the calibration menu and allows you to set up the output for manual or pulse mode.

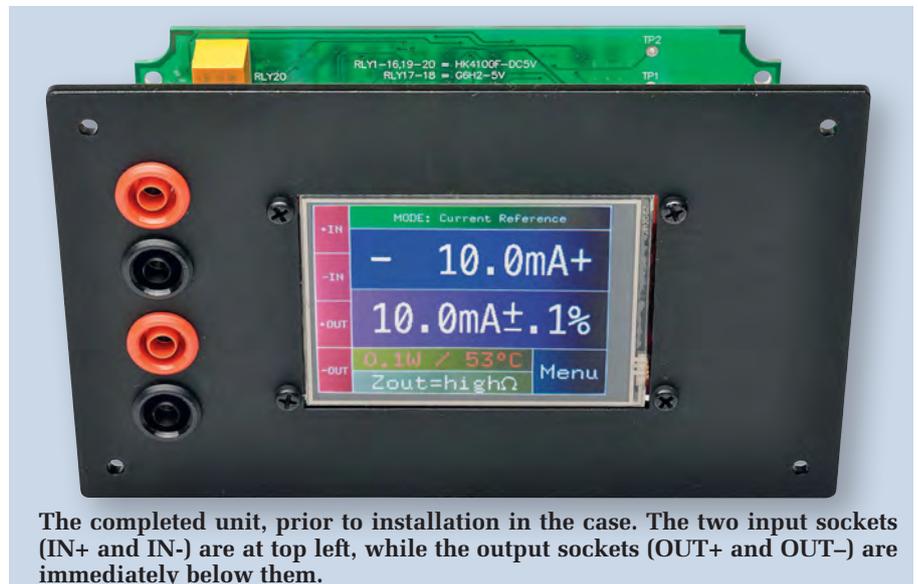


Fig.12: the calibration screen after pressing the Automatic calibration button. Note that the PGA resistors are now shown with the measured values.

automatically switches off after the set time. Note that the actual on-time may differ slightly from the set time due to relay switching times.

The on-time can be set via the set-up menu, accessed by touching the 'Menu' button in the lower right-hand corner. You then have the option to select either continuous (ie, normal) or pulsed operation and set the pulse duration (see Fig.11).

The mode and pulse time are stored in Flash memory and will be automatically restored on power-up. When in pulse test mode, a countdown is shown on the screen each time the output is switched on and a message displayed after the output is switched off, which can be dismissed by pressing on it.



The completed unit, prior to installation in the case. The two input sockets (IN+ and IN-) are at top left, while the output sockets (OUT+ and OUT-) are immediately below them.

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By Nicholas Vinen

Based on Geoff Graham's Micromite Plus and Micromite LCD Backpack



The Micromite Plus LCD Backpack

The *Explore 64* and the *Micromite LCD Backpack* have had an illicit affair and here are the secret baby photos to prove it! It has its mother's eyes and father's brain. OK, that's not really true, but we have taken the best features of each project and put them together onto a single board. Use it to supercharge your *BackPack* project or just as a convenient and cost-effective controller module.

READERS WILL have noticed that we've published a number of projects based on the *Micromite LCD Backpack*, first described in our May 2017 issue. It's a very convenient way of providing user control and feedback for a project, and combines the user interface and control logic in a compact module. Because it doesn't cost too much, we can integrate it into a larger project without making it overly expensive. And thanks to Geoff Graham's MMBasic interpreter, constructors can easily upgrade and modify our designs.

As it stands, the biggest problem with the *BackPack* is the limitation of the DIP (through-hole) PIC32 processor. It has significantly less Flash memory and RAM, and a much lower operating frequency compared to the surface-mount versions. The BASIC interpreter overhead exacerbates all of these. It also lacks the SD card and USB interfaces

introduced with the *Micromite Plus* in the August 2017 issue.

The micro used in the *Micromite Plus Explore 64/100* projects puts the original to shame, with a much more generous helping of RAM and Flash, much better speed (2.5 times as fast) and sufficient spare memory and pins to implement onboard microSD card and USB interfaces. But while the *Explore 64* can interface with many different displays, you have to wire it up yourself and the 5-inch touchscreen is quite expensive. So those projects can't easily replace the *LCD Backpack*.

But this one can! We have combined the convenience and low cost of the original *BackPack* with all those new *Micromite Plus* features. The *Micromite Plus LCD Backpack* uses the same 2.8-inch touchscreen TFT as before, but has the enhanced processor and peripherals of the *Explore 64*.

Backwards compatibility

One of the main aims when designing the *Plus Backpack* was to make it easy to improve projects that used the original *BackPack*. The original *BackPack* has three main connectors: one for 5V power and the serial terminal (CON1, four pins), one for the TFT interface (CON3, 14 pins) and one for interfacing to external circuitry (CON2, 18 pins). It also has an in-circuit serial programming (ICSP) connector for the microcontroller (CON4, six pins).

On the *Micromite Plus LCD Backpack*, we have fitted identical connectors, with the same names, positions and sizes. The PCB is the same size too, with mounting holes in the same positions. So it's largely a 'drop-in' replacement.

There are differences, however, in some of the pin numbers and properties assigned to these connectors. Going

Features and specifications

through each connector in turn, these differences are:

- **CON1:** the pinout is still 5V/Tx/Rx/GND, however the *Micromite Plus* uses pins 58 and 6 as the console Tx and Rx, compared to pins 11 and 12 on the original *Micromite*. However, the difference in these pin numbers should not affect usage at all.

- **CON2:** we have kept the functions of each pin in this I/O header as close as possible to those for the original *BackPack*. However, to keep the functions identical, we had to change most of the pin numbers. That means that you will need to change the software to use the new pin numbers – see Table 1 for a comparison. Note that this same information is also shown in the circuit diagram, which is discussed below.

There are only two small losses of function in this header (this was unavoidable). First, pins 8 and 11 are no longer 5V-tolerant and second, pins 9 and 10 can no longer operate as count inputs. But there are two extra benefits to the new configuration: four new analogue-capable inputs at pins 5, 6, 8 and 11, and the SPI bus is no longer shared with the one driving the TFT and touch sensor.

- **CON3:** this is intended to plug into the same ILI9341-based TFT display as the original *BackPack*. The pin functions are essentially the same, although again, some of the numbers have changed and thus the display/touch initialisation commands have changed (we'll go over this later). Table 2 shows how the pins are connected to the display board on both designs.

As noted earlier, the SPI2 bus is used for the TFT (this is required by MM-Basic) while the SPI1 bus is connected to CON2, for interfacing with external circuitry. This has a major advantage compared to the original *BackPack* as MMBasic's use of the SPI bus for graphics commands and touch sensing will not interfere with SPI data sent via CON2. This is especially helpful when using touch interrupts or using the SPI bus or graphics commands in interrupt handler routines.

Another major improvement over the original *BackPack* is the deletion of VR1 for TFT backlight control. The backlight is now driven by a MOSFET, which can have its gate controlled via the PWM2A output for software-controlled dimming over a wide range. The backlight can be turned off entirely when not used, which is especially helpful for battery-powered devices because it typically draws most of the supply current.

- **CON4:** the ICSP header is connected to PGED1/PGE1 in both versions, which are pins 4 and 5 on the original

- Display: 65,536 colour, 2.8-inch (7cm) diagonal TFT LCD with 320 x 240 pixel resolution and software backlight brightness control
- Input system: resistive touchscreen
- Processor: Microchip 32-bit 120MHz microcontroller with 512KB Flash memory and 128KB RAM
- Available memory: 100KB Flash program space, 100KB RAM
- I/Os: 31 free input/output pins, including 17 analogue inputs, 14 5V-tolerant pins, hardware SPI and I²C buses, two (or three) serial ports, four PWM outputs, a PS/2 keyboard interface, three frequency-counting inputs, a wake-up pin (for sleep mode) and an infrared input pin
- Digital I/O current capability: 15mA sink/source
- Communications protocols: SPI, I²C, asynchronous serial, RS-232, IEEE 485 and Dallas 1-Wire
- USB support: Integrated USB 2.0 interface with virtual serial port
- SD card support: handles cards up to 64GB with onboard microSD socket and SD card socket on back of display module
- Interpreter: Built-in MMBasic with support for 64-bit integers, floating point, strings, arrays and user-defined subroutines and functions
- Standard Micromite features: includes built-in communications protocols, PWM and SERVO outputs, variable CPU speed, sleep mode, watchdog timer and automatic start and run
- Additional features: built-in support for infrared remote receivers, temperature sensors, humidity sensors, distance sensors, numeric keypads and battery-backed real-time clocks
- Graphics commands: CLS, PIXEL, LINE, BOX, RBOX, CIRCLE, TEXT and TRIANGLE, using the full range of colours
- Advanced graphics commands: these include on-screen keyboards, buttons, switches, check boxes, number boxes, spin boxes and radio buttons
- Font support: six built-in fonts plus the ability to load custom user fonts
- Code editing: on-screen editor support when PS/2 keyboard is connected
- Power supply: 5V (4.5-5.5V) @ 80mA (backlight off) up to 250mA (backlight at full brightness)
- Dimensions: 86 x 50 x 27mm (same as original LCD BackPack)
- Compatibility: connector positions and pin-outs compatible with original LCD BackPack

BackPack and pins 16 and 15 on the *Plus BackPack*. On the original *BackPack*, these pins were also routed to CON2 and so the external circuit design had to take this into account if the chip could be re-programmed in-situ.

In contrast, on the *Plus BackPack*, only pin 11 on CON2 (pin 21 of the micro, COM1:TX) is so affected. The other programming pin is routed to new header CON5 and will rarely be used.

So in summary, to adapt software designed for the original *LCD BackPack* to the *Plus BackPack*, I/O pin numbers will need to be adjusted and you will need to ensure that you use the SPI1 bus and that pins 8 and 11 of CON2 are not required to be 5V-tolerant.

New features

Five new connectors have been added, with the following functions:

- **CON6:** since the *Micromite Plus* has many more I/O pins than the original

Micromite, we've added this extra 21-pin header to give access to most of those additional pins, for projects which may exhaust the connections available on CON2. This connector's pin-out has some similarities to CON6 on the *Explore 64*. However, we've had to use a number of different pins here because the others were already in use for other purposes.

In summary, the pins on CON6 consist of nine analogue-capable inputs, 11 5V-tolerant digital inputs, four PWM-capable outputs, two pins which can be used to connect a PS/2 keyboard, two counting inputs plus the same 3-pin SPI bus which is wired to CON2. Note that besides this shared SPI bus, none of the other pins are used for any other purpose and thus you are free to do what you like with them (with one slight exception, see the following section).

- **CON5:** this 3-pin header provides a convenient place to connect to the COM3 Tx/Rx pins (16 and 17 on IC1)

Table 1: CON2 Functions in original Backpack vs Plus Backpack

Pin Number	Original Backpack	Plus Backpack
1	RESET	RESET
2	3 SPI OUT	8 SPI1 OUT
3	4	12
4	5	14
5	9 COM2:TX	11 COM2:TX
6	10 COM2:RX	13 COM2:RX
7	14 SPI IN	45 SPI1 IN
8	16 COUNT/WAKEUP/IR	51 COUNT/WAKEUP/IR
9	17 COUNT/I ² C CLOCK	44 I ² C CLOCK
10	18 COUNT/I ² C DATA	43 I ² C DATA
11	21 COM1:TX	15 COM1:TX
12	22 COM1:RX	59 COM1:RX
13	24	24
14	25 SPI CLK	50 SPI1 CLK
15	26	27
16	+3.3V	+3.3V
17	+5V	+5V
18	GND	GND

Note: blue indicates analog pin. Red indicate 5V-tolerant pin.

Table 2: CON3 Functions in original Backpack vs Plus Backpack

Pin Number	TFT Pin	Original Backpack	Plus Backpack
1	VCC	+5V	+5V
2	GND	GND	GND
3	CS-bar	6 PWM1C	29
4	RESET	23	23 COUNT
5	D/C	2	2
6	SDI (MOSI)	3 SPI OUT	5 SPI2 OUT
7	SCK	25 SPI CLK	4 SPI2 CLK
8	LED (backlight)	to VR1	to pin 53 (PWM2A) via Q1 and Q2
9	SDO (MOSI)	14 SPI IN	47 SPI2 IN/PWM2B
10	T_CLK	25 SPI CLK	4 SPI2 CLK
11	T_CS	7 COM1:ENABLE	1
12	T_DIN	3 SPI OUT	5 SPI2 OUT
13	T_DO	14 SPI IN	47 SPI2 IN/PWM2B
14	T_IRQ	15 COUNT	3

as well as pin 33, if it is not being used as USBID (ie, if shorting block SB1 is not shorted). Unless you need to use the COM3 port, you're unlikely to need this header and it can be left off.

Note that pins 16 and 17 are already connected to CON4 and CON6 respectively; however, since CON4 is for in-circuit programming, you would not want to connect a COM port there. Note also that pin 33 (USBID) is only really needed for 'USB on-the-go' (USB OTG) which would probably require

a different connector for CON8 and thus is most useful as a 5V-tolerant general-purpose digital input; it can not operate as an output.

- **CON7:** this allows the use of the SD card socket on the TFT module. To use this, you need to fit a 4-pin female socket in this location and a matching pin header on the back of the TFT module. The SD card's CS, MOSI, MISO and SCK lines are routed to pins 21, 5, 47 and 4 on IC1 respectively. Since the latter three pins are SPI2 OUT, SPI2 IN

and SPI2 CLK, this makes interfacing with an SD card easy; the commands to do this are shown later.

Power for the SD card on the TFT module comes from a 3.3V regulator (on the module) that draws from the 5V supplied via CON3. So one advantage of using that SD card socket is that it doesn't reduce the current available from the 3.3V rail on the Backpack PCB.

- **CON8:** the onboard USB socket which can be used as a serial console. It's quite convenient since all you need is a USB Type-A to microUSB cable to communicate with the *Micromite Plus*. However, as noted in the earlier articles on the *Micromite Plus*, it has the disadvantage that the console is reset whenever the micro is reset (eg, when S1 is pressed). However, our experience has been that this is not necessary very often, so you certainly can program the *Micromite Plus* via this port.

If JP1 is fitted, then the unit will be powered from this cable as well, but take care that you don't back-feed 5V into the USB port since this could damage your PC. **In other words, only fit JP1 if you are not powering the board from any other source.**

The alternative to using CON8 for programming and communications is to use a USB/serial adaptor (as explained in multiple previous articles) and wire it up to CON1 (see Fig.3). This will allow the serial port to continue operating even if the *Plus Backpack* is reset. Power can also be supplied to the board via CON1, with the same proviso as above.

- **CON9:** the onboard microSD card socket. This is wired in parallel with CON7, so if you are using this, you can't use the SD card socket on the TFT module, and vice versa.

The card is powered directly from the onboard 3.3V supply (from low-dropout linear regulator REG1) and is provided with a 10µF bypass capacitor. The only additional connection is from pin 22 of IC1 to the card detect switch on the socket. Later on, we'll show the command to configure the *Micromite* to use this pin to detect card insertions and removals.

Circuit description

The full circuit of the *Micromite Plus Backpack* board is shown in Fig.1. It consists mostly of microcontroller IC1 and its connections to CON1-CON9, so essentially we have already described most of it above. But let's go over a few details.

IC1 has a 20MHz crystal connected between oscillator pins 39 and 40, with 22pF load capacitors. Its 100MHz or 120MHz clock signal is derived from this using an internal PLL (phase-locked loop) frequency multiplier that's

configured by the MMBasic software. A 10 μ F ceramic capacitor from pin 56 to ground stabilises its internal core supply rail.

Display backlight control is via IC1's output pin 53, referred to in MMBasic as PWM 2A. Note that the PWM 2B function is shared with SPI2 IN, which is already dedicated to the display interface, so there is no issue with interaction between these two PWM functions that share the same timer. Pin 53 drives the gate of N-channel MOSFET Q2, which has a 10k Ω pull-down resistor so that it is held off when the microcontroller is powering up, reset or not operating for some other reason.

When pin 53 goes high, Q2 switches on and this pulls the gate of P-channel MOSFET Q1 low. It is normally held high by a 1k Ω resistor from the 5V rail. When the gate of Q1 is pulled low, Q1 switches on, allowing power to flow from the 5V rail into the backlight LED anode pin, marked LED on CON3. The higher the duty cycle of the PWM signal from pin 53, the brighter the backlight. Commands to control the backlight will be shown later.

The $\overline{\text{MCLR}}$ reset input of IC1 is held high by a 10k Ω pull-up resistor from the 3.3V rail, preventing spurious resets. The chip can be reset either by pressing onboard tactile pushbutton switch S1 or by pulling pin 1 of CON4 low. A 470 Ω series resistor limits the current drawn from this pin when S1 is pressed.

Like the *LCD BackPack* and *Explore 64*, the *Plus BackPack* has provision for IC2, an MCP120 2.7V supply supervisor which will reset IC1 should the nominally 3.3V supply drop below 2.7V. Normally, this is not necessary, however it may prevent the unit from misbehaving in a harsh environment. If you want to fit the MCP120, the only other component you need is fit is its adjacent 100nF bypass capacitor.

Power supply

The unit is intended to be powered from an external regulated 5V supply. The acceptable voltage range is 4.5-5.5V, which means that the USB port of a PC or a USB charger is quite suitable for powering the *Plus BackPack*, either via CON8 or flying leads connected between pins 1 and 4 of CON1.

Current drain is up to 250mA with full brightness on the display backlight and the *Micromite* running at full speed. With the display backlight off, the supply current is more like 80mA, and this can be reduced if the *Micromite* is in sleep mode or running at less than maximum speed.

Note that you must not use an unregulated 5V supply as these can easily

Parts List

1 double-sided PCB, 86 × 50mm (from micromite.org)
 1 ILI9341-based LCD module, 320 × 240 pixels, 2.8-inch diagonal, with touch controller
 1 right-angle, through-hole, tactile pushbutton switch, short actuator (S1)
 1 20MHz crystal, low profile HC-49 (X1)
 2 4-pin headers, 2.54mm pitch (CON1 and SD card connector on display module)
 1 18-pin header, 2.54mm pitch (CON2)
 1 14-pin female header, 2.54mm pitch (CON3)
 1 6-pin right-angle header, 2.54mm pitch (CON4; optional)
 1 3-pin header, 2.54mm pitch (CON5; optional)
 1 21-pin header, 2.54mm pitch (CON6)
 1 4-pin female header, 2.54mm pitch (CON7)
 1 SMD mini USB type B socket (CON8) (Altronics P1308 or similar)
 1 microSD card socket (CON9) (Altronics P5717 or similar)
 1 2-pin header, 2.54mm pitch, with shorting block (JP1)
 4 M3 × 12mm tapped spacers
 4 M3 × 6mm machine screws
 4 M3 × 8mm machine screws
 4 Nylon washers, 3mm ID, 6mm OD, 1mm thickness
 1 USB-to-serial adaptor and jumper leads (optional, see text)

1 5V regulated power supply (see text)

Semiconductors

1 PIC32MX470F512H-120/PT microcontroller programmed with MMBASIC+ firmware (IC1)
 1 MCP1703A(T)-3302E/DB low-dropout 3.3V regulator, SOT-223 (REG1)
 1 MCP120(T)-270I/TT 2.7V supply supervisor, SOT-23 (IC2; optional – see text)
 1 DMP2215L P-channel MOSFET, SOT-23 (Q1)
 1 2N7002 N-channel MOSFET, SOT-23 (Q2)
 1 green SMD LED* (LED1)

Capacitors*

4 10 μ F 6.3V ceramic, X5R or X7R
 6 100nF 50V ceramic, X5R or X7R
 2 22pF ceramic, C0G/NP0

Resistors (1% or 5%)*

2 10k Ω 1 470 Ω
 2 1k Ω 1 10 Ω

* Use SMD 3216 (1206 imperial) size; 2012/0805 sizes are also suitable, but are not recommended for beginners

Where to buy parts

We strongly recommend you make micromite.org your first port of call when shopping for all Micromite project components.

reach over 6V, which is the threshold for damage to REG1 and possibly other components (eg, the display module). REG1 is a 250mA 3.3V low-dropout regulator which can deliver the rated 250mA with just 3.925V at the input. Its own supply current is just 2 μ A with a light load. It has 10 μ F input bypass and output filter capacitors.

IC1 has five 100nF bypass capacitors, located near its five supply pins, with a 10 Ω resistor to help filter its analogue supply (AVDD). Finally, LED1 indicates when power is present and is fed with around 1mA thanks to its 1k Ω series current-limiting resistor. Note that pads are provided to mount LED1 on either side of the PCB, depending on your preference.

PCB design

The *Micromite Plus LCD BackPack* is built on a double-sided PCB measuring 86 × 50mm, which is identical to the size of the original

Micromite LCD BackPack. Most of the components are on one side, which ends up facing the back of the display module. Fig.2 shows the details.

Besides routing all the tracks from IC1 to the various connectors, our main goal was to keep high-speed signals separated to prevent cross-talk and to provide a low-resistance ground plane across the whole board to minimise EMI and inductive coupling between tracks. As such, it is studded with numerous vias between the top and bottom layer ground planes, including many under IC1.

CON3 and CON7 are located to plug straight into the display module and the four mounting holes are spaced to suit that module too. CON1, CON2 and CON6 can either be mounted on the back of the module or on the display side but using right-angle headers. CON5 can be left off in most cases, and if you only need a few I/O pins, you don't need to fit CON6 either.

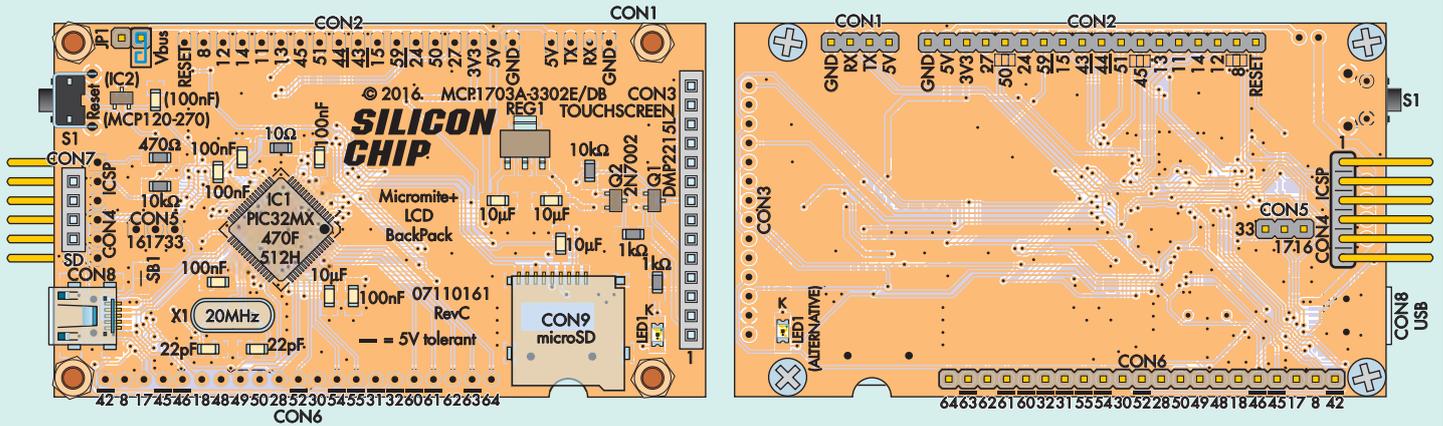


Fig.2: follow these top and bottom overlay diagrams to assemble the *Micromite Plus LCD Backpack* PCB. Most of the parts are SMDs and are fitted to the top side which later faces the rear of the attached LCD module. I/O connectors CON1, CON2, CON5 and CON6, along with in-circuit programming header CON4, are fitted to the other side. Reset switch S1, USB socket CON8 and microSD card socket CON9 are accessed via the edges of the module.

Construction

Construction is quite similar to the *Micromite Plus Explore 64* as we are using mostly the same parts. The only slightly tricky components to fit are IC1, CON8 and CON9, as these have relatively close pin spacings. The other components either have wide spacings or are conventional through-hole types.

The essential tools are a good magnifier, plenty of flux and a steady hand. The magnifier needs to be at least $\times 3$ power and preferably $\times 10$. A jeweller's loupe can be used but the best option is a stereo microscope. The flux should be a good quality flux paste/gel such as H1650A from Altronics or NS3036 from Jaycar.

Fig.2 shows the parts layout on the *Plus Backpack* PCB. The first step is to install microcontroller IC1. Apply flux to all of its pads, then position the chip so that its pin 1 (marked with a dimple) is lined up with the pin 1 marking on the PCB. Then hold it in position using a toothpick or tweezers and solder one corner pin.

An alternative technique is to first apply solder to one pad, then heat the solder on that pad while quickly sliding the IC into place, after which you lift the iron off the board. This requires practice but you can make several attempts, as long as you avoid spreading the solder onto adjacent pins.

Now check that the IC is correctly aligned; if not, re-melt the solder while gently nudging it into position. Once it's in position, apply more flux to all the pins and solder each one in turn, then recheck the first pin and add fresh solder if necessary.

The technique here is simple; put a very small amount of solder on your iron's tip, touch the tip to the solder pad and slide it forwards to gently touch the first pin. The solder should freely flow around the pin and the pad. You should

then be able to solder at least 15 more pins (one side of the IC) before you need to add more solder to the iron.

The secret is to be generous with the flux, as this will allow the solder to flow freely onto the pads and their corresponding pins. Alternatively, if you have a mini-wave tip or a very steady hand, with sufficient flux in place, you can drag solder across one side (16 pins) in a single movement.

Often you will find that you are actually soldering two or more pins simultaneously, but the solder will not usually bridge the pins. If it does, this is an indication that you have too much solder on your iron. If any pins are bridged, come back later with solder wick (and more flux) and remove the excess.

The SD card connector is next on the list. It's located on the PCB by two small plastic pins that match two holes on the board. Solder its four mounting lugs first, followed by the signal pins. These pins are soldered using the same technique as for IC1.

Note that the SD card connector's pins are fragile and the plastic they are embedded in will melt if too much heat is applied, so only touch the soldering iron to the pins for a very short time. As before, apply plenty of flux before soldering.

The mini USB connector can now go in. It also has locating pins to position it correctly. You may have to push it down firmly for it to sit flush with the board. Once again, solder the mounting lugs first and then the signal pins. These are a bit of a challenge as they are partially under the connector's body and you will need a fine-tipped soldering bit to reach them; we have extended the pads outside the body to make this easier.

You can now solder REG1 in place. This has a large tab which connects to the copper ground plane on the PCB. Start by applying flux to all four pads,

then slide it into place and solder one of the smaller leads before checking the positioning. Once you're happy, solder the other smaller leads and finally the large tab. It may take a few seconds to heat the part and PCB up enough to get a good solder joint on that tab.

Follow with small MOSFETs Q1 and Q2. These devices have wide pin spacings and heat up quite fast, so you should have them in place pretty quickly. If fitting the optional supply supervisor (IC2) which also comes in an SOT-23 package, solder that on now as well.

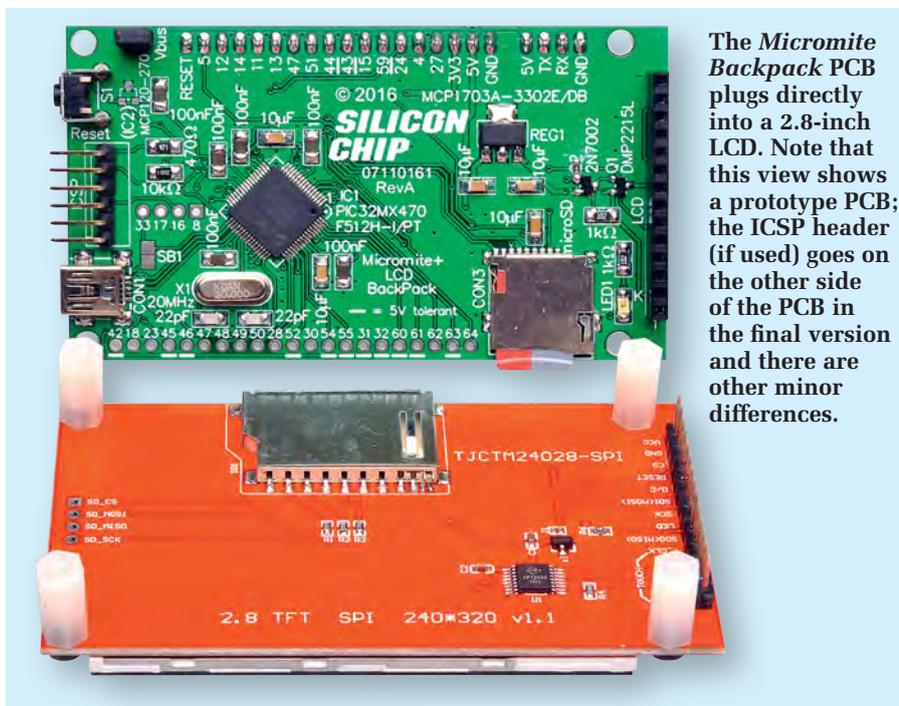
Passive SMD components

Soldering the passive SMD components requires a slightly different technique. Start by applying flux to one solder pad and then tin it by applying a thin layer of solder to it. That done, you have two choices.

First, you can place the component in position and hold it still with a toothpick or tweezers while you apply the iron's tip to the end sitting on the tinned pad and the component lead will sink into the solder underneath. Alternatively, you can slide the component into place while heating the solder on the pad. The second technique will probably require more practice, but it may be quicker once you get used to it.

Either way, once the component is secure, apply more flux and solder the other end before returning to the first to make sure that the joint is good. Once again, the secret is to use plenty of flux and don't forget that it may have boiled off one of the pads while you were soldering the other end of the component, so keep reapplying it. Solder the six resistors and 12 capacitors using this method.

LED1 (the power indicator LED) is the last SMD to be fitted. This device is polarised and should be marked with a bar or dot on the cathode end. Some



The *Micromite Backpack* PCB plugs directly into a 2.8-inch LCD. Note that this view shows a prototype PCB; the ICSP header (if used) goes on the other side of the PCB in the final version and there are other minor differences.

LEDs might be different, so it is good practice to use a multimeter's diode test facility to check the polarity. Solder it in place with the cathode towards the top edge of the board, as shown in Fig.2.

It's up to you whether to put it on the same side of the board as the other SMDs, where it will ultimately face towards the front of the unit (ie, aimed at the back of the TFT module) or on the other side, where it will be more visible, but facing the back of the unit.

Through-hole components

Install crystal X1 ensuring you leave a small (1mm) gap between the crystal body and the PCB. Alternatively, use an isolating washer under the crystal.

Next comes tactile pushbutton S1, which is soldered into place with its actuator sticking out (barely) over the edge of the PCB. Push its pins all the way down before soldering them. Now you can solder headers CON3 and CON7 in place, on the same side as the other components. You may find it best to temporarily plug in the TFT module and attach it using the tapped spacers to ensure these are positioned correctly.

Now you can solder CON1, CON2 and optionally CON4, CON5 and CON6 to the PCB's opposite side. Make sure they're all straight and flat on the board before soldering more than two pins.

JP1 can go on either side of the board. We've shown it on the side that will face the TFT module but this does make it difficult to change when the display module is in place (which may or may not be a good thing).

Finally, it's time to attach the TFT module. Use M3 × 6mm machine screws to attach M3 × 12mm tapped spacers to each mounting hole, with the

spacers on the same side as CON3 and CON7. Then plug the module into both CON3 and CON7 (noting that you'll need to fit the 4-pin male header on the TFT module, as it comes without it). Attach the module to the spacers using the slightly longer machine screws, with the nylon washers under each screw head. These will be used as spacers later if you decide to attach the whole thing to the lid of a box or case.

Loading the firmware

Programmed PIC32s are available from the SILICON CHIP Online Shop and will be supplied with any *Micromite Plus LCD Backpack* kits purchased. If using a blank PIC32 chip, you will need to program it yourself. In this case, you will need a suitable programmer such as a PICkit 3 from Microchip. This can be used to program IC1 via CON4.

The first step is to download the firmware from the *EPE* website and extract the *Micromite Plus* hex file (ie, the firmware). It's then just a matter of using your computer and the MPLAB software supplied with the PICkit 3 (or downloaded from Microchip) to program the hex file into the microcontroller; see page 18 of the May 2017 issue for further details.

During this procedure, the PICkit 3 will verify the programming operation by reading back the data on the chip. If it reports a fault, you will need to fix that before progressing. Usually, though, the programming operation will be verified as OK, indicating that the PIC32 has been correctly programmed.

Serial console

To set up and use the *Plus Backpack*, you must connect a terminal emulator

to its console. The console is a serial interface over which you can issue commands to MMBasic to configure the chip and edit or run programs. MMBasic also uses the console to display error messages.

As mentioned earlier, the *Plus Backpack* actually has two consoles, one serial and one USB. A USB-to-serial converter is required in order to use the hard-wired serial console. One end of this converter plugs into a USB port on your computer, while the other end connects to the *Micromite's* serial console – see Fig.3. To your computer, it will look like a serial port (via USB), while the connection to the *Micromite Plus* is a standard serial interface with TTL (0-3.3V) signals levels.

JP1 must be installed if you want to power the *Plus Backpack* via CON8. However, it must NOT be fitted if you are powering the unit externally and if there's any chance you will use CON8 to access the USB console. So check whether your fitting of JP1 is correct before proceeding.

Fig.3 shows how a CP2102-based converter is connected to the *BackPack* (other types will be similar). Note that the converter feeds through the 5V supply rail derived from the PC's USB port to power the *Plus Backpack*.

When the converter is plugged into your computer and the correct driver is installed, it will appear as a serial port (eg, COM3 in Windows). You then need to start a terminal emulator on your computer. For Windows, we recommend Tera Term which can be downloaded for free from <http://teraterm.en.lo4d.com>. You will need to set its interface speed to 38,400 baud and connect it to the serial port created by the USB-to-serial converter.

Once that's been done, hit the Enter key in the terminal emulator and you should see the *Micromite's* prompt ('>') – Fig.4. You can then enter, edit and run programs from the command prompt using nothing more than the terminal emulator and a USB cable.

Testing

If you don't see the *Micromite's* prompt, something is definitely wrong and you will need to go through the following troubleshooting procedure. The first step is to measure the current drawn by the *Plus Backpack* from the 5V power supply. With nothing attached to its I/O pins, this should be 60-80mA. If it is substantially more or less than this, it indicates that something is wrong with either the soldering, the microcontroller or its power supply.

If this is the case, check that +3.3V is present on pins 10, 26, 38, 57 and 35 of IC1 and on various other components –

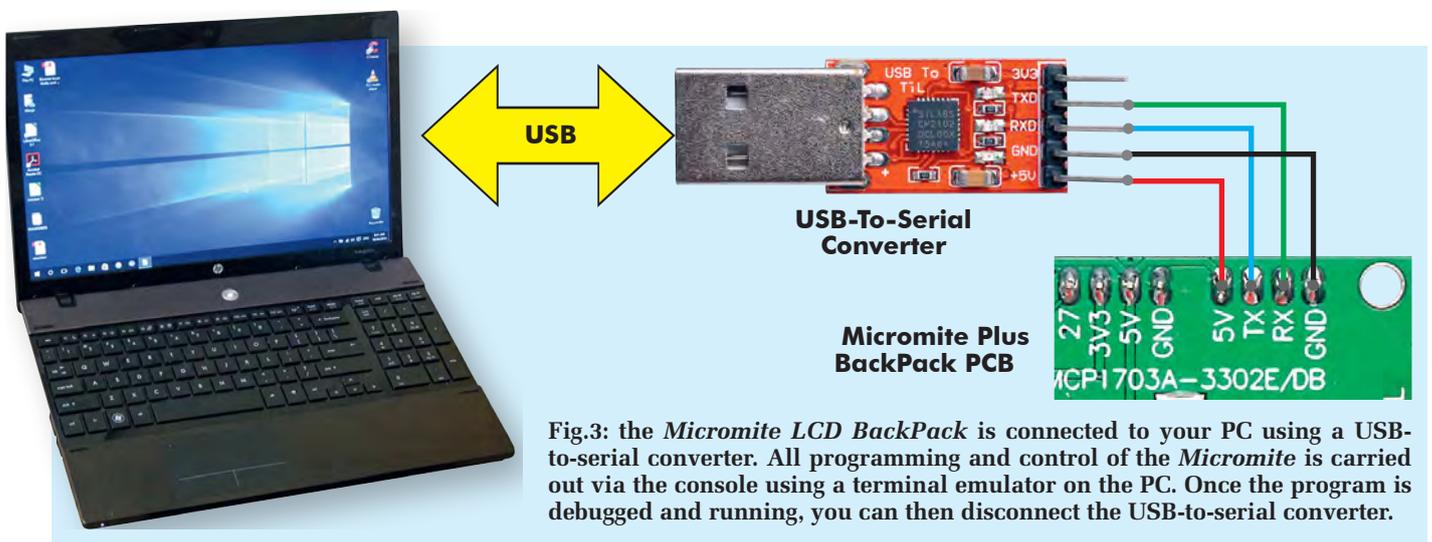


Fig.3: the *Micromite LCD Backpack* is connected to your PC using a USB-to-serial converter. All programming and control of the *Micromite* is carried out via the console using a terminal emulator on the PC. Once the program is debugged and running, you can then disconnect the USB-to-serial converter.

see Fig.1. If this checks out, check that the capacitor connected to pin 56 (Vcap) of IC1 is correctly soldered and is the correct type; it must be a 10 μ F multi-layer ceramic type. A faulty capacitor will prevent the internal CPU from running and the current drain will be quite low (less than 10mA).

A disconnected pin can also prevent the micro from running, so check the soldering on IC1's pins. It's easy to miss a pin and leave it floating just above its solder pad and without a decent magnifier and bright light, this may not be obvious.

Another cause of low current drain is either not programming the *Micromite Plus* firmware into the chip or ignoring an error during this operation. Check that the micro has been correctly programmed.

If the current drain is about right, the next step is to attach the *Plus Backpack* console to your computer or terminal emulator, as shown in Fig.3. You could also try using the USB connector as the console.

With the console connected, press the Reset button on the *BackPack* and you should see the start-up banner as shown in Fig.4. Note that you will not see this banner if you are using the USB console because resetting the *Plus Backpack* will also reset the USB interface.

If you don't see the start-up banner you should check the console Tx pin for some activity when the Reset button is pressed (this indicates that MMBasic is outputting its start-up banner). This can be done using a logic probe, oscilloscope or, at a pinch, a moving coil multimeter. If you do see some activity, the fault is probably either an incorrect console connection or is in the USB-to-serial converter.

User manuals

The *Micromite Plus* is quite an advanced device. After all, it is a full computer with a multitude of facilities. As

a result, it has two user manuals which together add up to almost 200 pages.

The first manual is the *Micromite User Manual* and it describes the features that are standard across the whole *Micromite* range, from the original 28-pin version to the 100-pin *Micromite Plus* (featured in the September and October 2017 issues).

The extra features of the *Micromite Plus* are described in the *Micromite Plus Addendum*, which covers subjects such as the GUI functions, the SD card interface and other features that are only found in the *Micromite Plus*.

Both manuals are in PDF format and available for free download at Geoff Graham's website: <http://geoffg.net>. Before you build and test the *Plus Backpack*, it would be worthwhile downloading and looking through them as they provide a lot more information than we can fit into these pages.

Configuring the display

While MMBasic for the *Micromite Plus* has inbuilt support for 10 different LCD panels, the *Plus Backpack* is specifically designed to attach to the 2.8-inch diagonal 320 \times 240 display with an ILI9341 controller. For details on how to connect it to other types of display, see the *Explore 64* article in the August 2017 issue.

Before configuring the display, you need to turn the backlight on or else it will be very difficult to see anything. Do this using the following command:

```
PWM 2, 1000, 50
```

This sets the brightness to 50% (approximately). You can adjust this value later if required. Assuming you can see that the backlight is now on, proceed to configure the display as follows:

```
OPTION LCDPANEL ILI9341, L, 2, 23, 29
```

To test the display, enter the command:

```
GUI TEST LCDPANEL
```

You should immediately see an animated display of colour circles being rapidly drawn on top of each other. Pressing the space bar on the console's keyboard stops the test. Note that once the display has been configured, you don't need to do it again as the configuration options are stored in the micro's Flash memory.

Configuring touch

Once the LCD panel has been configured, you can set up touch sensing using the following command:

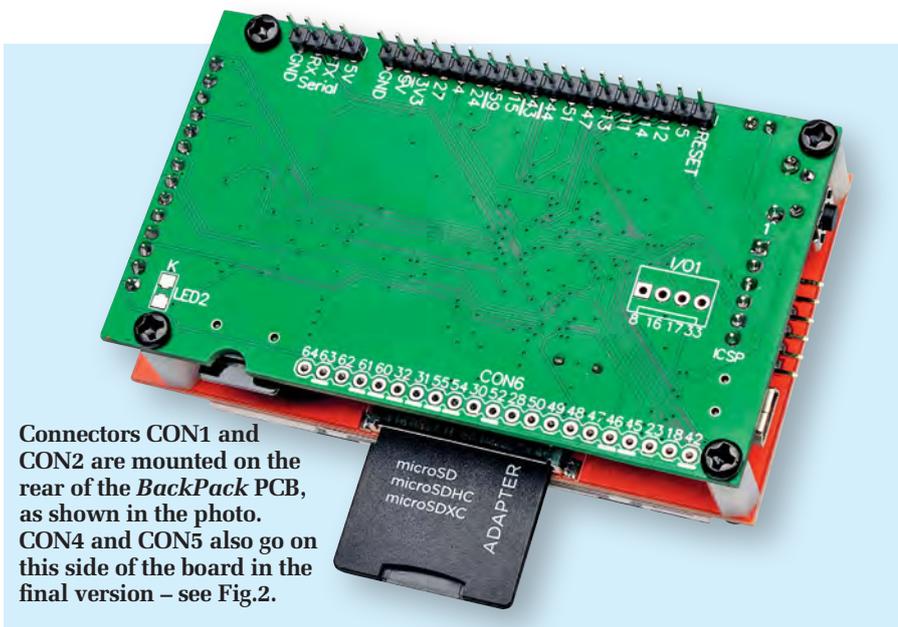
```
OPTION TOUCH 1, 3
```

If you have connected a piezo buzzer to one of the unit's pins via a driving transistor and want this buzzer to click when the screen is touched, you can add this pin number onto the end of the command (with a comma separating it from the final digit).

As with other options, this command only needs to be run once, then each time the *Micromite* is restarted MMBasic will automatically initialise the touch controller. If the touch facility is no longer required, the command `OPTION TOUCH DISABLE` can be used to disable the touch feature and return the I/O pins for general use.

Before the touch facility can be used, it must be calibrated using the `GUI CALIBRATE` command. The calibration process starts with MMBasic displaying a target in the top-left corner of the screen. A blunt, pointed object such as a stylus is then pressed exactly in the centre of the target and held down for at least one second. MMBasic will record this location and then continue the calibration by sequentially displaying the target in the other three corners of the screen.

Following calibration, you can test the touch facility using the `GUI TEST`



Connectors CON1 and CON2 are mounted on the rear of the Backpack PCB, as shown in the photo. CON4 and CON5 also go on this side of the board in the final version – see Fig.2.

TOUCH command, which will blank the screen and wait for a touch. When the screen is touched with a stylus, a white dot will appear on the display. If the calibration was carried out successfully, this dot will be displayed exactly under the location of the stylus. Pressing the space bar on the console's keyboard exits the test routine.

Configuring an SD card

Now that you've set up the display and touch interfaces, you can configure it to use an SD card. Assuming you have fitted CON7 and the matching header on the TFT module, you can plug a full-size SD card into the socket on the back of the display. Whether or not you have done this, you also have the option of plugging a microSD card into the onboard socket. You can't use both at the same time, though.

We would have liked to provide separate \overline{CS} lines so that both sockets could be used, however the *Micromite Plus* software requires a reboot to change the CS pin, making this impractical. So for now, they are connected in parallel and only one can be used at a time.

Before plugging in the card, you need to run the **OPTION SDCARD** command. Note that this must be entered at the command prompt and cannot be used in a program. To set up the microSD card socket, use:

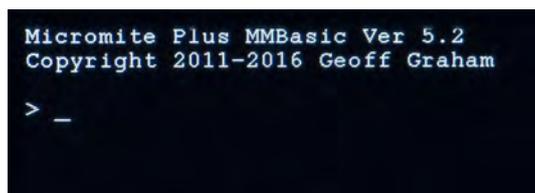


Fig.4: this is what you should see in your terminal emulator when you press the reset button on the *Micromite Plus LCD Backpack* (you'll see a newer version number). If you don't see this, the probable reason is that the USB-serial converter is not connected correctly.

OPTION SDCARD 21, 22

or for the full-size card socket:

OPTION SDCARD 21

Unfortunately, the TFT module does not break out the card detect pin on the full-size socket, so you can't change the card while the unit is running. After running either command, you will need to restart the *Plus Backpack* (eg, with reset button S1). After that, MMBasic will automatically initialise the SD card interface each time.

SD card not required

If the SD card is no longer required, the command **OPTION SDCARD DISABLE** can be used, which will disable the SD card and return the I/O pins for general use.

To verify the configuration, you can use the command **OPTION LIST** to list all options that have been set, including the configuration of the SD card. As another test, you can pop an SD card into the slot and run the command **FILES**. This will list all the files and directories on the card.

Note that some SD cards can be temperamental and may not work, so if you encounter a problem here, try a few SD cards before deciding that you have a fault. For example, some cards (especially high capacity, fast types) may demand more current than the power supply on the *Plus Backpack* can provide.

USB interface

The USB interface on the *Plus Backpack* doesn't need configuring. MMBasic monitors the interface and if it detects a host computer, it will automatically configure it for serial emulation over USB.

Competition!

See page 41 for details of a free-to-enter Micromite competition.

A Windows-based host computer (versions before Windows 10) will require the installation of the 'SILICON CHIP Serial Port Driver', which can be downloaded from the SILICON CHIP website. Macintosh and Linux based computers do not need a device driver, as support is built into the operating system. Windows 10 should not require any drivers to be installed.

Once configured, the USB interface works just like a serial port that's connected to the console. You can start up a terminal emulator such as Tera Term for Windows and tell it to connect to the virtual serial port created by the *Micromite Plus*.

Anything outputted by the *Micromite Plus* will be sent out on both the USB interface and the serial console. Similarly, anything received on either of these interfaces will be sent to MMBasic.

One benefit of using the USB interface as the console is that you can disable the serial console. This allows you to use the I/O pins allocated to the serial console for other duties, including use as a fourth serial I/O port. This is described further in the *Micromite Plus Addendum*.

Further details

We're publishing further information on using the graphics, GUI, SD card and touch functions of the *Micromite Plus* in two feature articles, one last month, and the second this month. For further details, refer to the *Micromite user manual* and *Addendum*, available from Geoff Graham's website at: <http://geoffg.net>

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Need more help?

If you need assistance with any Micromite project featured in *EPE* then send an email to:

phil.boyce@micromite.org

(Do ensure the subject is 'HELP!')

Phil is based in the UK and can help out with all things relating to the Micromite.

We recommend micromite.org as your first port of call when shopping for all Micromite project components. Phil can supply kits, programmed ICs, PCBs and many parts mentioned in recent articles.



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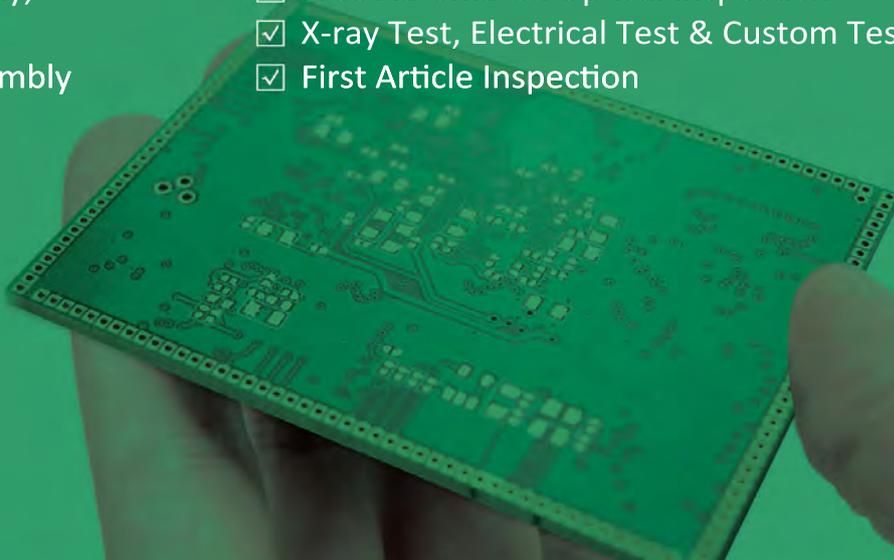
Assembly Capabilities:

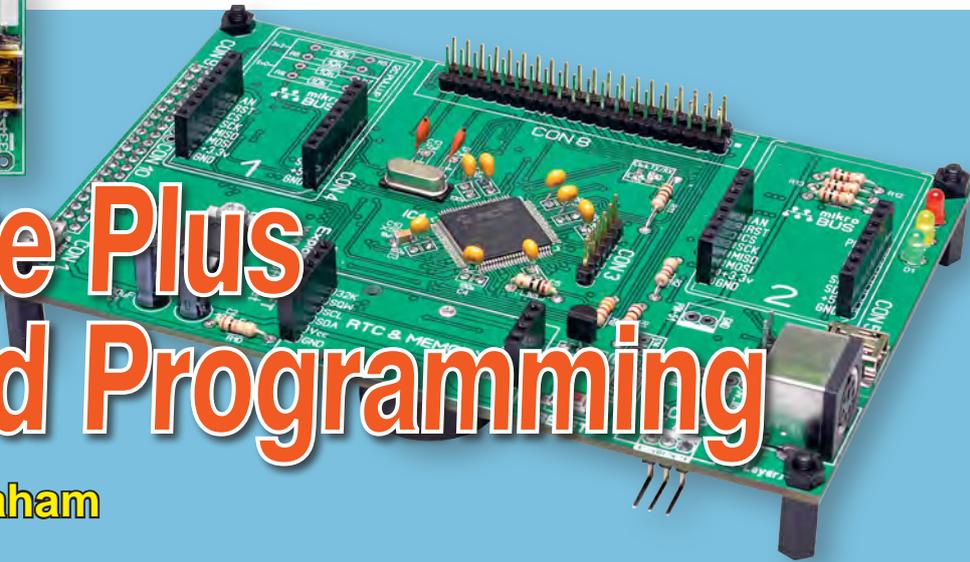
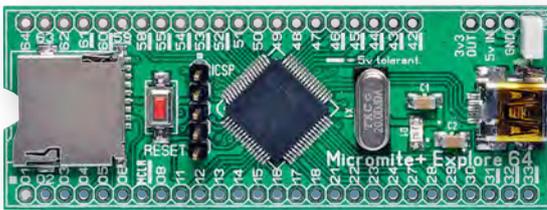
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Micromite Plus Advanced Programming

Part 2 – By Geoff Graham

Last month, we went over some of the new features of the Micromite Plus, including reading and writing files on an SD card and defining GUI (graphical user interface) controls. Now we're going to take a look at some extra features which allow even more advanced GUI controls to be built very easily.

AS EXPLAINED in Part 1 last month, it's trivial to create a GUI control using the *Micromite Plus*. In most cases, a single line of BASIC will create a check box, text input control or one of nine other different types of GUI elements. The *Micromite Plus* firmware manages these controls for you, taking care of display and user interaction via the touch interface. The BASIC program can query the state of the controls at a later time, to see what changes the user has made.

Sometimes, when a control is touched, you need your program to respond immediately. One way to do this would be with a simple IF statement in the main program loop; for example:

```
IF CTRLVAL(PwrSwitch) = 1 THEN ...
```

However, with a complex program, it is more efficient to use an interrupt to detect when a control has been touched. This is especially true if the program is performing background processing while the user is interacting with the GUI. To use a touch interrupt, you must first set it up; for example:

GUI INTERRUPT IntTouchDown

After this command, touching the screen will cause MMBasic to interrupt whatever the main program is doing and execute the code in the subroutine **IntTouchDown**. When this subroutine exits, the main program will continue as if nothing happened (apart from any state changes which occur in that subroutine).

Within the interrupt subroutine, you can discover what control was touched

by using the **TOUCH(REF)** function, which will return the reference number of the control currently being touched. Note that **REF** is a keyword and should not be replaced with a reference number or variable in this case.

In a large program with many controls, it is best to use the **SELECT CASE** statement to select the appropriate code for each control; for example:

```
Sub IntTouchDown
SELECT CASE TOUCH(REF)
CASE PwrSwitch
' do some action
CASE OTHERCTRL
' do some other action
END SELECT
END SUB
```

With this sort of structure, you can process almost any touch completely within the interrupt. As a result, the main program could consist of just the commands to set up the controls and then continue with its main job.

Interrupt example code

As an example of how an interrupt could be useful, consider the situation where you would like to run a motor whenever an on-screen switch is touched. This requires the BASIC program to activate the motor's power relay and illuminate a virtual LED on the screen.

First, you need to define two constants. The first is the reference number for the switch control and the second is the reference for the on-screen LED control:

```
CONST PwrSwitch = 41
CONST RedLED = 42
```

Then you would create the controls as follows:

```
GUI SWITCH PwrSwitch, c$, x, y, etc
GUI LED RedLED, c$, x, y, etc
```

Next, the main program should set up the GUI interrupt and initiate a never-ending loop:

```
GUI INTERRUPT IntTouchDown
DO : LOOP
```

The interrupt subroutine would look something like this:

```
Sub IntTouchDown
SELECT CASE TOUCH(REF)
CASE PwrSwitch
PIN(1) = CTRLVAL(PwrSwitch)
CTRLVAL(RedLED) =
CTRLVAL(PwrSwitch)
END SELECT
END SUB
```

In the above code fragment, we assume that the motor's relay is connected to pin 1. The **CTRLVAL()** function will get the state of the switch (0 for off and 1 for on) and copy that to pin 1, which will control the relay (ie, '1' means close the relay). We also get that value a second time and apply it to the on-screen LED so that it will reflect the state of the motor.

GUI programming

This concept of handling on-screen activity within an interrupt is common in GUI (graphical user interface) programming, but it may be unfamiliar to newcomers.

Conventional programs start by setting everything up, then doing something and then ending. GUI

programming is different and this is because it is the user who is in control of the program flow, not the program. The user might touch this control or that; there is no predicting which control will be touched next and a linear program is not the ideal way to handle this.

In a GUI environment, the program should set everything up and wait to see which control the user touches. When the user does touch a control, the appropriate action can be taken and when that action is complete, the program should resume waiting. This can be referred to as an 'event-driven program'.

The exception is when there is some lengthy processing that must be done as soon as a control is touched. When an interrupt occurs, MMBasic will only run the program in the interrupt subroutine and that means that other interrupts and the main program are blocked. This is fine when the interrupt action is quick (say, less than a millisecond) but if it is lengthy (say, over 100 milliseconds) the effect could be disastrous, as the main loop will freeze while the interrupt is processed.

For example, when a button is touched, you might want your program to send a message to some other item of equipment. Sending a message over a communications link can take some time (eg, half a second) and if that was done within the interrupt routine, it would appear to the user that the program has frozen for this time. Also, if the main loop is performing any real-time tasks, such as monitoring a motor and controlling its speed, the fact that this is not occurring for a significant amount of time could cause real problems.

To avoid this, the interrupt subroutine can set a flag which will let the main program loop know that an action is required. Setting a flag means that the program will write a value into a variable which can then be recognised in another part of the program as a signal to do something. The main loop can then handle that flag in any way it requires. For example, if the flag indicates that a message is to be sent, that message could be sent one character at a time while the main loop continues to run, so that it is not interrupted for a long period.

Here is an example of how you could tackle the above requirement. You first define the flag, then set up the button and the touch-down interrupt:

```
DIM CommFlag = 0
CONST ButtonRef = 42
GUI BUTTON ButtonRef, c$, x, y, etc
GUI INTERRUPT IntTouchDown
```

The interrupt would simply set the flag whenever the button is touched:

```
Sub IntTouchDown
SELECT CASE TOUCH(REF)
  CASE ButtonRef
    CommFlag = 1
  END SELECT
END SUB
```

The main program loop would then monitor this flag:

```
DO
  IF CommFlag = 1 THEN
    ... code to send the message ...
    CommFlag = 0
  ENDIF
LOOP
```

Note that it is the responsibility of the main program to reset the flag so that it then can detect when another message must be sent. If you want the code to avoid blocking the main loop while sending the message, you could increment **CommFlag** as each byte is sent and only reset it to zero at the end.

If doing this, the interrupt subroutine could disable the button (using the **GUI DISABLE** command) until the message has been sent. It could then be re-enabled when the flag is reset, to avoid interrupting a message when transmission has already begun.

Touch-up interrupt

In most cases, you can process all user input in the touch-down interrupt. But there are always exceptions and a typical example is when you need to change the characteristics of the control that is being touched. For example, you might want to change the foreground colour of a button from white to red when it is 'down'. When it is returned to the 'up' state, the colour should revert to white.

Setting the button colour when it is pressed is easy. Just define a touch-down interrupt and change the colour in the interrupt handler routine when that control is touched. However, to return the colour to white when it is released, you need to detect when the touch has been removed from the control (ie, touch-up). This can be done with a touch-up interrupt. To specify a touch-up interrupt, you add the name of the subroutine for this interrupt to the end of the **GUI INTERRUPT** command; for example:

```
GUI INTERRUPT IntTouchDown,
IntTouchUp
```

Within the touch-up subroutine, you can use the same structure as in the touch-down subroutine but you need to find the reference number of the last control that was touched. This is because no control is currently being

touched. To get the number of the last control touched you need to use the **TOUCH(LASTREF)** function.

The following example shows how you could meet the above requirement and implement both a touch-down and a touch-up interrupt:

```
SUB IntTouchDown
  SELECT CASE TOUCH(REF)
    CASE ButtonRef
      GUI FCOLOUR RGB(RED),
      ButtonRef
    END SELECT
  END SUB
SUB IntTouchUp
  SELECT CASE TOUCH(LASTREF)
    CASE ButtonRef
      GUI FCOLOUR RGB(WHITE),
      ButtonRef
    END SELECT
  END SUB
```

Switching screen pages

Most GUI interfaces will have a number of screens or pages that will be displayed for the user.

For example, there may be a main screen which is first displayed but when the user touches a button labelled 'Options', the screen switches to another display which allows the user to set various options.

With the *Micromite Plus*, this can be easily achieved using the **PAGE** command. For example:

PAGE 1

will hide all controls currently on the screen and show all the controls associated with page 1; similarly:

PAGE 2

will hide all the controls used for page 1 and reveal (un-hide) all the controls associated with page 2.

You can have up to 32 pages, ranging from page 1 to page 32, and you can display two or more pages at the same time; for example:

PAGE 1, 5

will display both pages 1 and 5. This is useful if you have a set of controls that is common on a number of screens; this set can be defined on one page and that page's number then used in the list for each page switch.

To define which controls are associated with a specific page, you use the following command immediately before the controls are created:

GUI SETUP nn

where **nn** is the page number that is being set up. In the following example, page 1 has two controls and page 3 has two different controls:

GUI SETUP 1



Fig.6: the *Micromite Plus* can drive an LCD panel with up to 800x480 pixels in true (24-bit) colour. This image was loaded from an SD card using the `LOAD IMAGE` command. The speed of loading is not super fast, so you would not use this as a photo frame but it is useful for loading logos and background images.

GUI SWITCH 41, c\$, x, y, etc

GUI LED 42, c\$, x, y, etc

GUI SETUP 3

GUI CHECKBOX 43, c\$, x, y, etc

GUI CHECKBOX 43, c\$, x, y, etc

When a program starts up, the set-up page will default to page 1. This means that if you do not use the **GUI SETUP** command, all GUI elements will be associated with page 1. Also, the page to be displayed will default to page 1 so your program will run perfectly as a single-page application.

Note that the control reference numbers must be unique across all controls, regardless of what page they are on. It is also perfectly legal for the program to change the characteristics of a control on a page which is not displayed. When that page is eventually displayed, the control will be drawn with its new characteristics.

For example, a hidden control might be on a page that's not active. If that page was selected for display, the control will still be hidden when the page is shown. However, the BASIC program can un-hide that control even if the page is not displayed and then, when the page is subsequently selected for display, the control will be visible and active.

Message boxes

One very useful GUI function is **MSGBOX()**. This will display a dialog box in the centre of the screen, with a message and up to four customisable buttons. When it is invoked, the message box will wait for the user to touch one of the buttons, then return with the number of the button touched. At the same time, MMBasic will redraw any controls that were obscured by the box. The syntax of the function is as follows:

MSGBOX(caption\$, b1\$, b2\$, b3\$, b4\$)

All the arguments are strings and **caption\$** is the message to be displayed in the centre of the box. Multiple lines can be displayed by inserting the ' | ' (pipe) character into the caption where the new line is to start.

b1\$ and **b2\$** etc are the captions for the various buttons. The number of buttons displayed is determined by the number of captions specified. The following is an example of how this function could be used:

```
IF MSGBOX("Start Failed", "Cancel", "Retry") = 0 THEN
  GOTO EXIT
ELSE
  GOTO RETRY
ENDIF
```

When run, the **MSGBOX** function would display a box containing the words 'Start Failed' and two buttons

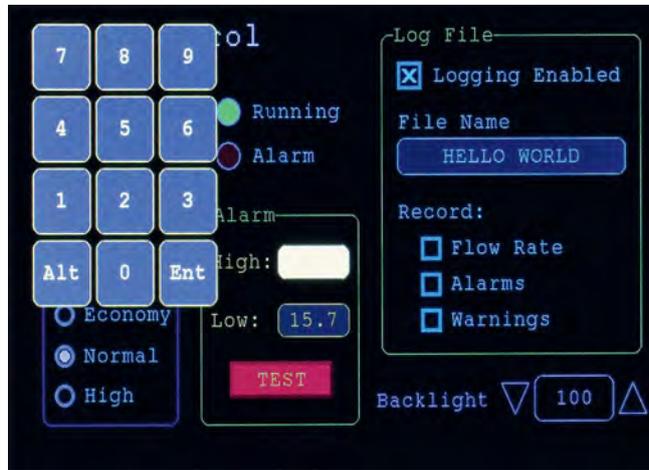


Fig.7: one of the more powerful controls is the **NUMBERBOX**, which is an on-screen box that can hold a number. When touched, a number pad will appear, allowing the user to enter any number, including floating point numbers, using scientific notation. Displaying the number pad and entering the number are both done without involving the main BASIC program, which can continue with other duties, such as monitoring sensors and other inputs.

track of where they are on the screen and their state (ie, visible, hidden) and it will use this information while it is managing the screen. For example, when the user touches a text box, MMBasic will disable all GUI controls on the screen and display them in dull colours. MMBasic will then draw the QWERTY keyboard (to enable user input) over these controls.

The reason that MMBasic disables these controls, by the way, is to indicate to the user that the on-screen keyboard is the only active part of the screen.

On the other hand, MMBasic does not track the location and state of any general graphics commands and they will not be dimmed. Even worse, they may be partially overwritten by the on-screen keyboard and when the user has finished with the keyboard, MMBasic will not redraw them. You should therefore use either the general graphics commands (**CIRCLE**, **BOX**, etc) or the GUI controls but not both on the same screen display. The one exception is the clear screen command (**CLS**) which will first run through the GUI table and set any visible GUI controls to hidden before it then clears the screen.

If you do want to mix the two types of graphics commands, you should intercept the touch-down and touch-up interrupts for any text box and number box controls. This will indicate that a virtual keyboard has been displayed or removed. During these interrupts, you could then redraw any general graphics that you may have used.

Likewise, you should redraw these graphics straight after the **MSGBOX()** function has been used, as it will have also overwritten parts of the screen.

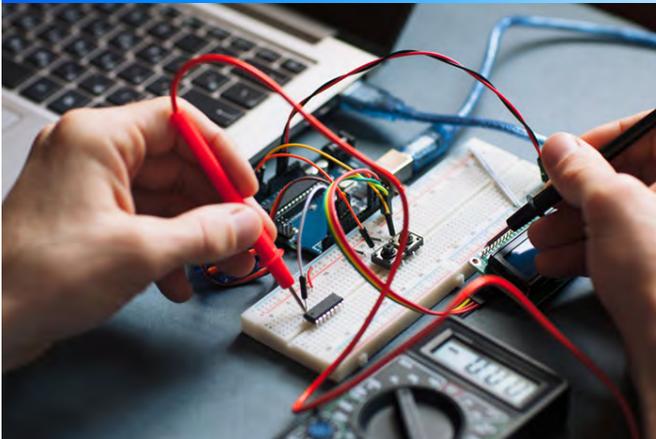
Finally, MMBasic for the Micromite Plus will be improved and updated into the future, with new features already planned. To access these updates and other information relating to the Micromite Plus, please check the author's website at geoffg.net/micromite.html

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YouTube video

The author has produced a video which describes and demonstrates the capabilities of the Micromite Plus. You'll find it at: <https://youtu.be/j12LidkzG2A>

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This month, *EPE* and **Micromite.org** are giving you another chance to win a fully assembled Micromite+ LCD Backpack Module, complete with a 2.8" Touch Screen. For details about this powerful, yet compact module, turn to page 28.

To enter, simply send an email to epe@micromite.org with the email subject as **BP64 Raffle**. Please ensure you email before the closing date: **31 December**

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

Look out for future competitions throughout 2018 to win other fantastic Micromite products!

Good Luck!

Send us your pictures!

Now that many of you have been using Micromite since it first appeared in *EPE* in January 2017, there must be lots of you out there with some great 'creations'. So why not send us some pictures (along with a brief explanation) of your masterpiece! (Thanks to those of you who have already done so.)

Each email received will be entered into a monthly draw; with one winner chosen at random to receive a £30 voucher to use at micromite.org. Outstanding projects will win a £50 voucher. Simply email your pictures to: epe@micromite.org with the subject: **MyProject**.

We are pleased to announce the E100 Raffle winner from the October 2017 issue of *EPE*:

Andy Davies (from Kirkcaldy) wins a fully assembled Explore100 Module.

Well done Andy!



(PLEASE NOTE: No SD card is included; however the 2.8" Touch TFT is!)

T&Cs

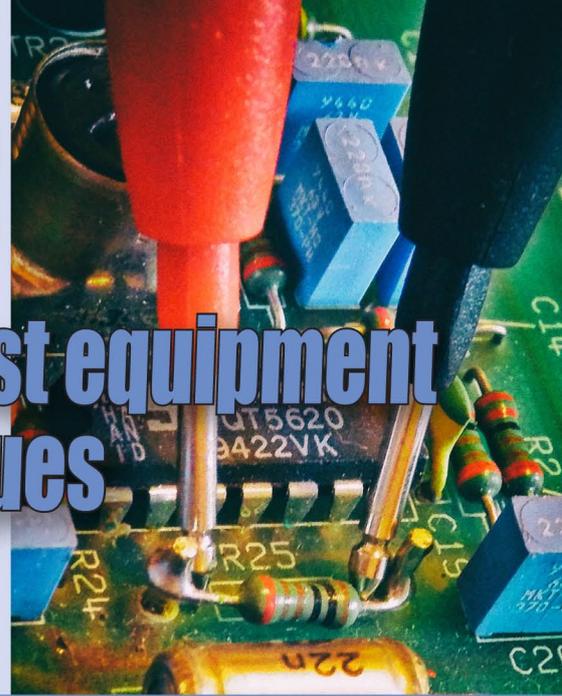
1. You may enter as many times as you wish
2. All entries must be received by the closing date
3. Winners will be notified by email within one week after the closing date
4. Winners will need to confirm a valid address for their prize to be shipped
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Teach-In 2018

Get testing! – electronic test equipment and measurement techniques

Part 3: AC millivoltmeters

by Mike Tooley



Welcome to *Teach-In 2018: Get testing! – electronic test equipment and measurement techniques*. This *Teach-In* series will provide you with a broad-based introduction to choosing and using a wide range of test gear, how to get the best out of each item and the pitfalls to avoid. We'll provide hints and tips on using, and – just as importantly – interpreting the results that you get. We will be dealing with familiar test gear as well as equipment designed for more specialised applications.

Our previous *Teach-In* series have dealt with specific aspects of electronics, such as PICs (*Teach-In 5*), Analogue Circuit Design (*Teach-In 6*) or popular low-cost microcontrollers (*Teach-In 7* and *8*). The current series is rather different because it has been designed to have the broadest possible appeal and is applicable to all branches of electronics. It crosses the boundaries of analogue and digital electronics with applications that span the full range of electronics – from a single-stage transistor amplifier to the

most sophisticated microcontroller system. There really is something for everyone in this series!

Each part includes a simple but useful practical *Test gear project* that will build into a handy gadget that will either extend the features, ranges and usability of an existing item of test equipment or that will serve as a stand-alone instrument. We've kept the cost of these projects as low as possible and most of them can be built for less than £10 (including components, enclosure and circuit board).

This month

In this third part, *In theory* will be introducing measurements using sensitive AC voltmeters, often referred to as 'millivoltmeters'. Such instruments are handy for measuring signal voltages in audio amplifiers and other circuits at frequencies extending from a few tens of Hertz to several MHz. We also introduce the use of decibels (dB) for expressing voltage, current and power ratios. *Gearing up* provides guidance on choosing and purchasing an AC millivoltmeter, both new and second hand, while *Get it right!* will help you avoid some measurement pitfalls, providing useful tips on how to make AC measurements and improve the accuracy of your results. Finally, our third *Test Gear Project* is a handy wide-band RMS voltage adapter, which can be used to greatly improve the performance of most digital multimeters when used for AC signal voltage measurements.

In theory: AC measurement

When it comes to measuring alternating current (AC) the multimeters that we introduced in the first part of this series are usually somewhat limited in terms of their frequency response and often restricted to a range extending from about 40Hz to 400Hz (ie, the range generally associated with the distribution of AC power). Unfortunately, this isn't too helpful

if you need to make measurements on audio frequency and wideband equipment where signals occupy a much wider frequency range. In addition, there's often a need to read signals at relatively low levels, from as little as 1mV to as much as 100V. When measuring such signals, and depending on the circuit in which we are measuring, we may be concerned with the peak, average (mean), or root mean square (RMS) value. This merits a little explanation, starting with what mean by the term 'average value'.

Average values

As you've already seen, a sinewave comprises two symmetrical halves; one half is positive and the other is negative. When taken over one complete cycle the average (or mean) value of the wave is zero. So, taken over one complete cycle, the average value, doesn't help. Instead, we could consider the average value for just half of one complete cycle (see Fig.3.1) which, for a sinewave, amounts to approximately 63% of the maximum (this can be either positive or negative depending on which half we are considering). The relationship is:

$$V_{\text{mean}} = 0.636 \times V_{\text{pk}}$$

RMS values

The RMS or 'effective value' of an alternating voltage is the value that would produce the same heat energy in

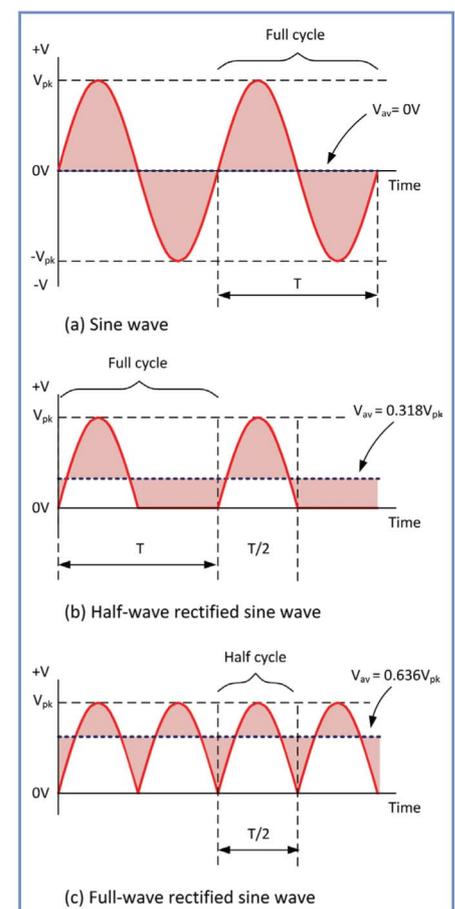


Fig.3.1. Mean values of various waveforms

AC type	Waveform	V_{rms}	V_{av} (half-cycle)	Form factor
Sine wave		$0.707V_{pk}$	$0.636V_{pk}$	1.11
Half-wave rectified sine wave		$0.5V_{pk}$	$0.318V_{pk}$	1.57
Full-wave rectified sine wave		$0.707V_{pk}$	$0.636V_{pk}$	1.11
Square wave		V_{pk}	V_{pk}	1
Triangle wave		$0.577V_{pk}$	$0.5V_{pk}$	1.15

Fig.3.2. Form factors for several common waveform types

a resistor as a direct voltage of the same magnitude. Since the RMS value of a waveform is very much dependent upon its shape, values are only meaningful when dealing with a waveform of known shape. Where the shape of a waveform is not specified, RMS values are normally assumed to refer to sinewaves.

For a given waveform, a set of fixed relationships exist between average, peak, peak-peak, and RMS values. The multiplying factors for sinusoidal voltages are shown in Table 3.1.

Form factor and crest factor

The form factor of an AC waveform is simply the RMS value divided by the average value of the waveform (measured over a half cycle). Fig.3.2 illustrates the form factors for several common waveforms. The crest factor of an AC waveform is the peak (ie, crest) value divided by its RMS value. The crest factor of a sinewave is thus $1.414 (\sqrt{2})$.

Decibels

Decibels (dB) provide us with a very convenient way of expressing AC voltage, current and power gain in relation to a reference value. It is important to

Table 3.1 Multiplying factors for average, peak, peak-peak and RMS values

Given quantity	Wanted quantity			
	Average	Peak	Peak-peak	RMS
Average	1	1.57	3.14	1.11
Peak	0.636	1	2	0.707
Peak-peak	0.318	0.5	1	0.353
RMS	0.9	1.414	2.828	1

realise that they are not, in themselves, a unit of voltage, current or power, but simply a means of comparing one value with another. They are also a means of expressing gain (amplification) and loss (attenuation) in electronic circuits. When used as an absolute (rather than relative) measure, decibel quantities *must* be specified in conjunction with the reference quantity (ie, the compared value). For example, dBV are decibels relative to 1V.

As its name implies, a decibel is one-tenth of a bel. When used to express a power ratio, a bel is defined as the logarithm, to the base 10, of the ratio of measured power (P_m) to reference power (P_{ref}). A decibel will be ten times this value, thus the number of decibels, n , would be given by:

$$n = 10 \log_{10}(P_m/P_{ref}) \text{ (dB)}$$

Note that P_m and P_{ref} must be expressed in the same units, for example both in W or both in mW.

The power in an electrical circuit is proportional to the square of the voltage (or the square of the current) and so the equivalent relationships are:

$$n = 20 \log_{10}(V_m/V_{ref}) \text{ (dB)}$$

and

$$n = 20 \log_{10}(I_m/I_{ref}) \text{ (dB)}$$

If this is beginning to sound rather complicated, here's a simple example. Let's assume that an amplifier is producing an output of 400mW and we need to express this relative to a reference power of 1mW. Using the earlier relationship, we would have:



Fig.3.3. Typical dB scales on an AC voltmeter

$$\begin{aligned} n &= 10 \log_{10}(400/1) \\ &= 10 \log_{10}(400) \\ &= 10 \times 2.6 \\ &= 26\text{dBm (note the 'm')} \end{aligned}$$

Alternatively, if our amplifier had been producing an RMS output of 8V and we needed to express this relative to a reference of 1V we would have:

$$\begin{aligned} n &= 20 \log_{10}(8/1) \\ &= 20 \log_{10}(8) \\ &= 20 \times 0.9 \\ &= 18\text{dBV (note the 'V')} \end{aligned}$$

A positive result will be obtained whenever P_m , V_m , or I_m is greater than P_{ref} , V_{ref} , or I_{ref} , respectively. A negative result will be obtained whenever P_m , V_m , or I_m is less than P_{ref} , V_{ref} or I_{ref} . A negative result simply denotes loss (attenuation) rather than gain (amplification).

Fig.3.3 shows how, for convenience, a decibel (dB) scale is often incorporated on the front panel of an AC voltmeter. Note how the dB scale is marked in either 'dB' (ie, dB relative to 1V where 0dB = 1V) or 'dBm' (ie, dB relative to 1mW where 0dB = 1mW into a load resistance of 600Ω). Table 3.2 shows some RMS

Table 3.2 Voltages and corresponding decibels relative to 1V

V (V)	dBV
0.10	-20.0
0.20	-14.0
0.30	-10.5
0.40	-8.0
0.50	-6.0
0.60	-4.4
0.70	-3.1
0.80	-1.9
0.90	-0.9
1.00	0.0
2.00	6.0
4.00	12.0
6.00	15.6
8.00	18.1
10.00	20.0
20.00	26.0
40.00	32.04

Table 3.3 Powers and corresponding decibels relative to 1mW

P (mW)	dBm
0.10	-10.0
0.20	-7.0
0.30	-5.2
0.40	-4.0
0.50	-3.0
0.60	-2.2
0.70	-1.6
0.80	-1.0
0.90	-0.5
1.00	0.0
2.00	3.0
4.00	6.0
6.00	7.8
8.00	9.0
10.00	10.0
20.00	13.0
40.00	16.0

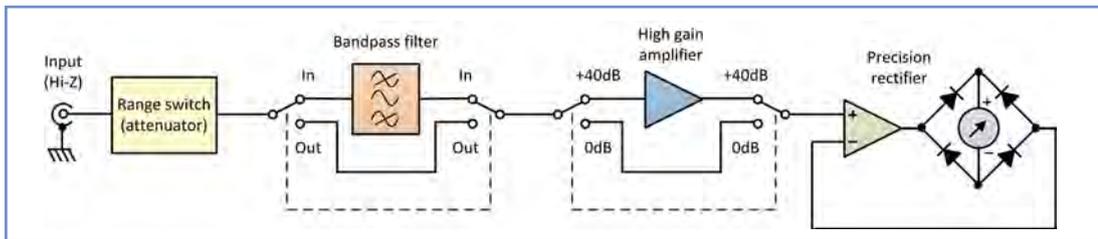


Fig.3.4. Simplified block schematic of a typical AC millivoltmeter

voltages and corresponding dBV values, while Table 3.3 shows corresponding powers and dBm values.

AC millivoltmeters

The simplified block schematic of an AC millivoltmeter is shown in Fig.3.4. To cater for a wide range of input voltages (as mentioned earlier) the first stage usually takes the form of a compensated switched-range attenuator. In some instruments, this may be followed by a switchable filter that can be used to remove high-frequency noise or low-frequency supply hum from the signal to be measured. The next stage comprises a high-gain wideband amplifier. The gain of the stage may either be fixed or selected by means of a further range switch. The high-gain amplifier is followed by a precision rectifier that produces a DC output directly proportional to the input AC signal voltage.

Negative feedback is used to increase the linearity of the rectifier arrangement and the resulting DC output is usually fed to a meter calibrated in RMS volts, dBV and dBm. Note that analogue displays are usually preferred for this type of application because it is much easier to observe the movement of a pointer moving over a scale than a fluctuating digital readout. Some instruments can also be fitted with external probes for making high-frequency measurements.

Gearing up: AC millivoltmeters

For most audio frequency and general-purpose applications you will need an instrument that offers several ranges from 10mV to 100V RMS full-scale. As a minimum, the instrument should have a frequency response covering the

range 20Hz to 20kHz ± 3 dB, but most instruments will offer a wider frequency response than this, often extending from 10Hz to 1MHz, or more.

New instruments can be purchased from a variety of sources at prices ranging from £120 to £250 for a single-channel meter, and £200 to £500 for a dual channel instrument (the latter can be useful for simultaneously comparing two signals, for example in a stereo system). Fortunately, second-hand instruments are widely available from various suppliers and on-line auction sites. Representative instruments include the Farnell TM1 and TM2 (1mV to 300V over the range 10Hz to 5MHz), Philips PM 2454 (1mV to 300V over the range 10Hz to 12MHz), as well as more modern instruments from Instek, Leader and Tenma. Prices range from as little as £25 to around £120 for



Fig.3.5. Dual-channel AC millivoltmeter (the meter movement has two separate pointers so that two indications can be produced at the same time)

an AC millivoltmeter in good condition (but invariably supplied without a current calibration certificate). It should go without saying that if you do purchase such an instrument, your first task should be to carefully check its

calibration on all ranges.

The Levell TM6B millivoltmeter (see Fig. 3.7) can often be purchased from on-line auction sites for around £50. This instrument can be used as both an AC voltmeter and as an AC amplifier. The frequency response extends from 1Hz to 3MHz, on the mV and V ranges. Sixteen ranges are provided in 10dB steps from 15 μ V full-scale to 500V full-scale with an accuracy of $\pm 1\%$ of reading $\pm 1\%$ of full-scale. The TM6B uses two separate negative feedback amplifiers. The gain of the first amplifier is varied in 10dB steps up to 80dB with negative feedback applied to stabilise the gain. The output is connected to panel sockets and to the input of the second amplifier, which drives a full-wave precision rectifier circuit and a moving coil meter (see Fig.3.4).



Fig.3.6. Laboratory-grade AC millivoltmeter – similar lab-grade instruments are regularly available at low-cost from on-line auction sites)



Fig.3.7. A Level TM6B AC millivoltmeter capable of reading less than 1mV at 3MHz using its external probe

Get it right when using an AC voltmeter

- Check that the signal being measured is noise and hum free (use an appropriate bandpass filter setting if one is available)
- Check that the instrument has been calibrated before use and also before attempting to make accurate measurements
- Check that you are measuring a 'clean' waveform. Indications will usually be inaccurate if the signal being measured is non-sinusoidal or distorted in some way
- Avoid over-driving the instrument (many millivoltmeters are rated for inputs of only 100V, or so, and they should not be used for measuring power-line voltages)
- Ensure that the range selector is adjusted for indications at around mid-scale on the meter (accuracy will be impaired if you are only using the bottom end of the meter scale)
- Don't rely on voltage measurements in circuits where signals may be outside the bandwidth of the instrument.

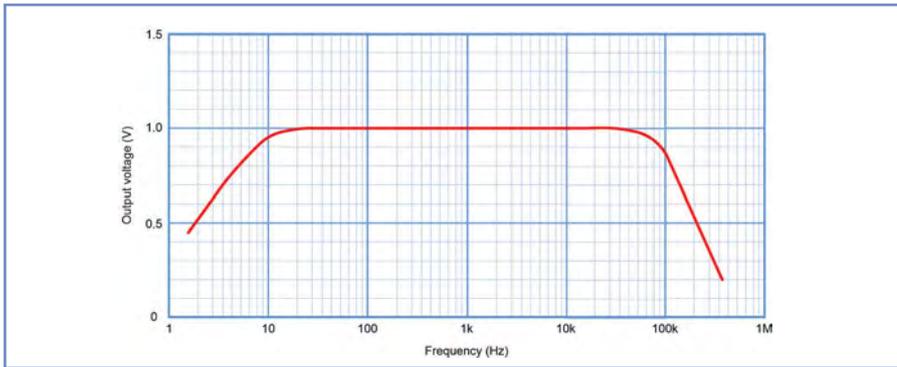


Fig.3.8. Frequency response of the wideband AC range extender

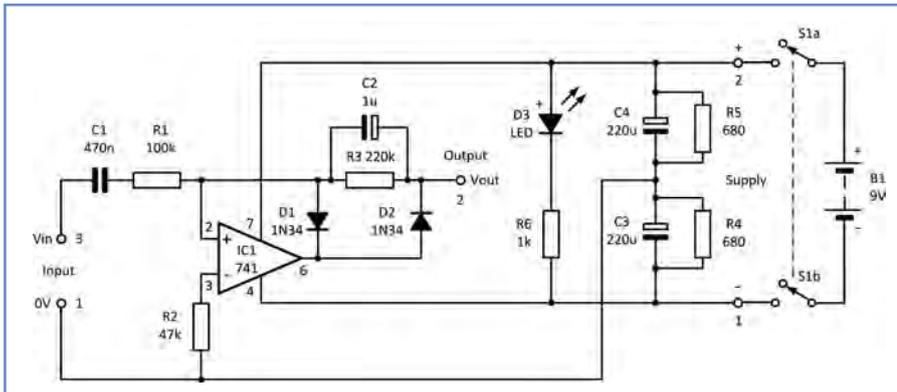


Fig.3.9. Complete circuit of the wideband AC range extender

Gearing up: wideband AC range extender

Conventional digital multimeters usually only offer a rather limited frequency response (40Hz to 400Hz is typical). Furthermore, resolution and sensitivity can be inadequate for many applications. Our wideband AC range extender is intended to overcome this problem and it is ideal if you need to carry out occasional audio frequency measurements and don't wish to purchase a dedicated millivoltmeter. The wideband AC range extender can be used with any existing

digital multimeter (set to the DC voltage ranges). It can be used with RMS input voltages from 20mV to 20V and covers a frequency range that extends from 10Hz to 100kHz, as shown in Figure 3.8. At approximately 100kΩ, the input impedance of the amplifier is sufficiently high for most measurement applications.

The complete circuit of our *Test Gear Project* is shown in Fig.3.9. The design is very simple and uses only a handful of inexpensive components. The circuit comprises a precision rectifier based on a single-stage operational amplifier and, to ensure accuracy, the output should only be fed to a high-impedance load. Since digital multimeters usually exhibit an input resistance of 10MΩ the effect on

accuracy will be minimal. Note that the AC range extender is unsuitable for use with low-cost analogue instruments as they often have an input resistance of less than 1MΩ when used on the 10V DC range.

You will need

- Perforated copper stripboard (9 strips, each with 25 holes)
- 1 2-way miniature terminal block (PCB 9V supply)
 - 1 3-way miniature terminal block (PCB input and output)
 - 1 ABS case with integral battery compartment
 - 1 9V PP3 battery clip
 - 1 9V PP3 battery
 - 1 Miniature DPDT toggle switch (S1)
 - 2 red 2mm panel-mounting sockets (SK1 and SK4)
 - 2 black 2mm panel-mounting sockets (SK2 and SK3)
 - 1 741CN operational amplifier (IC1)
 - 1 8-pin low-profile DIL socket
 - 2 1N34 diodes (D1 and D2)
 - 1 5mm red LED (D3)
 - 1 100kΩ resistor (R1)
 - 1 47kΩ resistor (R2)
 - 1 220kΩ resistor (R3)
 - 1 680Ω resistor (R4)
 - 1 680Ω resistor (R5)
 - 1 1kΩ resistor (R6)
 - 1 470n 63V miniature polyester capacitor (C1)
 - 1 1μF 63V radial lead electrolytic capacitor (C2)
 - 1 220μF 16V radial lead electrolytic capacitor (C3)
 - 1 220μF 16V radial lead electrolytic capacitor (C4)

Assembly

Assembly is straightforward and should follow the component layout shown in Fig.3.10. Note that the yellow stripes on diodes D1 and D2 mark their cathodes, while the '+' symbol shown on D3 indicates the more positive (anode) terminal of the LED. The pin connections for the LED is shown in Fig.3.11. The reverse side of the board (NOT an X-ray view) is also shown in Fig.3.11. Note that there is a total of 24 track breaks to be made. These can be made either with a purpose-designed spot-face cutter or using a small drill bit of appropriate size. There are also 10 links that can be made with tinned copper wire of a suitable diameter or gauge (eg, 0.6mm/24SWG). When soldering has been completed, it

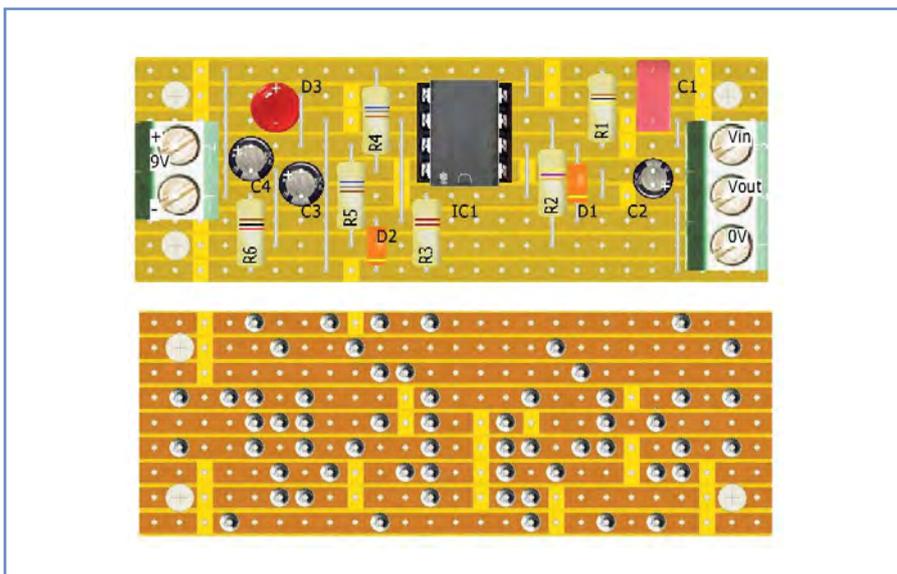


Fig.3.10. Stripboard layout of the wideband AC range extender

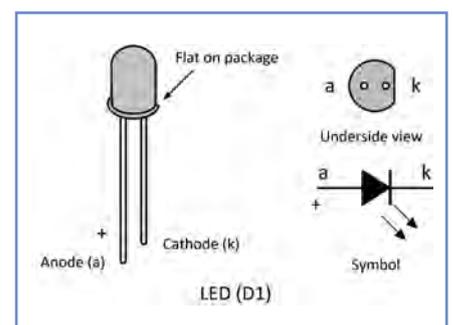


Fig.3.11 LED pin connections

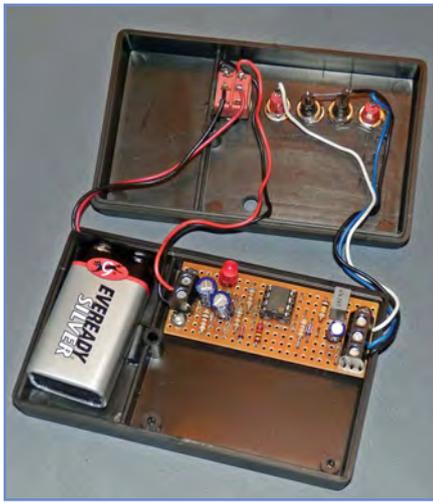


Fig.3.12. Internal wiring of the wideband AC range extender



Fig.3.13. Rear panel wiring

is very important to carry out a careful visual check of the board as well as an examination of the track side of the board, looking for solder splashes and unwanted links between tracks. The internal and rear panel wiring of the AC range extender is shown in Fig.3.12 and Fig.3.13 respectively. Note SK2 and SK3 (the two black 0V connectors).

Setting up

No setting up is required after assembly – all you need to do is connect a PP3 battery and switch on. D1 should light up; if not, check the battery and circuit connections carefully. Next, connect the output (SK3 and SK4) via red and black test leads to your digital multimeter. Connect an input source (eg, a signal generator set to provide a 1V RMS 1kHz



Fig.3.14. External appearance of the finished wideband AC range extender



Fig.3.15. Using the wideband AC range extender to check the output of a signal generator. The meter is indicating 0.976V when the signal generator is set to 1V RMS output

sinewave) to the two input connectors (SK1 and SK2). Select the 2V DC range on the multimeter and observe the indication produced. This should be very close to 1V. If not, switch off and carefully check your wiring and PCB layout. Next, vary the signal frequency from 10Hz to 100kHz and note the indication produced. This should not fall by less than 10% (0.1V) at the two extremes of frequency and should remain substantially flat at 1V over the full audio frequency range (20Hz to 20kHz).

Next month

In next month's *Teach-In 2018* we will look at component measurement and our practical project will feature an accurate constant-current source that can be used for testing resistors as well as a variety of semiconductor devices, such as diodes, LEDs and transistor junctions.

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Teach-In 8 – Exploring the Arduino

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NET WORK

by Alan Winstanley

Take 10

RECENTLY, one of the author's PCs, a two-year old Asus Windows 8 machine, decided to throw some tantrums during a tiresome cycle of Windows updates that seemed never-ending: updates always halted at 97% before rolling back again, wasting an awful lot of bandwidth as well as time. This Windows 8 machine then decided it was no longer officially activated any more, but it refused to accept the PC's legitimate Windows product key (which was only found by using Belarc Advisor, download free from: www.belarc.com).

PC users will recognise the pattern of endless and fruitless support emails, re-downloads of updates, uninstalls, trawling around forums and more hairpulling that followed, after which the obstinate PC still refused to 'activate' itself properly. Microsoft's phone support was revelatory, talking me through some arcane commands to check the Windows product key (confirmed as non-existent/damaged), before suggesting I ask Asus for another one! In the end, a total Windows re-installation was necessary, backing up precious data using a hard disk docking station while I still could.

After rebuilding it from scratch I found the stubborn system would not activate and the Restore USB key that I created two years ago didn't help either. Then, after rebooting one more time, the machine displayed a Blue Screen of Death: the hard disk had failed and the entire system was toast. Time for an update to Windows 10!

Searching online for an official Windows 10 DVD, I was struck by some suspiciously cheap OS software downloads, offered complete with serial number. Often these are rescued from salvaged corporate systems and are sold with claims that software serial numbers could legitimately be recycled by IT vendors this way. Websites were peppered with glowing five star customer testimonials to add credibility to these very cheap wares. Simply pay up, download the software and a serial number will be sent to you, cheap! It's a gamble – as some reviewers will confirm to their cost, these cheap Windows downloads would time out after a few months, or



a licence for business software had already been pre-used on the maximum number of PCs already permitted.

Dealing with eBay or Amazon Marketplace also keeps things at arm's length, so you never quite know who you're dealing with. Reputable UK vendors such as Scan.co.uk and Ebuyer.com offer legitimate product and activation keys, and I opted for that route. It wasn't long before a genuine Windows 10 DVD arrived by courier from Scan and I was in business again – followed by hours of more updates, downloads and frantic searches for the latest drivers.

Firefox's Quantum leap

Windows 10 has some neat, slick features and runs very smoothly on the two-year-old Asus. There have been no problems (yet) in running legacy software, but it exemplifies the current trend for flat, 2D design that readers know I dislike so much.

Mozilla, the not-for-profit developers behind the Firefox browser, are girding their loins for the launch of their next generation Firefox version 57, dubbed 'Quantum'. This new release, due on 14 November but already out in Beta, promises to be faster and slicker than any version of Firefox before it. It has the same flat 2D styling that apes Windows 10. Improvements in Firefox have been long overdue, and according to the website W3Counter, Firefox holds a pitiful 9% market share, while Chrome is the most popular browser with almost 60%. Chrome's popularity has straight-lined upwards ever since 2009 – see: www.w3counter.com/trends

Significantly, the Quantum web browser engine has been totally rebuilt to take advantage – not before time – of the multi-core processors found in modern computers, also using code that is claimed to be intrinsically robust and safe. Quantum is twice as fast as before and uses 30% less memory than Chrome, says Mozilla, and it promises to run add-ons in a more stable environment as well.

Having installed it on a 64-bit Windows system, I found Firefox Quantum was sprightlier to launch than its single-core predecessor. Firefox Quantum brings with it a number of useful features, including its screenshot service that enables you to save snapshots of entire or partial webpages to the cloud. You can download or recall them, or share links to them for up to 14 days, or longer if you need to, perhaps useful for research or storing citations. It worked well when tested. You can also save web pages in a clutter-free style for later reference by using Firefox's Pocket feature.

A range of optional extensions can enhance the browser's functionality but, historically, add-ons often stopped working with new releases of Firefox, and a regular cycle of refreshing them was necessary. Firefox has adopted support for the WebExtensions API from V.57 and from November 2017 legacy-style add-ons will be disabled permanently: look for the 'Compatible with Firefox 57' icon for future-proof compatible extensions. In theory, this should dispense with the need to constantly update Add-ons with each new release of Firefox, but the switch to WebExtensions is also infuriating many web surfers.

One casualty of this change is the author's faithful and indispensable Roboform 7 toolbar, which automates the logins for over a hundred websites: it's used through the day and is a real lifesaver during busy surfing sessions. In Firefox Quantum, Roboform 7 no longer displays its



Firefox Quantum (V.57) is Mozilla's next-generation browser, rebuilt and optimised for multi-core processors. It has a squarer Metro design

toolbar onscreen at all, and it turns out that Roboform 7 is incompatible with Firefox 57 due to the move towards the WebExtensions API.

Robocopped

Instead, Roboform Version 8 is needed which (naturally) is incompatible with Version 7 data, though it imports and converts legacy logins into a new format well enough. It also uses the same trendy, featureless flat 2D design. Roboform 8 recognised the biometric fingerprint reader that I coaxed into operation (*Net Work*, March 2017) but still no essential browser toolbar appears in Quantum. Instead, Roboform is relegated to a muted pop-out button needing multiple mouse clicks to get anywhere with it. (The same, it must be said, is true of Roboform in Chrome.) For many Roboform users this is a step backwards, and many have expressed extreme dissatisfaction with this change.

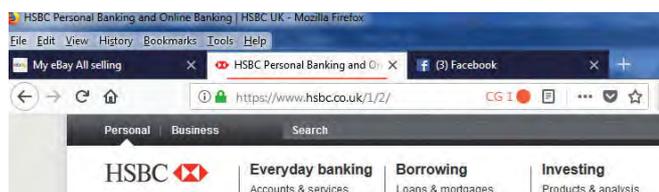
It also turns out that 'Roboform Everywhere' (V8) is not a standalone program licence like Version 7 was, but becomes an annual \$20 subscription service instead. For the writer, the loss of the Roboform toolbar coupled with the need to subscribe to Roboform for ever more is like losing a favourite screwdriver and being forced into paying \$20 a year for something half as useful. However, subscription costs of rival systems are similar or sometimes much higher. There is always that nagging doubt about not independently 'owning' your database and software (or a licence anyway) and instead needing to subscribe permanently into the future, or maybe risking losing all your login data if you forget to renew a subscription. I hope to examine some options for password security in a forthcoming column.

Containing privacy

Some Firefox users might like the new Multi-Account Containers extension for V.57 that lets you adopt multiple different personal settings online, depending on the kind of task you're dealing with. First floated as a Firefox experiment earlier this year, the purpose of 'containers' is to protect personal privacy by preventing cookies and other information used in one particular session (eg, when banking online) from being accessed by other sites (eg, social media). You could consider a container as being an individual sandbox devoted to a particular task; cookies and other data cannot 'leak out' from it into other containers. More details at: <https://testpilot.firefox.com/experiments/containers/>

Different settings can be configured and colour-coded – Mozilla calls them 'tab-specific containers' – allowing you to switch from one colour-keyed container tab to another without cookies or browser history being nabbed by other websites.

A neat timesaver could be the 'Containers On the Go' extension for Firefox 57, which lets new container tabs be created with a simple key combo (Alt+C). Each tab is again colour coded and sequentially numbered CG1, CG2... Users can easily log into multiple accounts in their own 'containers' at the same time, using different tabs. This way, I was able to log into two separate online accounts with the same bank, both at the same time. The containers are closed automatically when the corresponding tab is closed. Google Chrome has a similar but less elegant function, allowing anonymous browsing in 'Guest' mode – click the username button displayed at the top right-hand screen to learn more.



The Containers On The Go extension for Firefox 57 enables users to run protected 'sandboxed' sessions without leaking browser data or cookies to other sites. Here the CG1 Container tab is running online banking

Overall, the latest release of Firefox packs in some new features to make one's surfing more productive. It's a useful alternative to Chrome and a welcome upgrade that should make it more resilient and future-proof, though the implications for legacy add-ons must be considered. Versions suitable for all popular platforms can be downloaded from: www.mozilla.org

Amazon Echoes success

Amazon is oiling its cash registers in time for the Christmas rush by announcing a slew of new or updated products aimed at the home network user. The Echo Show, with built-in LCD (see *Net Work*, September 2017) officially launches in the UK on 16 November, and will be available in black or white for just under £200. Amazon's familiar cylindrical Echo and Echo Dots can handle a variety of duties such as smart device control and voice interaction. Heavily trailed on TV and online, Echo and its cheery assistant Alexa have been part of a new wave of interactive smart speaker



Echo Spot is the latest in a new line up of interactive Alexa gadgets from Amazon. It has a 2.5-inch LCD, camera and microphone

gadgets that Amazon hopes will play an everyday role in a domestic network. The next generation of Echo has now been announced and should start shipping by the time you read this. The new Amazon Echo has a choice of fabric finishes for the style-conscious and claims to offer better 'wake word' recognition across the room and improved sound reproduction. It will cost £89.99. Next up is the new Echo Plus, which incorporates a smart hub intended for better IoT control, and costs £139.99.

A smaller gadget, the Echo Spot, is being released in the US before the year end for \$129.99. It offers all of Alexa's command and control skills in a round form factor. Its 2.5-inch LCD screen is smaller than the Echo Show, which makes it suitable as a bedside clock or unobtrusive desktop accessory – as long as you remember it has a forward-facing camera and an eavesdropping microphone!

Just around the corner is Echo Connect, an interesting telephone adaptor that hooks directly to a landline to let you handle calls in Alexa speakerphone-fashion. The compact box allows an Echo device to make and receive hands-free calls using your contacts list. Now on sale in the USA for \$34.99, expect Echo Connect to arrive in Europe in early 2018. A fun-loving little gadget called Echo Buttons is first in a family of 'Alexa Gadgets' that's designed for playing interactive trivia and quizzes. It may or may not launch in the UK and is expected to cost \$19.99 for two.



CZ latest

Regular readers are reminded that the *EPE Chat Zone* forum is currently switching to 'read-only mode' pending the launch of a new online home for our CZ regulars. This is very much a work in progress and we hope to share some exciting news soon. More will be posted at: www.chatzones.co.uk so be sure to keep checking there for updates. You can email the writer at: alan@epemag.net

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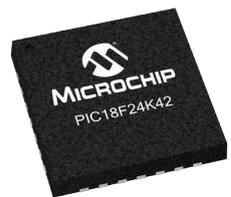
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Four-digit, seven-segment LED display – Part 1

ABRAND new topic this month – we're going to look at the widely used four-digit, seven-segment display. Now, as you all know, with the rise of smartphones and a host of other consumer gadgets, touch-sensitive LCD displays are the most common kind of modern electronic display. So why should we use an LED display that not only is limited to four, rather crudely designed digits, but also doesn't even offer low power consumption? Surely LCD displays do a better job, are cheaper, smaller, use (much) less power and offer full colour.

All of this is true, but there are plenty of advantages to seven-segment displays. They are relatively easy to use, have a long operating life and are easy to read. They are most commonly seen in alarm clocks and timers on cookers (that never seems to get set properly). Plus, with LEDs we have much greater control over power consumption than with a typical LCD display.

What is it?

Let's start with the basics. In a seven-segment display, each segment is a light-emitting diode – an LED. Fig.1a shows an LED circuit symbol. It's the same as an ordinary diode symbol, but with arrows added to indicate light emission. Under normal operating conditions diodes only pass current in one direction – from anode to cathode. For that current to flow, the voltage across the diode needs to be greater than the device's 'forward voltage' (also known as the 'cut-in voltage' or 'on-voltage').

It is important to note that LEDs are greedy! They will use as much current as they possibly can, far too much for their own good if you simply hook one up to a voltage source. Stick 5V across an LED and it will illuminate once – very briefly – and then be a candidate for

the dead-silicon box. You must always add a series resistor to limit the current through an LED. The critical question is what value of resistor – we'll look at that a little later.

Each segment in a seven-segment display is an individual LED, referenced with an industry-standard labelling system: a, b, c, d, e, f and g, as shown in Fig.2. (In fact there are often *eight* LEDs in a seven-segment display! An additional round LED or dot/decimal point (DP) is usually included.) The main seven segments allow us to show any digit from 0 to 9. For example, if we want to display the number 5, we would turn on segments a, f, g, c and d.

If each segment and the dot is an LED, then we need 16 pins in total – one for each anode and one for each cathode. In order to reduce pin count, seven-segment displays typically come in either common-anode or common-cathode configuration. These configurations connect ('common') all the anodes or cathodes together, which reduces the total number of pins from 16 down to nine.

Let's consider the four-digit, seven-segment display. If we have four digits, then we need $9 \times 4 = 36$ pins. However, the number of pins can be reduced again using multiplexing. To do this the display designers connect together each of the four 'a' segment, and the 'b' segments, and so on. This reduces the pin count significantly. Now we have eight pins representing a, b, c... DP. We also have the common anode or cathode for each digit, giving us four extra pins. This adds up to twelve pins, down from 36. The obvious catch here is that we have to do some clever and fast switching (in code) so that we can display different digits on each segment at the same time.

The pin connections in Fig.2 hint at how we can do this with a four-digit seven-segment display. Note how there is only one pin for 'a'. If this was a common-cathode display, then D1, D2, D3 and D4 would all be the cathode side of the LEDs. To light an LED, we would need to connect the cathode to ground and pull any of the anode pins

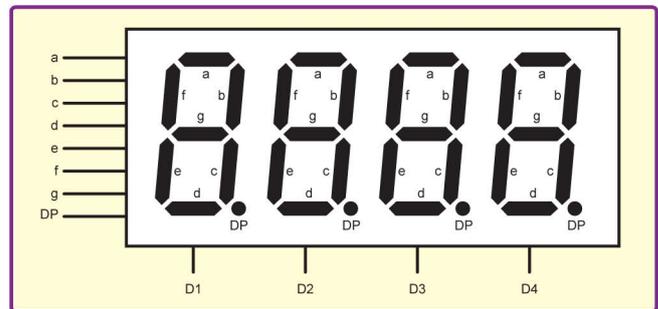


Fig.2. Four-digit, seven-segment display

to a voltage higher than the forward voltage. If all four of the common cathodes are connected to ground and 'a' is pulled high then all the 'a' segments in all four digits would light. In order to illuminate an individual 'a' segment, for example the 'a' in digit 1, we would need to pull 'a' high, D1 low and at the same time ensure D2, D3 and D4 are kept high to keep those digits' LEDs turned off.

In order to display numbers on each digit, we would need to alternate from one to the other. Starting off with displaying a digit on D1, we enable the correct segments, then we turn them all off and move onto illuminating the LEDs in digit 2, and so on. If this is done fast enough then the human eye cannot see the switching and the four digits appear to be continuously displaying their allotted individual values. This will be covered in greater detail next month when we work through the code.

Constructing the veroboard board

This design is based on the now familiar PIC16LF1829, which has been used extensively in recent articles. The four-digit, seven segment-display is a Vishay TDCG1060M. It uses green LEDs, and comes in a small form factor with 0.1-inch pin pitch, so it mounts easily on veroboard. It's a common-cathode device and is relatively inexpensive.

The full list of the components is as follows:

- PIC16LF1829
- Vishay TDCG1060M green four-digit, seven-segment display
- 10 off 150Ω resistors
- 5-pin programming header
- 100nF ceramic capacitor
- Veroboard
- Hook-up wire

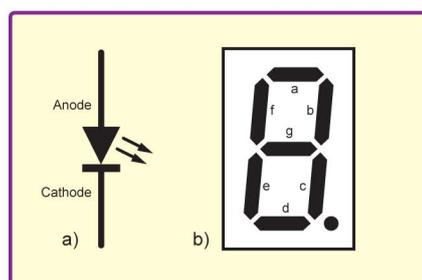


Fig.1. The circuit symbol for an LED and seven-segment display

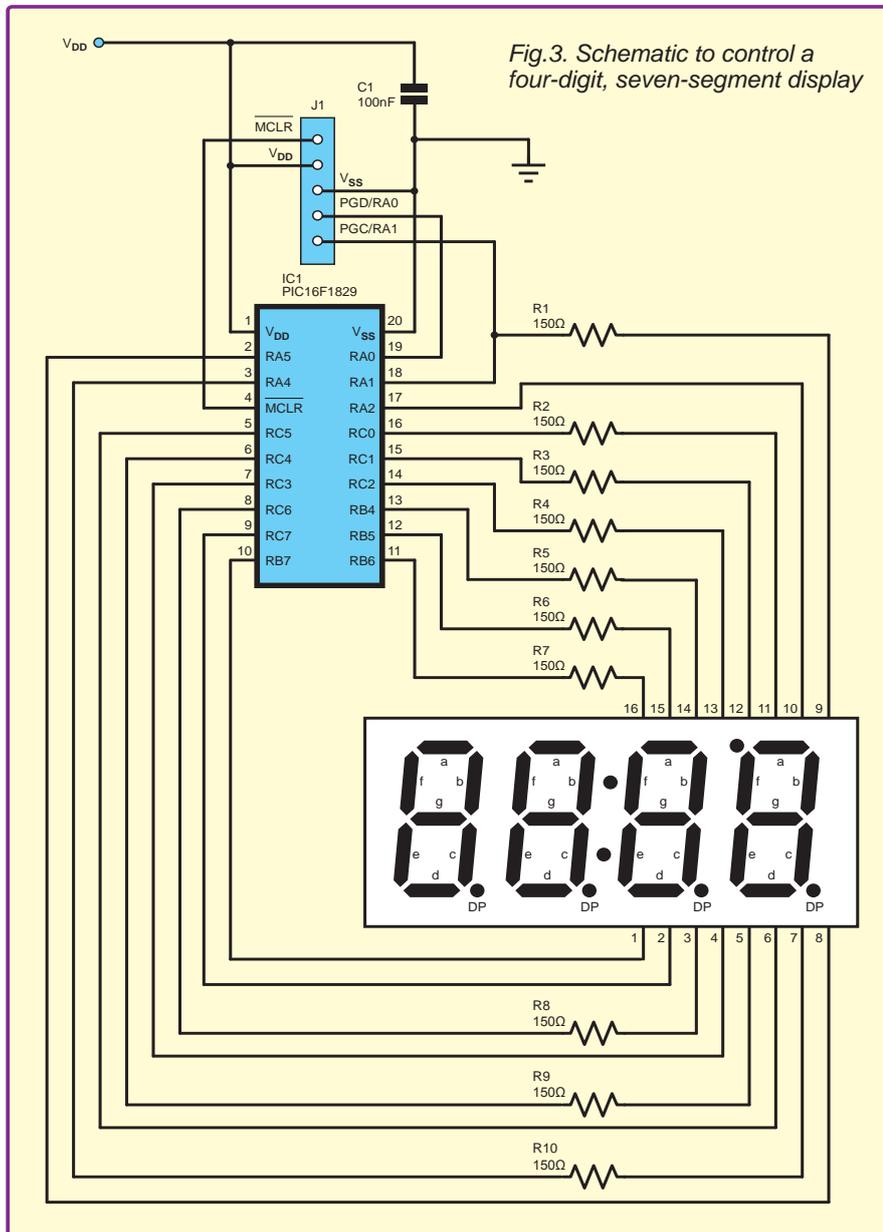


Fig.3. Schematic to control a four-digit, seven-segment display

If you want, you can solder a 20-pin DIP socket onto the veroboard, instead of directly soldering the PIC. The 100nF capacitor is the usual noise-decoupling capacitor that is recommended for most ICs to minimise supply line noise from being injected into the device.

I program my PIC projects using the PICKit 3, which has six pins. However the sixth pin is typically not connected, so I don't bother with a 6-pin programming header. This is why I've specified a 5-pin programming header. Do ensure you line up the little white arrow on the PICKit 3 with the MCLR pin 1 on J1 – see Fig.3 (also top pin in Fig.4). Alternatively, if you use an IC socket, you could do away with the programming header completely and program the PIC in the Low Pin Count Demo board that we've used in previous articles and then just drop it into the circuit's socket.

The PIC16LF1829 can accept up to 4.0V on its power pin, so the resistors I have specified are for a 3.3V circuit. Alternatively, you could use the PIC16F1829 (without the 'L') which can

be powered up to 6.5V. The datasheet for Vishay's TDCG1060M states that the forward voltage ranges from 2V to 2.4V. Taking 2V as the minimum, a series resistor must then drop the difference between 3.3V and 2V, which is 1.3V. The datasheet says the *maximum* forward current is 20mA, so a good working current is 10mA. Using Ohm's law, we can calculate the required resistance at the given voltage: $R = V/I = 1.3/0.01 = 130\Omega$. I used a slightly higher value of 150Ω for a current of 8.6mA. In fact, any value from 150Ω to 65Ω would work at 3.3V, giving a current range from 8.6mA to 20mA. For 5V operation, these resistor values range from 340Ω down to 150Ω. Either way, 150Ω works as a nice value for both 3.3V or 5V operation.

The design must also take into consideration that each LED will be driven using the PIC16LF. The datasheet for the PIC16LF says each pin can sink or source 25mA. However, it is important to note that the maximum current into the V_{DD} pin of the PIC is 800mA. This is quite high, even if all 18 GPIOs were outputting their maximum

25mA, only 450mA would be drawn. In this case, we are safe, but this isn't always the case and current/power levels should always be verified in a design. For example, the PIC18F27J13 can sink or source 25mA on each of its GPIO pin, but the maximum current sunk by all ports is only 200mA, which limits the number of GPIOs at full power to eight pins.

Returning to the schematic in Fig.3, examine the connections from the PIC to the seven-segment display. Note that the series resistors are all connected to the anode side of each segment – could we use fewer components if these individual resistors were combined and connected on the common-cathode side? This is possible, however not all of the LEDs in each segment are the same. Note earlier we said the forward voltage ranges from 2V to 2.4V. As a result, using a series resistor on the common cathode, some segments would end up brighter than others, which wouldn't look neat. Good engineering practice dictates the resistor in this situation should be placed on the anode instead to give a more equal distribution of the current through the display.

Feel free to check the use of a series resistor on the common cathode. Nothing will break, but it's always interesting to see why one method is better than another. I would imagine this becomes more evident as the series resistor is decreased, increasing the current through the segments.

A single series resistor on the common-cathode side would need to be able to handle higher power consumption because it would be sinking the current consumption from each segment. This is calculated using $P = VI = 8 \times 0.02A \times 1.3V = 0.208W$. Most standard through-hole resistors are rated at 0.25W, so with all eight segments running at maximum current, the resistor might get a little warm. With the series resistor connected to the anode, only the current for one segment will run through each resistor, which works out as $20mA \times 1.3V = 0.026W$, which is much less and well within the normal operation of the resistor.

Back to Fig.3, the seven-segment display has 16 pins with the following connections:

Pin Function

- 1 common cathode for digit 1
- 2 common cathode for digit 2
- 3 segment d
- 4 common cathode for L1 and L2
- 5 segment e
- 6 common cathode for digit 3
- 7 segment DP
- 8 common cathode for digit 4
- 9 segment L3
- 10 common cathode for L3
- 11 segment f
- 12 segment L1 and L2
- 13 segment c
- 14 segment a
- 15 segment g
- 16 segment b

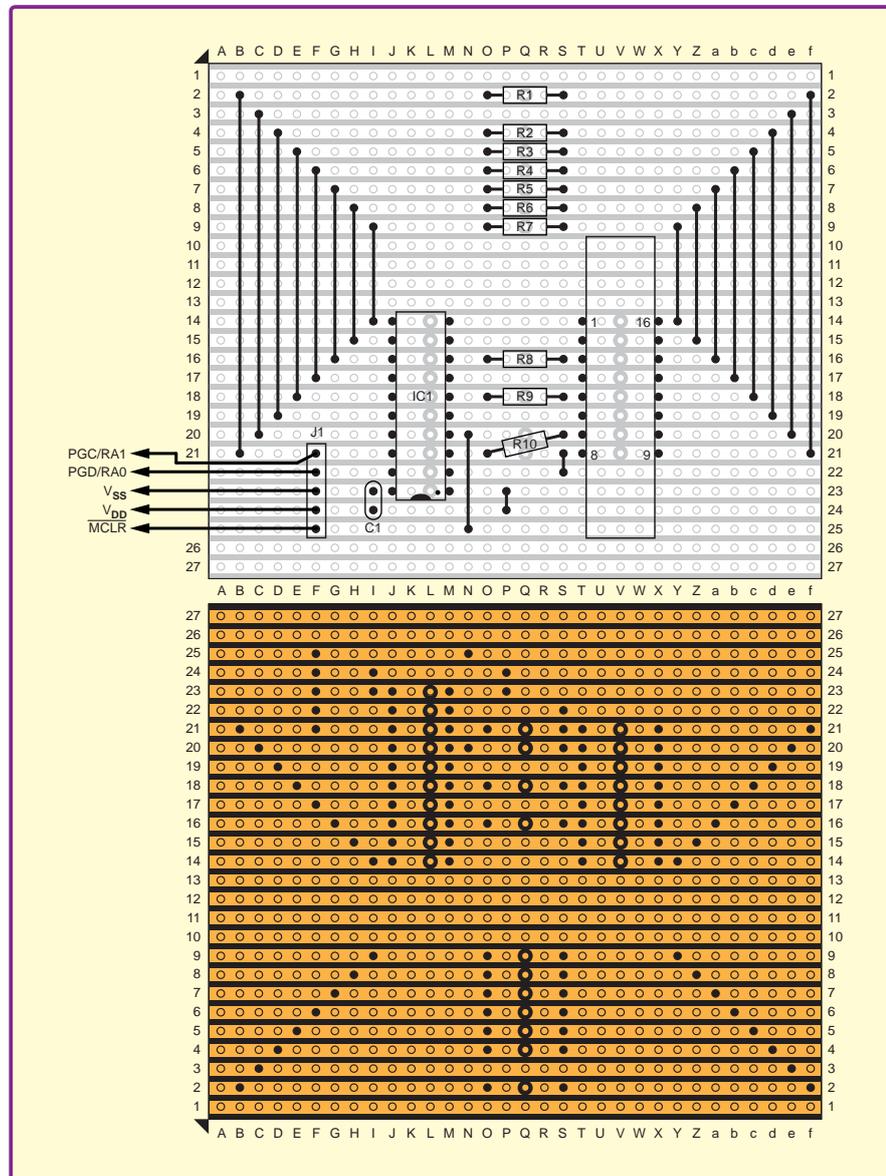


Fig.4. (Left) Veroboard project layout

For our chosen display, L1 and L2 is an additional function shown in Fig.3 as the semicolon between digit 2 and digit 3. L3 is the extra dot shown top left of digit 4. Fig.4 shows the top and underside location of all the components on the veroboard. Note the track cuts in the lower part of Fig.4, where a large circle represents a break in the track on the copper side of the veroboard. It's always a good idea to use a multimeter to verify the track is cut before applying power to the board.

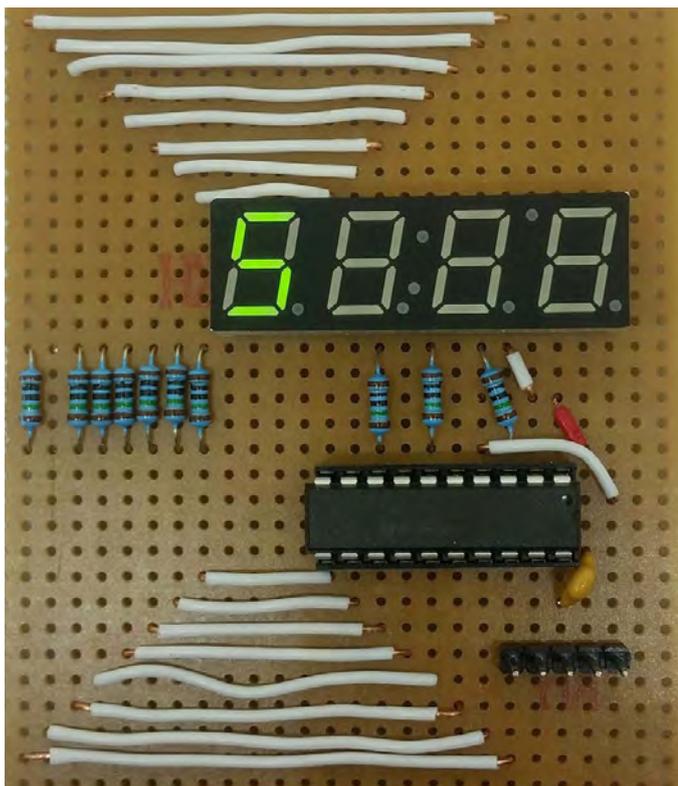
Last, Fig.5 shows the completed board (with a few trivial wiring differences to the veroboard schematic). I've programmed the PIC to show a single digit, but next month we will delve into the software and look at how to control the display.

Could we improve this circuit? Yes, there are always improvements to try down the line. For example, by decreasing the series resistors we could make the display brighter. To increase control over the brightness we could add an npn transistor or FET to the common-cathode pins and with PWM adjust the duty cycle with a potentiometer (as we have done in previous articles). This would enable fine control of the display brightness.

Next month

In the next *PIC n' Mix* column I will focus on the software used to drive the LED segments and create a small clock.

Fig.5. (below) Completed four-digit, seven-segment display controller



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

You can follow the rest of it on Twitter at @MikePOKeeffe,

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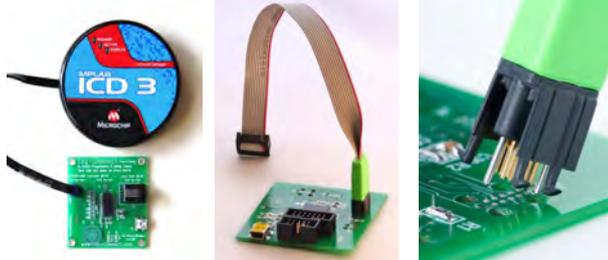
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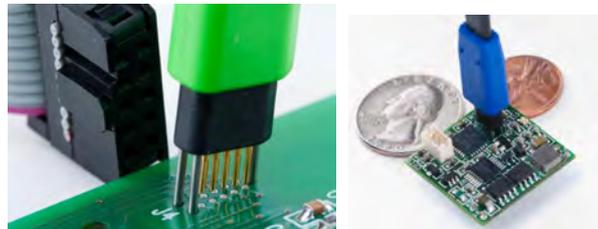
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Temperature sensors – Part 3

TWO MONTHS ago we started looking at temperature sensors in response to a letter to *EPE* from Ewan Cameron (published August 2017) suggesting topics of interest related to PIC microcontrollers, including accurate temperature sensing. Last month, we looked at temperature measurement circuits using self-contained analogue and digital temperature sensor ICs. These ICs do much of the work for you, providing an output voltage or current proportional to temperature, or allowing the temperature to be read as a digital value by a microcontroller over a standard interface such as an SPI Bus.

Sensors vs ICs for temperature measurement

Temperature sensor ICs are convenient but do not necessarily deliver the best accuracy, and are limited in the temperature ranges over which they can operate. For greater accuracy and/or range it is often necessary to use an individual sensor device, building the associated circuitry to set up the operating conditions of the sensor (if required) and process the sensor's response to get a good measurement. It may also be necessary to write software to correct for known issues in the sensors response (nonlinearities).

The main types of electronic temperature sensors, beyond IC sensors are thermocouples, resistance temperature detectors (RTDs) and thermistors. Last month, we looked at the theory of thermocouples – this is often misunderstood because of the commonly used over-simplified description that a junction of two dissimilar metals generates an electromotive force (EMF), thus producing a measurable voltage. It is true that thermocouples contain such junctions, but the EMF is generated when a temperature gradient occurs along a wire (known as the Seebeck effect).

Thermocouples

The main advantage of thermocouples over IC sensors is that they can measure temperature over a very wide range (eg, from -270°C to 2300°C and beyond, although different types are optimal within particular ranges). This month, we will look at examples of the circuits used to perform thermocouple-based temperature measurement and discuss some of the issues associated with getting a good measurement.

To recap a little more from last month, the structure of a thermocouple system is shown in Fig.1 (slightly extended from last month's version). Two connected wires (at junction 1) of different metals (materials 1 and 2) with the same temperature gradient along them produce a measurable voltage due to the two different Seebeck EMFs. Assuming this junction (called the hot junction) is at the temperature being measured, then the two other ends must both be held at the same reference temperature – the physical implementation of this same-temperature requirement is referred to as an isothermal block.

Connecting the two thermocouple wires to other materials (typically the copper of standard PCBs and/or wiring leading to the measurement circuitry) creates more junctions in the isothermal block – referred to as the cold junction. Gradients along these wires could create further EMFs, but if the material is constant these will tend to occur as equal and opposite values round the whole circuit, which will cancel. Furthermore, gradients should be small within the instrument, resulting in very small (offset) EMFs.

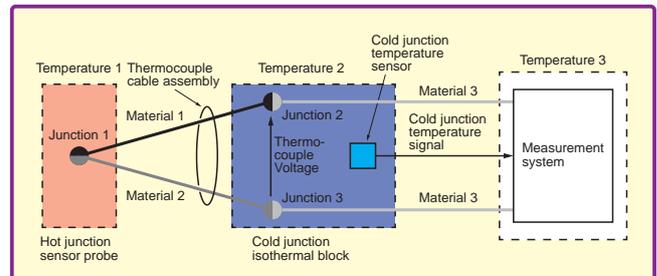


Fig.1. Structure of a thermocouple-based temperature measurement system

Seebeck coefficient

The thermocouple voltage is dependent on the difference between the hot and cold junction temperatures and the difference in Seebeck coefficients of the two materials (materials 1 and 2 in Fig.1) used to form the thermocouple. There are a variety of internationally standardised thermocouples that use specific pairs of materials, and which can be characterised in terms of a Seebeck coefficients for the pair – indicating the voltage produced for a given temperature difference between the hot and cold junctions. These standard thermocouples varieties are identified by a letter, such as 'J' or 'K'.

Seebeck Coefficients for thermocouples are typically less than $100\mu\text{V}/^{\circ}\text{C}$ and are commonly in the range 20 to $60\mu\text{V}/^{\circ}\text{C}$. Thus, the voltages produced by thermocouples are quite small, and this needs to be considered when designing measurement circuits. For example, offset voltages and drift in amplifiers are a potential problems. If relatively long thermocouple wires are used, as is often the case to cover the distance from the point of measurement to the instrument, the two thermocouple wires (materials 1 and 2 in Fig.1) should be formed as a twisted pair, or be held in very close proximity in cable assembly. This will reduce interference pick-up, which is potentially troublesome when measuring small voltages over long wires. Close proximity also helps ensure that any such unwanted signals are the same in both wires (known as common-mode noise). Shielding can also be used and the wiring should not be routed close to interference sources such as power cables and motors.

The thermocouple instrument measures the voltage difference between the two thermocouple wires at the cold junctions. Measuring the difference will remove any common-mode noise. Typically, the thermocouple signal is connected to a differential amplifier. If this amplifier is not perfect (and none are of course) then it will respond to some extent to common-mode noise. Because the signal is small in this application (and so vulnerable to interference) we need an amplifier, which is very good at removing common-mode noise – that is one with good common-mode rejection.

Thermocouple non-linear response

Another issue is that, unfortunately, thermocouples are not linear; that is the Seebeck coefficient of a thermocouple varies with temperature. This is illustrated in Fig.2, which shows the variation in Seebeck coefficient for commonly

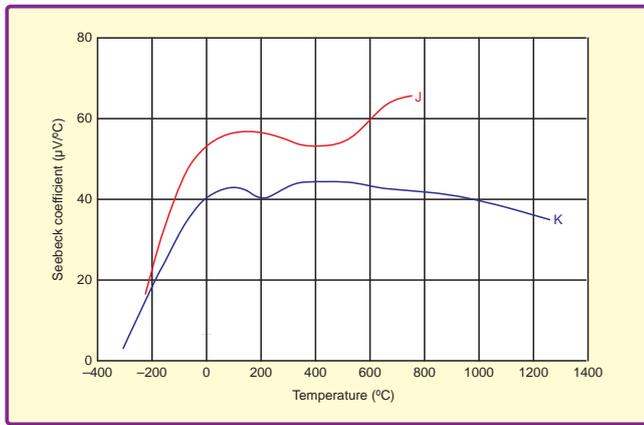


Fig.2. Variation of Seebeck coefficient for J and K-type thermocouples

used J and K-type thermocouples. Ideally, these curves would be horizontal lines, indicating a constant coefficient, but this is clearly not the case. The K-type thermocouple is one of the most frequently used because it is one of the most linear, having the flattest curve, above around 0°C. The variation in coefficient is particularly problematic if temperatures have to be measured over a wide range. For smaller temperature variations the measurement system can be calibrated for the Seebeck Coefficient of the thermocouple at the temperature range of interest. If it is then used to measure outside that range then the result will be much less accurate.

The response of standard thermocouples is well known, that is all K-type thermocouples (for example) will have the same pattern of non-linearity – they will all follow the curve shown in Fig.2. This knowledge can be used to correct for the non-linearity in software. One approach is to use a look up table of output voltages vs actual temperature. The voltage measured is used to look up the two nearest table entries (above and below) and linear interpolation is used to accurately find the temperature between the two data points. More sophisticated approaches use polynomial equations, which fit the thermocouple responses. NIST – the US-based National Institute of Standards and Technology measurement standards laboratory publishes tables and equation coefficients for standard thermocouples, which can be used for this purpose.

Cold-junction compensation

In a typical instrument the cold junction will be at room temperature within the instrument, but will be subject to some variation. Therefore the cold junction temperature often must be either measured and included in software calculations, or directly used within the measurement circuitry, a process called cold-junction compensation. The cold-junction temperature sensor is located in the isothermal block, as shown in Fig.1. Temperature sensor ICs, like those discussed last month, can be used to obtain a signal proportional to the cold junction temperature, either for use in software or in-circuit compensation. The range of these sensors is not an issue here because the cold junction will usually be within their range, even if the thermocouple is being used to measure high temperatures of hundreds of degrees Celsius.

Analogue cold junction compensation circuitry can be built from scratch using basic components. The principle is reasonably simple – obtain a signal proportional to the cold junction temperature and add/subtract it to/from the voltage from the thermocouple before or after amplification. To get this right, however, requires that gain/scaling factors of the amplifier and compensation signal are correct and any amplifier offset voltages have been trimmed out. These parameters will depend on the type of thermocouple used and variation of individual circuit components, so some form of adjustment/calibration process will be required (eg, using trimmer potentiometers).

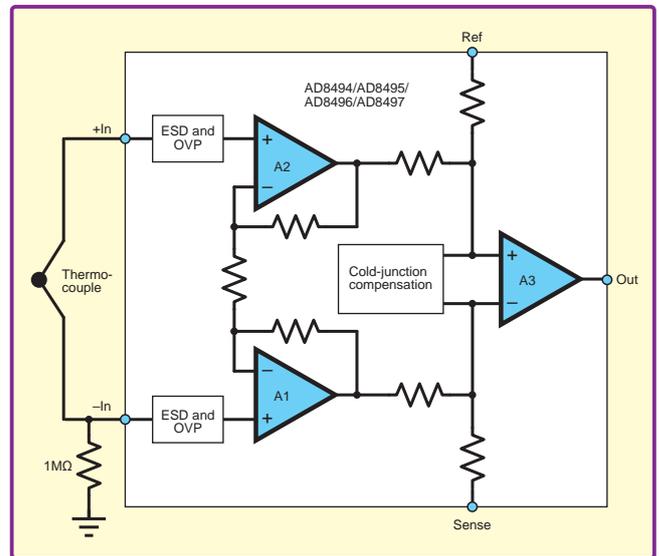


Fig.3. Block diagram of the AD894x precision thermocouple amplifier with cold-junction compensation (from Analogue Devices datasheet)

ICs for thermocouples

A simpler approach is to use a specialist IC designed to do the job. One example is the AD8494/AD8495/AD8496/AD8497 range of devices from Analogue Devices. These are instrumentation (differential input) amplifiers designed to amplify the small voltage difference from the thermocouple, with an on-chip temperature sensor to provide cold junction compensation. They are pre-calibrated by laser wafer trimming to give a 5mV/°C output with minimal errors.

The different versions of the AD894x are calibrated for J and K-type thermocouples over different temperature ranges – this relates to our previous discussion on variation of the Seebeck coefficient. They also have different ambient/cold junction ranges (0°C to 50°C, or 25°C to 100°C); note these are much smaller than the range of thermocouple, but this does not matter because the instrument will not usually experience wide temperature fluctuations. For improving accuracy in software, Analogue Devices publish an application note (AN-1087) containing their own AD849x output lookup table and information on using the NIST tables with these devices.

A block diagram of the AD894x, along with the thermocouple connections, is shown in Fig.3. The AD894x effectively drops into the circuit in Fig.1 as the ‘measurement system’ block and provides an output voltage proportional to temperature that is suitable for input to an ADC. Because the cold-junction temperature sensor is on-chip, the AD894x device must be located in the isothermal block, or at least as close as possible to the cold junction. The circuit should be designed to minimise the output current required from the AD894x – if this too high the power dissipation will result in self-heating of the chip and consequently measurement errors due to an incorrect cold-junction-temperature value.

Instrumentation amplifier

The AD894x chips are built around an instrumentation amplifier. This is a standard three-op-amp circuit which is widely used in measurement applications – hence its name. A generic instrumentation amplifier circuit is shown in Fig.4. Op amps A1 and A2 provide very high input impedance by virtue of the direct connection of signal to the input of the op amps. A1 and A2 also provide gain, set by the values R_C and R_1 .

A3 and the R_2 and R_3 resistors form a standard differential amplifier. A1 and A2 buffer the inputs to the differential amplifier (A3), and prevent loading of the input source. This buffering could be achieved by two isolated amplifiers, but the cross-connection via R_C results in an output from A1 and A2, which is dependent on both V_1 and V_2 . This

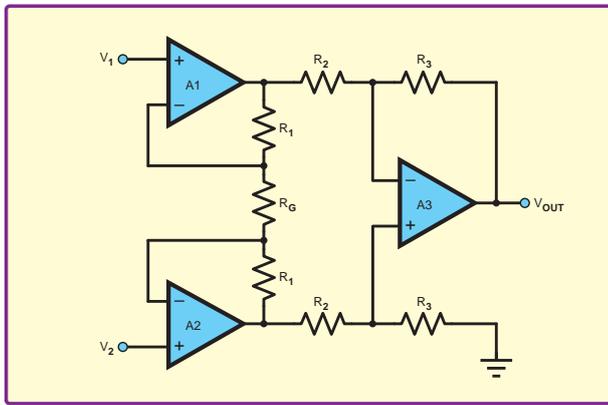


Fig.4. Generic instrumentation amplifier

enhances the differential gain of the whole circuit and its ability to reject common-mode noise.

You can build an instrumentation amplifier with discrete components, but its performance may not be very good, particularly in terms of common-mode rejection. The circuit requires very close matching of resistors (eg, the two R_3 resistors in Fig.3 must have exactly the same value). Characteristics of A1 and A2 should also be closely matched. The matching is much easier to achieve when the circuit is built as an IC on a single silicon chip, as is the case with the AD894x. (Of course there a number of general instrumentation amplifier ICs available which are not specifically aimed at thermocouple circuits.)

Comparing the generic instrumentation amplifier with the AD894x we see that the cold-junction temperature signal is input (added/subtracted) via the differential amplifier stage (A3). Also, the AD894x has the R_3 resistors from the generic instrumentation amplifier connected to pins rather than hard-wired to the schematic in Fig.3. This provides greater flexibility from the chip. The 'grounded' R_3 resistor is connected to the REF pin, which may simply be grounded to obtain the basic configuration. Alternatively, it can be connected to a DC voltage, which will produce an offset in the output voltage. The main use of this feature is to facilitate measurement of negative temperatures in single supply systems, where the output of the AD894x is unable to go to negative voltages.

The 'feedback' resistor is connected to the SENSE pin, which can simply be connected to the output pin to obtain the standard amplifier circuit. If this is not done, A3 will be open loop and will behave as a comparator. Connecting the SENSE pin to a fixed voltage will cause the output of the AD894x to switch between the positive and negative supply voltages depending on the whether the temperature is above or below that corresponding to the voltage on the SENSE pin. Thus the AD894x can be used in this way

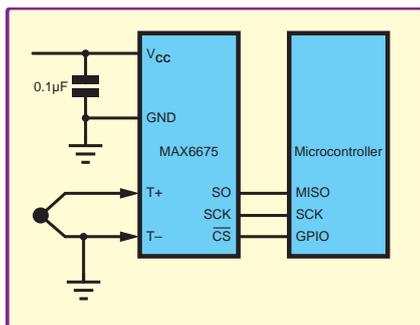


Fig.6. Typical MAX6675 circuit (from Maxim Integrated datasheet)

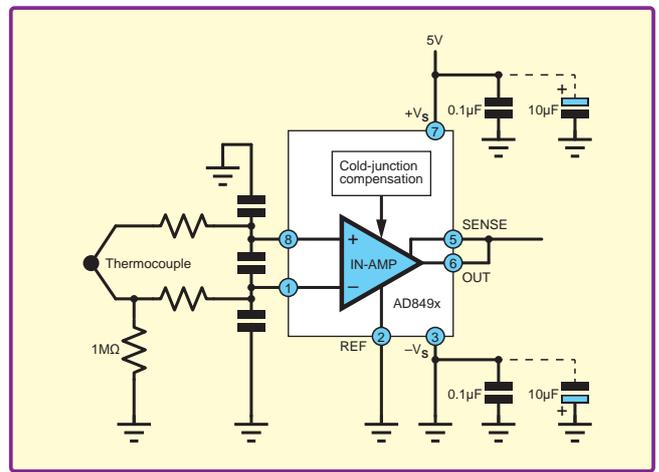


Fig.5. Typical AD894x thermocouple measurement circuit (from Analogue Devices datasheet)

to form a simple on/off temperature controller. Another feature of the chip is that it will output the temperature of just the on-chip sensor if the thermocouple inputs are shorted, which can assist with test and debug.

Fig.5 shows a typical schematic for an AD894x circuit, as provided by the datasheet. This includes supply decoupling and an RC low pass-filter on the input to remove high-frequency noise (the thermocouple leads may pick up RF signals). The 1MΩ resistor grounds one of the thermocouple inputs without interfering with measurement.

MAX6675 SPI-bus thermocouple IC

The AD894x has provided a useful reference for discussing some general points about thermocouple circuits, as well as the specifics of these chips. However, other thermocouple ICs are available and these may be in different formats from the AD894x. One example is the MAX6675 cold-junction-compensated K-thermocouple-to-digital converter from Maxim Integrated. If you want to use a K-type thermocouple with a microcontroller, the MAX6675 is even more straightforward than the AD894x, although it is less versatile and flexible (K-type thermocouples only and positive temperatures only).

A typical MAX6675 circuit is show in Fig.6 – it simply requires a supply decoupling capacitor and an SPI

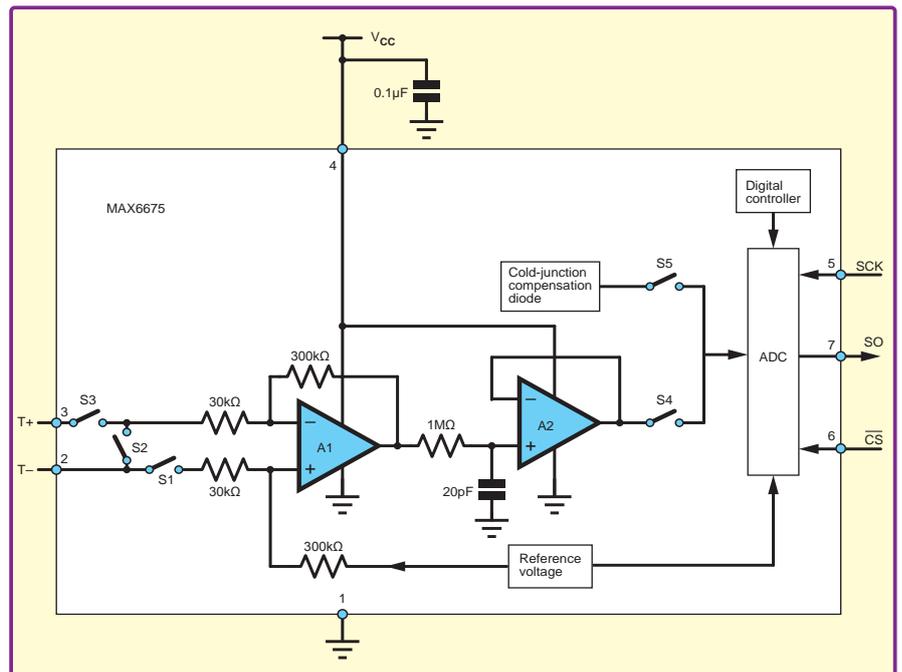


Fig.7. MAX6675 block diagram (from Maxim Integrated datasheet). Cold junction compensation can also be applied further down the analogue signal path, for example within a differential amplifier stage.

connection to a microcontroller. The temperature measured by the MAX6675 is read serially via the SPI bus as a 16-bit word. The actual temperature reading is a 12-bit value within this word, which conveys the measured temperature in Celsius as an unsigned binary number. The measurement range is 0°C to +1023.75°C in 0.25°C steps. Although the step size (the resolution, one least-significant bit or LSB) represents 0.025% of the range, the accuracy is less than this, at ± 5 to ± 19 LSBs, depending on temperature. The cold-junction temperature is measured with about $\pm 3\%$ accuracy. As with the AD894x, the MAX6675 has an on-chip temperature sensor for cold-junction compensation and so should be placed in the isothermal block, or as close as possible to the point where the thermocouple wires connect to the measurement instrument. If the MAX6675 is not at the same temperature as the cold junction then errors will occur. Self-heating of the chip can lead to measurement errors and connection to a large ground plane is recommended to reduce this. The MAX6675 can operate over a (ambient/cold junction) temperature range of -20°C to $+85^{\circ}\text{C}$, like the AD894x, this is much smaller than the thermocouple measurement range.

A block diagram of the MAX6675 is shown in Fig.7. The thermocouple voltage is amplified by a low-noise differential amplifier (A1) followed by an RC low-pass filter and buffer (A2). The resulting voltage is input to an ADC. The cold-junction temperature measurement voltage is also input directly to the ADC (switches S4/S5 select the ADC input). This shows that the approach to cold junction compensation is different from that of the AD894x – the MAX6675 performs a calculation digitally in the specially designed ADC rather than using an analogue circuit to do the job.

Grounding the T-pin (as shown in Fig.5) close to the chip enables the MAX6675 to detect a thermocouple open circuit (disconnection) and this information is output in one of the spare bits not used for the temperature.

MAX31855 SPI-bus thermocouple IC

Another, more recently produced chip from Maxim, the MAX31855 cold-junction compensated thermocouple-to-digital converter, overcomes some of the key limitations of the MAX6675. Like the MAX6675, it is SPI based, and it has a similar circuit structure, although it is not a drop-in replacement. It is available calibrated for seven different thermocouple types, not just K-type – indicated by a suffix to the chip's part number (eg, MAX31855J for J-type). It is also able to measure temperatures below 0°C (its output is 14-bit signed, rather than 12-bit signed.), going down to -250°C with a T-type thermocouple – if you happen to have anything that can get that cold! Its accuracy is about $\pm 2^{\circ}\text{C}$ over the range -200°C to $+700^{\circ}\text{C}$ using K-type thermocouples. The MAX31855 has more comprehensive fault detection than the MAX6675 (ground short, supply short and open –ie, not just open circuit) and its 32-bit output data includes the cold junction temperature as well as the compensated thermocouple reading.

The MAX6675 is described as obsolete in some places, although at the time of writing Maxim Integrated's website states that it is in active production. However, for new designs, where the MAX31855's 3.3V supply requirement (rather than the MAX6675 3V to 5V supply range) is not an issue, the MAX31855, which costs less (current Farnell UK prices), will be the better choice in most cases. Both the MAX6675 and MAX31855 are available in pre-build modules, together with software libraries and/or code examples for popular microcontrollers such as Arduino and PIC, although the simple SPI read from these chips should not present any difficulties to an experienced microcontroller coder.



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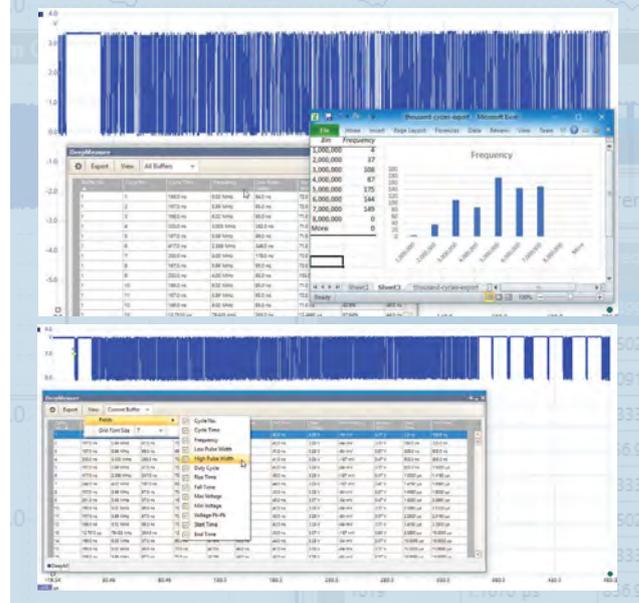


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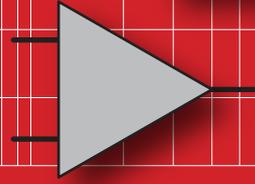
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By Jake Rothman

MX50 power amplifier circuit tweaks – Part 2

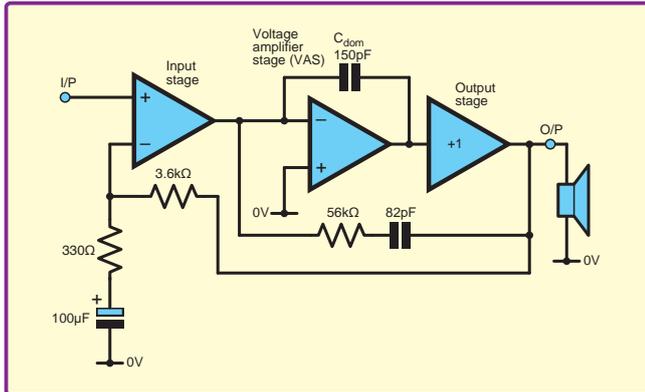


Fig.10. Nested feedback compensation scheme based on 'A New 100W Class-B Topology' by Russel Brenden in Electronics World June 2000.

Last month, we started to look at the issues involved in eliminating wet capacitors from the MX50 amplifier. This month, we will finish the modified amplifier design and provide some useful hints on testing the final result.

Capacitance multiplier

A capacitance multiplier is used to decouple the low-power supply for the bias, driver and input stages. This circuit is an emitter follower, which amplifies the effect of a capacitor, effectively multiplying the capacitance by the transistor's H_{fe} . This allows a small $10\mu\text{F}$ tantalum capacitor to do the smoothing of a $2000\mu\text{F}$ unit. It is also more effective than a large electrolytic, which can put ripple currents into the ground rail. Simple capacitance multipliers like this drop around 0.7V , causing a little power loss. They are not short-circuit proof, so watch out with that oscilloscope probe. The current source bias capacitor C_5 can be reduced to a $47\mu\text{F}$ 25V tantalum or polymer. The lower gain and the capacitance multipliers reduced the hum and noise to 1mV peak to peak, compared to 2.5mV on the original design.

Gain reduction

Most users of power amplifier chips will know there is normally a minimum gain (typically 26dB) that can

be used before oscillation occurs. This is because the negative feedback can become positive at some combination of gain and phase due to slow output devices. Unfortunately, this means the gain of a power amplifier cannot simply be lowered by just reducing the feedback resistor like an op-amp, it has to be recom-pensated as well. This usually entails increasing the compensation or C_{dom} capacitor (C_6). However, increasing this too much can cause slew limiting by overloading the input stage due to the reduced load impedance. Also, the open-loop gain can be reduced so the total feedback margin remains the same. This allows the same capacitor value to be retained.

In this case, the gain is reduced to 11.9x (21.5dB) from 28x (29dB). This allows full drive from a line-level source with the Baxandall volume control. I increased C_{dom} to 220pF , which the input stage current could drive (see Bob Cordell's formula on page 51 of his book, *Designing Audio Power Amplifiers*). This will give a slew rate of $9\text{V}/\mu\text{s}$.

I also reduced the open-loop gain by 3x . This was done by increasing the emitter resistors on the input transistors (R_4, R_5) from 100Ω to 180Ω . The emitter resistor (R_{18}) on the voltage amplifier stage (TR_9) was also increased from 68Ω to 100Ω . Finally, I split the compensation capacitor into two (150pF and 82pF) with the smaller capacitor (C_{13}) going to the output via 56Ω stopper resistor R_{31} . This nested (loop within a loop) Miller compensation trick works excellently and also gives a reduction in crossover distortion, since the output stage is partially included. The idea is



Fig.12a. A quiescent current trimmer VR_1 enables optimisation of bias current.

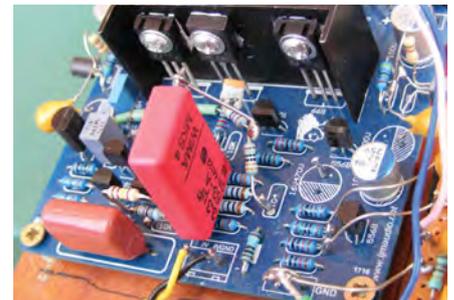


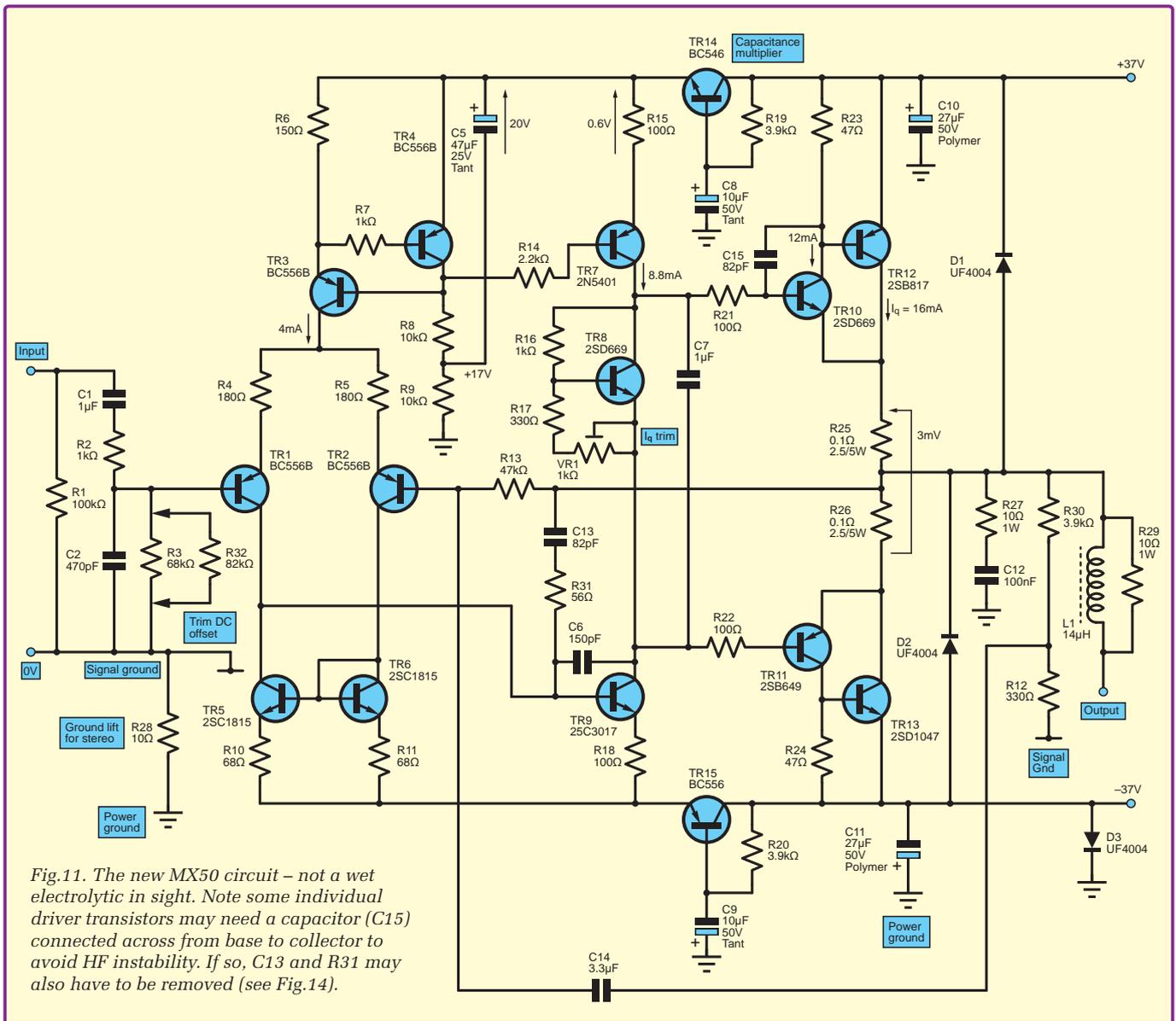
Fig.12b. The negative feedback network rearranged to eliminate the lower arm electrolytic capacitor. The red $3.3\mu\text{F}$ film capacitor is C_{14} .



Fig.12c. The new decoupling arrangement showing the capacitance multiplier TR_{15} with its associated tantalum capacitor. Note also the polymer decoupling capacitor C_{11} .



Fig.12d. It is simpler to solder R_{17} and the TO_5 preset VR_1 together before installing on the board in place of the original $1\text{k}\Omega$ resistor.



shown in Fig.10. The final circuit for the MX50 is illustrated in Fig.11.

The photos in Fig.12 illustrate some of the modifications I have made; for example, Fig.12d shows the insertion of a quiescent current preset in series with R17.



Fig.13. MX50 prototype being tested for instability with a massive Citronic bass unit. The Citronic unit is rated at 500W and has an inductance of 3.7mH with plenty of resonant back electromotive force (emf) – it upsets most power amplifiers.

Testing power amplifiers

When testing the stability of power amps I try to do all I can to provoke instability. A simple load resistor with just sinusoidal test waveforms can give a false sense of security. My personal favourite technique is to use

a huge highly inductive 4Ω 500W 15-inch Citronics bass unit driven with pulse waves and low frequency sine-waves at all levels – see Fig.13 and Fig.14. I drive it up to clipping wearing ear protectors. I adjust the capacitors back to the point oscillation just starts. I then triple their value to give a safety

margin for production purposes. This is because a semiconductor's high-frequency parameter, such as junction capacitance, is subject to very wide tolerances. However, if building an amplifier for yourself, put in the minimum required for your particular set of devices and you will be rewarded with optimum fidelity.

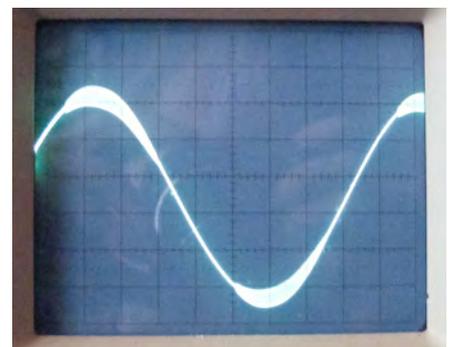


Fig.14. Typical power-amp high-frequency instability riding on a sine wave – watch out for this! It was caused by a combination of the Citronics bass unit and a new batch of driver transistors at 114Hz, 15V_{pk-pk} output.

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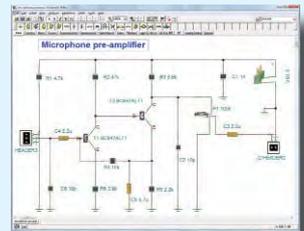
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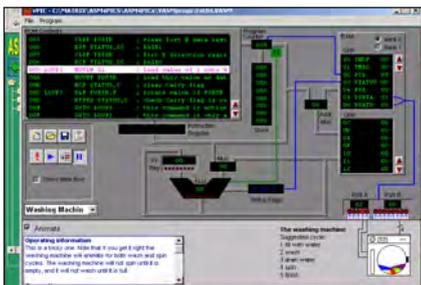
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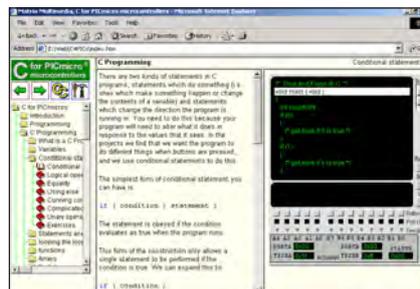


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The C for PICmicro microcontrollers CD-ROM is designed for students and professionals who need to learn how to program embedded microcontrollers in C. The CD-ROM contains a course as well as all the software tools needed to create Hex code for a wide range of PICmicro devices – including a full C compiler for a wide range of PICmicro devices.

Although the course focuses on the use of the PICmicro microcontrollers, this CD-ROM will provide a good grounding in C programming for any microcontroller.

- Complete course in C as well as C programming for PICmicro microcontrollers
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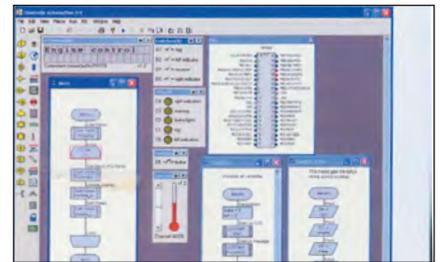
This software will run on Windows XP or later operating systems

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- Requires no programming experience
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- Full on-screen simulation allows debugging and speeds up the development process.
- Facilitates learning via a full suite of demonstration tutorials
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Please note: Due to popular demand, Flowcode is now available as a download. Please include your email address and a username (of your choice) on your order. A unique download code will then be emailed to you.



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Teach-In 2017

Introducing the BBC micro:bit Part 1: Meet the micro:bit



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 x 52mm but despite its diminutive footprint it has all the features of a fully fledged microcontroller together with a 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

The books listed have been selected by *Everyday Practical Electronics* editorial staff as being of special interest to everyone involved in electronics and computing. They are supplied by mail order direct to your door. Full ordering details are given on the last page.

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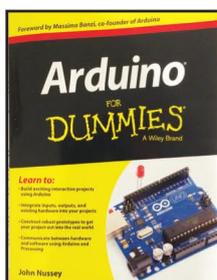
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Teach-In 2016

Exploring the Arduino



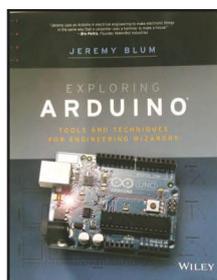
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John Nussey

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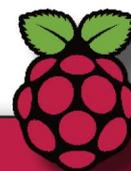
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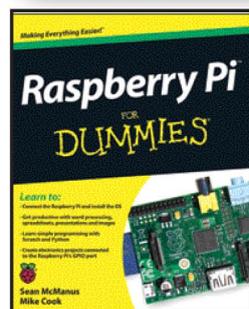
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Sean McManus and Mike Cook

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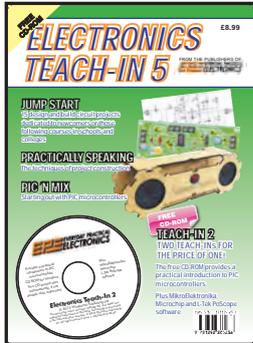
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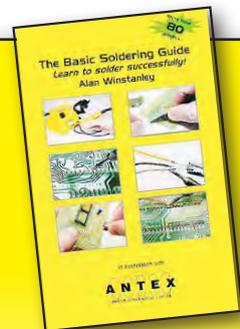
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Max's Cool Beans

By Max The Magnificent

Hammer... nail

I'm sure you've heard an old saying along the lines of: 'If the only tool you have is a hammer, everything starts to look like a nail.' This concept is known as 'The law of the instrument' or 'The law of the hammer'. No one knows who first coined this expression, although in his book, *The Psychology of Science* (1966) the American philosopher Abraham Maslow wrote: 'I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail.' As an aside, the English expression, 'a Birmingham screwdriver,' meaning a hammer, refers to the habit of using the one tool for all purposes, and predates Maslow by at least 100 years, but I digress...

Oooh, shiny

There is a reason for my ramblings – seriously – but first I need to remind you of my previous column in which I introduced my hobby project *du jour* – a *Countdown Timer*. The idea is that I will use 12-LED-based Nixie-esque displays presented in six groups of two to represent the years, months, days, hours, minutes and seconds remaining to some event.

OK, I concede that watching such a display could grow a tad boring after the first year or so unless we throw in some interesting effects. As a case in point, take a peek at a video I posted showing my display implementing a simple randomiser effect (<http://bit.ly/2yBWuIT>).

In this case, all we do is cycle round generating random numbers (50 in this example) and pausing for some time between numbers (10ms in this example). At the end, we hold the final value for one second, then we do the whole thing again. Even though this first-pass implementation is rudimentary at best, the resulting effect is really rather tasty, but now I want to experiment further. For example, take a look at Fig 1.

The idea is that we start off using some initial rate of transitions (generating and displaying numbers) per second (tps). We maintain this rate for some amount of time we might call the sustain time, then we gradually slow the transitions down over some period we might call the decay time until we reach the final value. But which combination of values for the initial rate, sustain time, and decay time will offer the best visual effect?

Hardware rules

In my case, I'm a hardware design engineer by trade, so whenever I see a problem (a nail), I tend to wield a hardware solution as my hammer. In this particular case, I decided to create a hardware control panel out of whatever physical components I had to hand. These turned out to be five 10kΩ linear potentiometers, three momentary push-button switches, three toggle switches, and an old single-throw, 14-pole rotary switch. (This

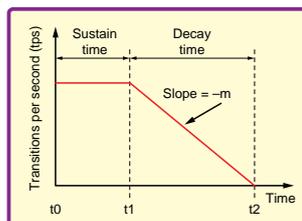


Fig.1. A more sophisticated randomiser effect.

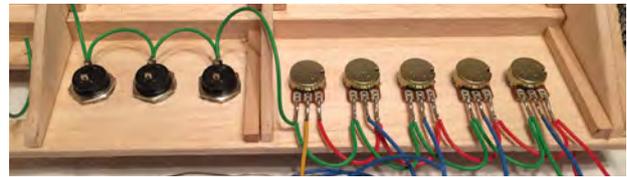


Fig.2. A physical/hardware control panel.

is overkill for the randomiser effect, but I'm building something I can use to fine-tune lots of projects in the future.) Fig 2. shows the pots and pushbuttons attached to a balsawood panel in the process of being wired together.

Software drools

I was chatting to my chum, Ivan, about this, and he asked if I'd considered creating a virtual (software) control panel. The basic idea is for your program to write text and values to a Serial Terminal window, for example:

```
>> Initial Rate (I) = 100 tps
      Sustain Time (S) = 500 ms
      Sustain Time (D) = 500 ms
```

Your program then monitors your host computer's keyboard. In this example, it would look for 'I', 'S', or 'D' characters to tell it if you wished to vary the Initial rate, Sustain time, or Decay time, respectively. Whichever of these was currently selected would be indicated by the '>>' characters. Using the up and down arrow characters would vary the value of the selected variable.

Now, I'm using an Arduino for my *Countdown Timer*. The Arduino IDE has an in-built Serial Monitor, and the Arduino does allow you to both write text and values to the Serial Monitor and to access values from the keyboard. There's a *Serial Input Basics* thread on the Arduino forum that describes all of this in excruciating detail (<http://bit.ly/2xHiz4D>). The problem is that the Arduino's Serial Monitor is somewhat limited in this regard.

VT100 to the Rescue

Way back in 1970s, the Digital Equipment Corporation (DEC) introduced a terminal called the VT100 that supported a suite of escape codes, so-called because they commenced with the <ESC> ('Escape') character followed by one or more numbers and letters. These codes allowed you to do things like placing your cursor at a specific X/Y location on the screen.

So now I'm pondering how to take a free Serial Terminal that supports VT100 emulation, and connect it to my Arduino IDE so that I can use it to implement a software control panel. In turn, I would use this control panel to experiment with different effects on my *Countdown Timer*. If you have any thoughts on this topic, I'd love to hear them. Until next time, have a good one!

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



micro:bit



element14

And the winners are...

In response to the micro:bit competition in our October 2017 issue of EPE, the five lucky winners are:

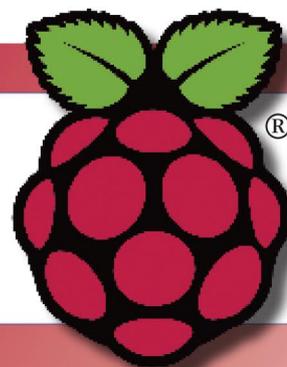
1. Mr Paul Cooper
2. Mr David Searle
3. Mr Steve Swindells
4. Mr Glenn Jones
5. Mr Alf Cooper

Each of the five winners will receive a BBC micro:bit GO Evaluation Kit worth £12.99 - a big thank you to all of you who entered!



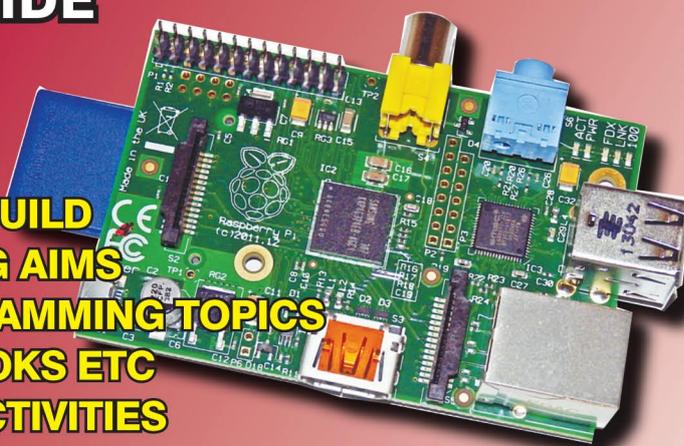
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* See NOTE left regarding PCBs with eight digit codes *

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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

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Next Month

JANUARY '18 ISSUE ON SALE
7 DECEMBER 2017

SC200 audio amplifier – Part 1

This completely new amplifier circuit uses easy-to-solder through-hole components. There are no tiny surface mount components or obscure transistors, making it straightforward to build. The audio performance is exceptional and it delivers a very healthy 200W power output into a 4Ω load

DC speed controller: 12 to 60V at up to 40A – Part 1

So you need a speed controller for a powerful DC motor. How much grunt do you want? This design has bags of it and can run with a DC supply from 12V to 60V, at currents up to 40A. Plus, it has low battery cut-off, speed regulation, soft start and other useful features.

Arduino meets the ATtiny85 Microcontroller

No doubt you have seen heaps of interesting applications for Arduino boards. But what if you want to use some of those ideas in a design of your own using the Atmel ATtiny85 microcontroller? It's actually quite easy and you can use Arduino software. Interested? – then don't miss this project next month!

Low Cost Electronic Modules – Part 1

This is the first of a series of small articles that will help you take full advantage of the wide range of handy pre-built electronic modules that are now available from Asia. In this article, we look at the DS3231 real-time clock (RTC) module.

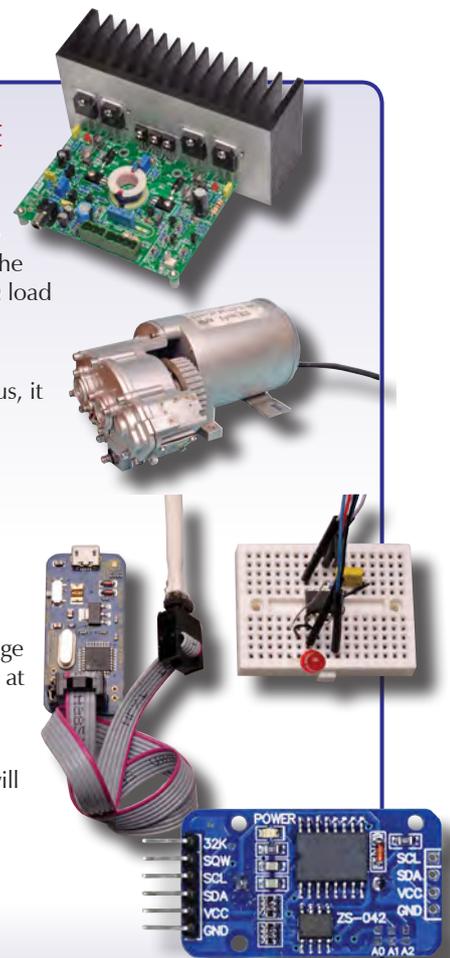
Teach-In 2018 – Part 4

Next month's *Teach-in 2018* will look at component measurement and our practical project will feature an accurate constant-current source that can be used for testing resistors, diodes, LEDs and transistor junctions.

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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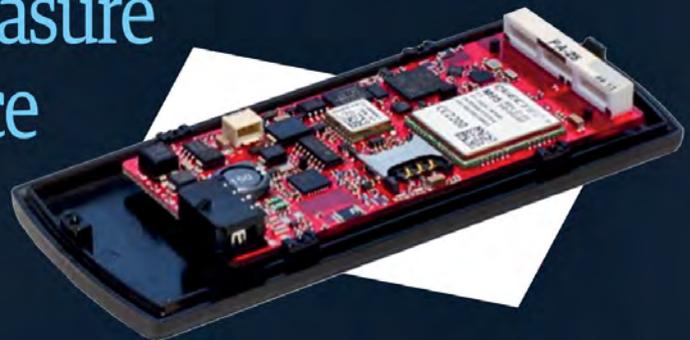
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