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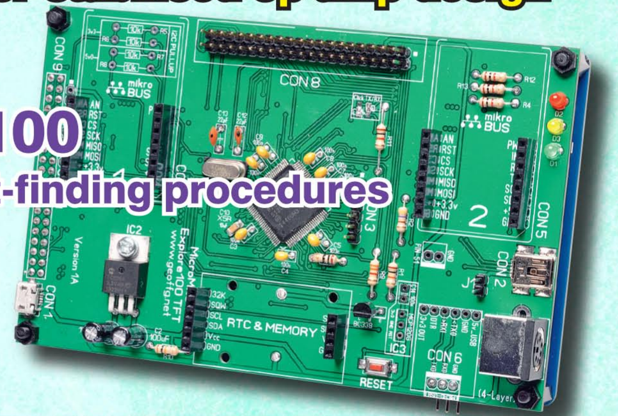

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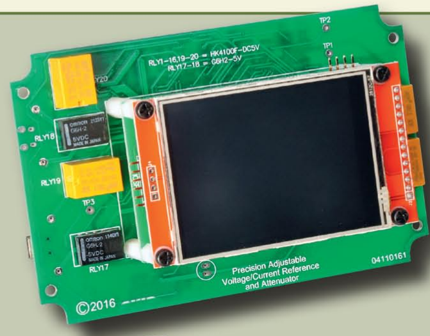

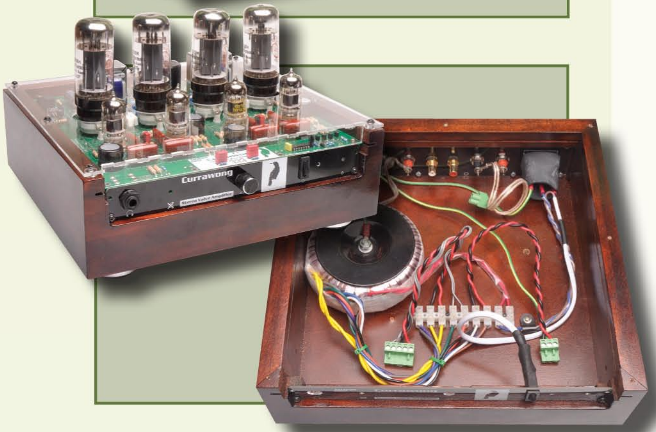

NEW

Teach-In 2018

Get testing! – electronic test equipment and measurement techniques

Part 1: Multimeters

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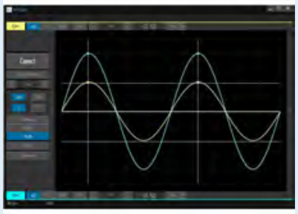

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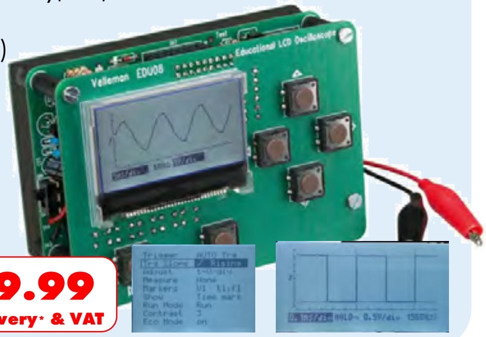

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EPE Chat Zone is retiring

The current *EPE Chat Zone* forum is now over a dozen years old and the elderly but solid Perl-based software that it relies on is completely obsolete. Its original programmer (DiscusWare) shut up shop long ago, leaving us with a legacy system and no support.

We have looked at a number of other forum programs, but they all leave us with the problems of very low traffic levels and the constant need to patch and guarantee user privacy. The level of usage these days has fallen dramatically, often with just a few posts a week appearing from regular *Chat Zone* users. There is much wider online 'competition' from major forums and social media, meaning that the traffic on the *Chat Zone* has dwindled dramatically since its halcyon days.

It is with much reluctance that we have decided that the *EPE Chat Zone* will therefore be semi-retired in approximately two months' time. Messages that are archived become less relevant as time moves on, but we expect that all posts dating back to 2005 will still be available for the foreseeable future.

The forum will switch to 'read-only' mode and it will no longer be possible to post messages from October 2017 – it will become a reference-only resource. Forthcoming changes in data protection legislation also leave us with no choice but to remove all user details from our servers. This is the only way that we can safeguard user privacy.

We know that this will disappoint *EPE* regulars, but hope readers will understand that the very low levels of traffic, the outclassed usability of the software and (most of all) the intensifying needs for data protection have left us with no choice but to semi-retire the forum.

We thank our loyal readers and contributors to the forum – your generosity with time and advice has helped and supported each other, in particular, newcomers to electronics.

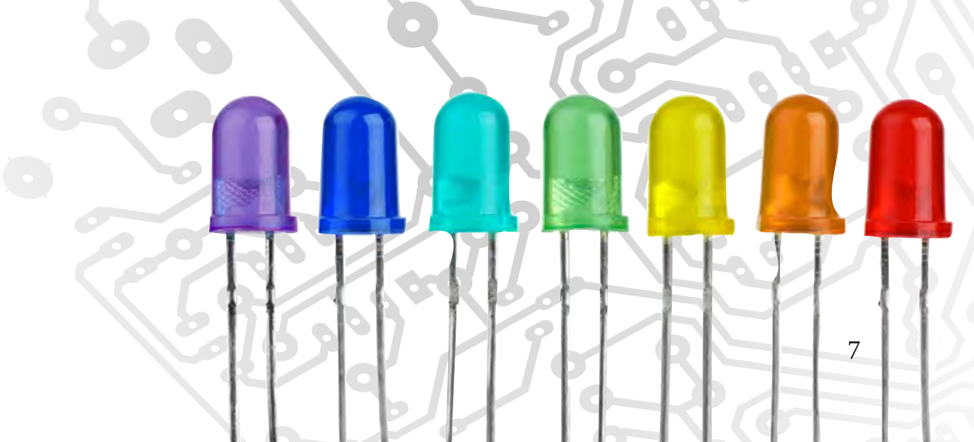
Webmaster Alan Winstanley goes into further details in this month's *Net Work* column.

Teach-In 2018 is here!

Do please understand that this is not a foretaste of doom and gloom for *EPE* itself, which I am pleased to say is flourishing on paper and online!

To emphasise that point, this month sees the start of Mike Tooley's latest *Teach-In* series, which will appeal to anyone involved in electronics – from newbies to old hands, and from digital obsessives to the keenest of analogue fans. I'm talking about test equipment and measurement, which covers a range of disciplines and techniques that all designers, constructors, hobbyists and professionals need to master and understand.

It promises to be a fantastic series and I'm already looking forward to the next article.



NEWS

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

Trademark madness and smoothing chaos – report *by Barry Fox*

The three-month window for objection to Samsung's application to register the plain word 'HDR10' as a trademark for high dynamic range TV in Europe closed late June – without anyone objecting. Samsung had earlier withdrawn the application in the US, following behind the scenes moves by industry trade bodies, but has not yet done so in Europe. (See: **http://bit.ly/2xyp5qQ**)

No objection?

If Samsung now completes the registration process in Europe, the company will in theory be able to stop anyone else in all 28 countries of the European Union – other manufacturers, retailers, trade bodies, magazines and web sites – using the word 'HDR10' to describe the Open HDR System that is a standard feature in HDR TVs and UHD Blu-ray.

A European Union trademark (EUTM) is valid for 10 years. It can be renewed indefinitely, for 10 years at a time.

I personally made all the major TV manufacturers, and also retail trade body RETRA (Radio, Electrical and Television Retailers' Association) and industry body Digital Europe (which controls the use of TV logos such as HD and UHD) aware of Samsung's application, long before the opposition period expired.

I asked RETRA and Digital Europe why they had chosen to let Samsung go ahead without opposition. Says RETRA Chief Executive Howard Saycell: 'I did not believe it was RETRA's place to get involved and that is still my view'. Digital Europe did not respond.

Do they even know what they've registered?

Even Samsung's own management in Europe appears confused. At a trade conference in Lisbon in April, Michael Zoller, Samsung VP, Head of Visual Display Europe, appeared genuinely surprised when asked for comment. 'I was not aware we are trademarking' he said. 'HDR10, according to my understanding is an open standard. We need to come back to you on this.' But he did not.

At an industry conference on 4K UHD held by satellite operator SES Astra in London, in June, John Adam, Head of Business Development & Industrial Affairs, Samsung, UK appeared equally surprised when conference chairman Chris Forrester directly asked him about Samsung's application. John Adam initially assured that 'sanity had prevailed' and Samsung had dropped the application for the HDR10 application because it referred to an industry standard. But when challenged he acknowledged that he was unaware that the public records of the European Union Intellectual Property Office showed the application to be still pending and active in Europe.

What happens next? Will 'sanity prevail' and Samsung's lawyers drop the application – or will they press through to registration and perhaps start sending out 'cease and desist' letters, as happened after Bose successfully registered the word 'Lifestyle' for audio? Watch this space.

HDR10™(?)

People prefer 'rough' to smooth

The SES conference was enlivened by a passionate outburst from David 'Klaf' Klafkowski, CEO of TV production company The Farm Group.

'I can't see the production industry switching fully to UHD (ultra-high-definition TV) for a while' he warned, citing the petabyte data storage demands for 4K production and post-production. 'I just can't see it. But I do see a time in two years or so when everything is in HDR (high-dynamic-range TV), with wider colour gamut. It will become the norm. We'll just park here and move on.'

'But I have a message for any TV manufacturers who are here'.

'Please, please, please, turn off video smoothing by default' he begged, referring to the motion interpolation processing systems which up-scales low-resolution and low-frame-rate video to 4K 50 fps. 'Just turn it off. It is the most off-putting thing. We spend a lot of time making content and then go home and watch it and say, 'what have they done to it?' And it's not just people in the business. If they are watching a film people say 'is that 4K?' I don't like it.'

'I really mean it. Video smoothing is really, really bad. And they put the option two menus down. This is a big deal. There should be a big button on the remote saying "Video Smoothing Off". People who have these sets don't realise what it is and does. UHD is being spoilt by video smoothing – utterly ruined'

BBC technology

Andy Quested, BBC HD&UHD Head of Technology, then gave some

Trademark madness and smoothing chaos – *continued*

insight into how the BBC's flagship productions *Planet Earth I* and *II* have pushed technical boundaries.

The BBC's first move with *Planet Earth I* was from Super 16 film to HD video. 'It was like pulling teeth without anaesthetic for most technicians' Quested recalled. *Planet Earth II* has been shot with UHD, HDR and wide colour space, 'but not necessarily higher frame rates'.

'There are only two frame rates in the world' he digressed, '25 and all the rest, depending on which side of the Atlantic you are. And when the last engineer dies we'll drop to 24fps.'

'The BBC cannot disenfranchise licence payers, many of whom have TV sets without HDR' he explained, 'so compatibility is essential and all BBC commissions will be HLG (Hybrid Log Gamma, the system developed by the BBC and Japanese state broadcaster NHK) unless someone pays us a considerable amount of money not to use HLG. And BBC distribution will be HLG. That's our target.'

While discussing HDR, Quested added his voice to spreading concern over the over-bright images which over-blown HDR can inflict on viewers. He said he has simple advice for BBC engineers and producers, he tells them: 'If it hurts your eyes in the grade, then it will hurt the eyes of the audience. So don't do it'.

The 'sweet spot' for screen brightness, Quested believes, is around 1000 candelas per square metre (nits). 'It will do for TVs for quite some time to come, even though manufacturers seem to want to go for 10,000. If anyone saw the 10,000 candela demonstration of HDR at IBC last year, every time the screen showed peak white the whole demonstration area lit up. I am sure you could see through people, to their skeletons'.

Flat is back

Discussing another questionable TV technology, John Adam of Samsung admitted that curved screens are 'a British Marmite thing' – people either love them or hate them. 'People in the industry – professionals – tend to hate them. Consumers love them,' he said.

Robert Taylor, Senior Product Manager, Home Entertainment, LG Electronics UK confirmed that LG has now dropped all curved screens. 'We had curved TVs for two years and this year is the first we have removed all of the curved TVs. It hasn't damaged us in any way, shape or form – in fact, it has helped the sale of flat OLED screens'.

Pico waveform analysis

Pico Technology, manufacturer of PC oscilloscopes and data loggers, has introduced the DeepMeasure analysis tool. Included as standard with their 3000, 4000, 5000, and 6000 series oscilloscopes, DeepMeasure delivers automatic measurement of waveform parameters on up to a million successive waveform cycles. Results can be easily sorted, analysed and correlated with the display.

IoT design challenge

Farnell/element14 has issued a challenge to designers to propose a device that makes a vehicle safer, smarter or more efficient, whether it has one, two, three, or four wheels.

Judges will choose 10 applicants to become sponsored challengers, all of whom will receive a kit of parts including: STM32 Nucleo Board, Sensor expansion board and Bluetooth LE / Wi-Fi expansion boards.

The sponsored challengers then create an exciting and original project that will make their vehicle of choice safer, smarter, more efficient, or which improves traffic management through the use of Internet connectivity and embedded devices.

The deadline for project submissions is 13 November. Further details available at: **http://bit.ly/2vcWn23**

Colossus VR experience brings remote access to museum

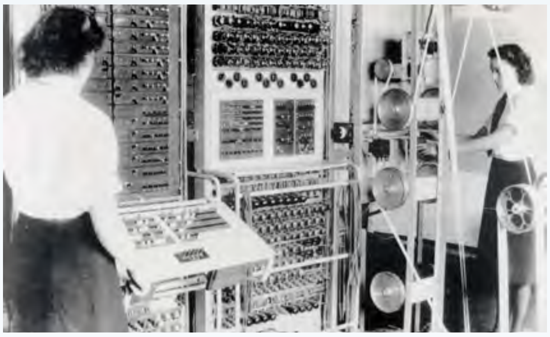
Immersive virtual reality technologies have brought the story of the world's first electronic computer Colossus and the breaking of Lorenz, Hitler's most secret cipher to a wider public. The Colossus VR experience is being revealed to visitors at The National Museum of Computing.

Web and mobile developers, Entropy Reality, have brought to life the experience of visiting the world-famous Colossus and Tunny galleries at The National Museum of Computing on Bletchley Park. By donning a virtual reality headset, users can 'walk' around the galleries and immerse themselves in the story of how Bletchley Park code breakers shortened the Second World War by unravelling Lorenz, the most complex enemy cipher used in communications by the German High Command.

Margaret Sale, a trustee at The National Museum of Computing, said: 'This Colossus Virtual Reality Experience is astonishingly good and pushes the boundaries of current technology in homage of the world's first computer. It brings a whole new dimension to the possibilities of computer conservation and for the outreach display of Museum artefacts.'

Eddie Vassallo, CEO of Entropy Reality, gave a glimpse of the complexity of the task and revealed that the two museum galleries provided his company with its greatest challenge yet, requiring new innovative approaches. 'We filmed the galleries in 360 degrees with six Go Pro Hero 4 cameras operating in sync, adding extra footage to emphasise important 3D elements in the scenes.

'The biggest challenge was Colossus. Its size and detail are mind-blowing in real life – for the virtual world, we required massive servers to process its 65 million points of data. Each shot took 31 hours to process and export. Then we had the huge post-production task of stitching together all our images and deploy various tricks of the trade, just like a magician, to make sure the viewer looks where we want them to.'



A Colossus Mark 2 computer being operated by Wrens

Phase One is now complete and being used by the Museum on site and in roadshows. Later this year, Entropy Reality will release the app to the app stores. To use the downloadable app, users will need only a VR-capable mobile handset (ideally a Google Android handset compatible with Google's DayDream VR), an Oculus Rift or HTC Vive machine.

But there is even more to come. Phase Two, expected early next year, will incorporate elements such as touch. Phase Three will see it all working, giving users the ability to send messages between locations.

Microcontroller Closes the Graphics Gap

First MCU to Combine 2D Graphics Processing Unit and DDR2 Memory

The industry's first MCU to combine a 2D Graphics Processing Unit (GPU) and integrated DDR2 memory delivers groundbreaking graphics with increased colour resolution and display sizes.

The three-layer graphics controller in the 32-bit PIC32MZ DA family drives 24-bit colour Super Extended Graphics Array (SXGA) displays up to 12 inches, whilst expansive storage is provided by up to 32 MB of on-chip DRAM or 128 MB externally addressable DRAM.

The PIC32MZ DA MCUs bridge the graphics performance gap to create complex graphics with easy-to-use MPLAB® X IDE and MPLAB Harmony development tools and software from Microchip.

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www.microchip.com/PIC32MZDA

Plain daft

TechnoTalk

Mark Nelson

Combine new technologies and a lack of technical understanding and you have a recipe for confusion and dissatisfaction. That's the theme underlying both of our topics this month.

I'M CONFIDENT THAT LIKE MOST readers of this magazine, you are generally well-informed. You buy *EPE* at your own expense out of a desire to enjoy your hobby and further enhance your skill sets. That's commendable, so take a bow! I also consider myself reasonably well-informed, so it saddens me when I come across technologies that are being poorly implemented or described. You too?

Smoother video

Fruit smoothies are good for you (as long as they don't contain too much sugar), so what's not to like about smoother video, whatever that may be? Well, just about everything, according to David Klafkowski, chief executive at television post-production company The Farm. But before we examine his protestations, you may need to know what video smoothing actually is.

Essentially – if I have got this right – video smoothing is a sophisticated interpolation technique that 'fills in the gaps' between frames of high-def television to eliminate the residual jerkiness you might see; for instance, in fast-moving sports footage. Video smoothing is a viewer option on the new 4K television sets, but because it is normally enabled as the default setting, some customers are unaware that it should sometimes be turned off.

At a trade conference earlier this year, Klafkowski told TV set manufacturers that while video smoothing is great for people watching sport, it is 'really bad' for watching movies, making them look as if they had been made on a cheap camcorder. This is because most films have been made with a frame rate of 24 or 25 frames per second (fps), whereas 4K television receivers are able to handle frame rates of up to 60fps. If video smoothing is turned on by default, watching a movie made to be viewed at 24fps is going to look very strange when upconverted to 60fps. Viewers end up confused and dissatisfied, wondering why they spent so much money on a sub-standard viewing experience.

Video smoothies

None of the foregoing should be confused with a 'video smoothie' or 'smooth motion video', which is a set of still images that have been panned, zoomed and sequenced using special software to create a 'filmic' impression that looks rather more appealing than a simple slideshow when uploaded to a website.

TLAs and jargon

When I started writing professionally, back in 1980, I had a very unforgiving boss. If I used any TLAs (three-letter acronyms) without first explaining what they meant, he would fly into a rage. 'But everyone knows that so-and-so means,' I argued. 'Really?', was his reply; 'Would your grandmother know?' He had a point, and it annoys me now when I see trade journals reprint press release material without explaining what, let's say, HDR and UHD mean. I rather suspect the journalists don't know either, but are afraid to expose their own ignorance. I wasn't 100 per cent certain myself. I assumed that 'UHD' was 'ultra-high definition' and 'HDR' stood for 'high dynamic range'. Looking up these acronyms I found I was right, but discovered there is also SDR (standard dynamic range). Ironically, the article was titled 'Consumers need a PhD to understand UHD'. Journalists should remember their readers as well! (*Philosophiae Doctor*, in case you were wondering – Latin for doctor of philosophy.)

The same goes for jargon. Of course there is nothing wrong with jargon; within specialist circles one single jargon word can save setting out a whole slew of words. But when you are writing for the general public you need to take greater care. When I was working for British Telecom there was jargon by the shed load, and it was a highly convenient shorthand for talking to colleagues. But we had it drummed into us that we were not to use jargon words when writing for customers (we were not allowed to call them subscribers any more!). So what we called 'telephone traffic' had to be translated as 'the number of phone calls' and a 'public call office' had to be de-jargonised into a 'phone box'.

Rant warning

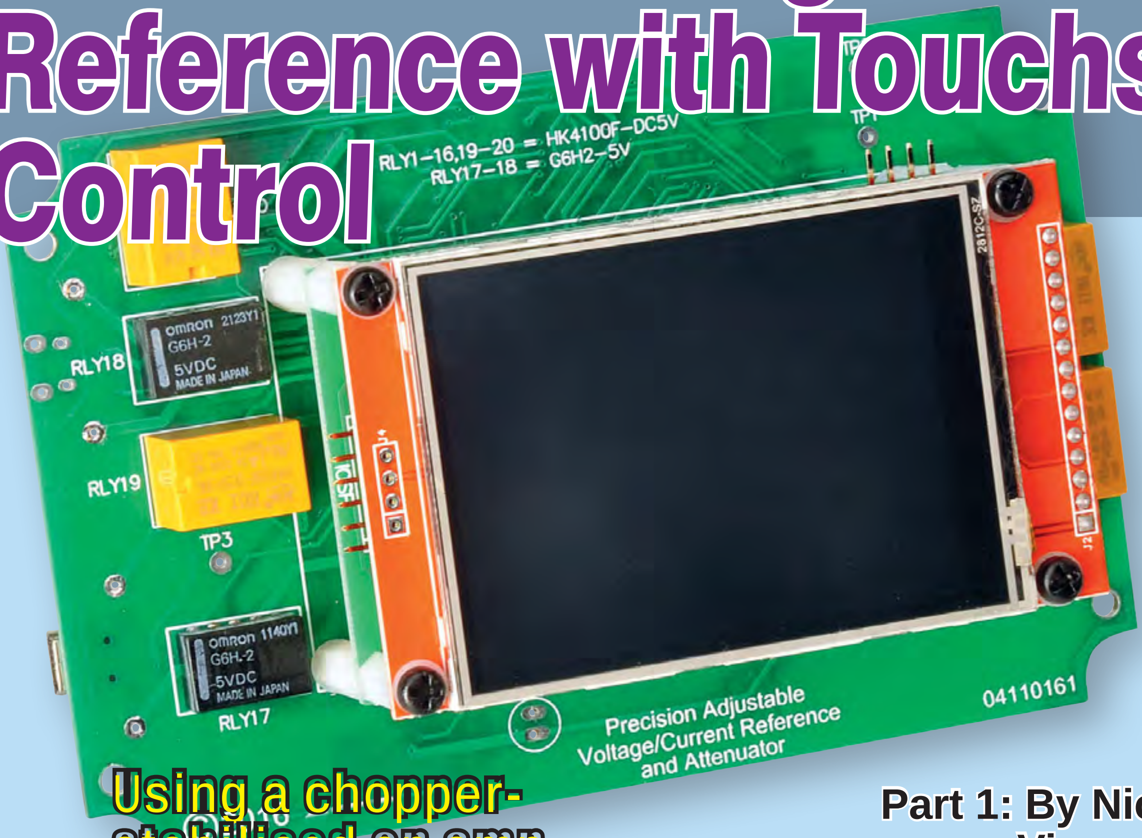
What is even worse than jargon is the misuse of jargon (yes, I'm in full rant mode now!). By this I mean the (mis) use of a specific and well-understood word to describe vague, fluffy concepts. One of these words is 'digital' and among the worst perpetrators of its misuse are the BBC and Network Rail, who both use the word to mean 'electronically assisted or enabled'. On one of its web pages, the BBC states: 'Whatever content you create, whether fact or fiction, you can use digital production and distribution techniques to help you reach a wider, more committed audience.' But you could equally use analogue means, so the transmission and production technologies employed are actually irrelevant. What the confused writer means is you can use computers to convert material created for one purpose into other media by using computers, also to create websites and downloadable podcasts and deliver them by means of the Internet. But focussing on the word 'digital' creates a totally misleading impression of what 'digital' actually means.

More drivel

The 'digital railway' is Network Rail's 'improved plan to tackle the UK's capacity crunch by accelerating the digital modernisation of the railway.' The website continues: 'Digital Railway is the proposal for the UK to adopt modern digital signalling and train control within the next 25 years and create credible options to upgrade the railway to next-generation technology as it becomes available. By using in-train signalling and traffic management systems that optimise the speed and movements of trains on the network, they can be run closer together without supervision.'

In which case, the word 'digital' is no more descriptive in this scheme than it is for the BBC's joined-up model of multi-media content creation and dissemination. To sum up, 'digital' is clearly not the right word to use for either the BBC or Network Rail; 'cross-platform data-enabled' might sum it up better. Sure, that's four words instead of one, but at least those words are descriptive. Calling this 'digital' just reveals lazy and muddled thought.

Precision Voltage and Current Reference with Touchscreen Control



Using a chopper-stabilised op amp

Part 1: By Nicholas Vinen

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

THE SPUR FOR this project was the success of the *Low-cost, Accurate Voltage/Current/Resistance Reference* project described in the August 2016 issue. That project's popularity is no doubt due to its simplicity and low cost to build. But it's also quite limited, with just one reference voltage, one unbuffered current option and one resistance value.

So we decided to come up with a new project which would be a lot more useful, offering a huge range of reference voltages and currents without being too expensive, large or difficult to use. This unit is the result.

We decided to use the *Micromite LCD BackPack* as the user interface. This keeps things nice and simple, with no buttons or knobs – all settings are done via the touchscreen. You can simply punch in a voltage or current value or attenuator ratio. Or you can swipe to adjust the already set value. It also gives a nice clear read-out of the current state of the unit. We decided it should be powered from a USB socket, due to the prevalence of suitable supplies (both mains- and battery-based).

The PIC32 in the *LCD BackPack* does all the control work, so we just needed to add a precise voltage source, an accurate gain stage and programmable divider, a voltage-to-current converter, a boosted supply to provide a usefully wide voltage range and some switching to allow the user to easily switch between the various modes.

Design process

We immediately decided to use the same Maxim voltage reference IC as the earlier reference project. It has the advantage of being relatively cheap, but with a good basic accuracy of ±0.04% and low noise.

To attenuate its output, we considered using either a precision DAC or a discrete 'R-2R' resistor ladder network switched by relays, like Jim Rowe used in his *Lab-Standard 16-Bit Digital Potentiometer* project, from the July 2012 issue.

You would think a single DAC IC would be the cheaper option, but high-precision DACs are surprisingly expensive. We now have sources of suitable relays and high-precision SMD resistors that are cheap enough that the discrete option ends up being the same cost, or even lower.

Using a DAC IC would give us the ability to quickly vary its output, eg, ent

n

Features and specifications

- Four modes: AC/DC attenuator/divider without buffering, AC/DC attenuator/divider with buffering, voltage reference, current reference
- Interface: 320 × 240 pixel colour TFT touchscreen
- Power supply: 5V 1A USB supply (micro or mini connector)
- Protection features: over-voltage disconnect (buffered attenuator and voltage reference mode); over-voltage, over-current and over-heat disconnect (current sink/source mode)

Unbuffered attenuator/divider mode

- Maximum input voltage: ±60V
- Input impedance: variable, displayed on screen; 3.5-114kΩ
- Output impedance: fixed; 2.4kΩ
- Attenuation steps: 65,535
- Attenuation accuracy: typically within ±0.01%

Buffered attenuator/divider mode

- Input voltage range: 0-38V
- Input impedance: variable, displayed on screen; 3.5-114kΩ
- Output impedance: effectively 0Ω
- Output current: 12mA source; 12mA sink above 1V, reducing to ~5 @ 0V
- Bandwidth: >50kHz
- Attenuation steps: 65,535
- Attenuation accuracy: typically within ±0.01%

Voltage reference mode

- Output voltage range: 0-5V in 0.1mV steps; 5-10V in 0.5mV steps; 10-37V in 1mV steps
- Output current: 12mA source; 12mA sink above 1V, reducing to ~5 @ 0V
- Uncalibrated accuracy: ±2mV 0-2.5V; ±3mV 2.5-5V; ±5mV 5-10V; ±10mV 10-20V; ±20mV 20-37V
- Typical output noise (1MHz BW): <200µV RMS 0-2.5V; <5mV RMS 2.5-37V
- Typical output noise (50kHz BW): <100µV RMS 0-2.5V; <500µV RMS 2.5-37V

Current reference mode

- Output current range: 0.5mA-5A in 0.5mA steps.
- Maximum applied voltage: 30V
- Calibrated current reference accuracy: typically better than ±0.1%
- Continuous sink/source current: up to 83mA
- Continuous dissipation: up to 2.5W
- Peak dissipation: 50W (10ms), 20W (100ms)

for pulse testing purposes. However, that is not the primary intention for this project; it was envisioned more as a DC reference so that was not considered an important feature. Anyway, the relays do allow for output 'bursts' as long as they are not too short.

The discrete ladder approach has further advantages which convinced us to stick with this approach. It allows the unit to be used as an attenuator for a wide range of external AC signals or DC voltages, including those which swing below ground. It also provides full isolation from the unit's own power supply in this mode.

Double-sided PCB

By producing a double-sided PCB which is stacked with the *LCD BackPack* PCB, we can easily fit the 16 relays and 50-odd resistors required for the precision attenuator into a standard jiffy box, with room for the other components required to provide the various extra modes.

Besides having more features, another important advantage of this design over the *Lab-Standard Digital Potentiometer* is the fact that our R-2R ladder uses resistors which are all the same value. This is made possible since precision SMD resistors are both smaller and cheaper than their through-hole equivalents, so we could simply create one value by combining two resistors.

We're using pairs of 12kΩ 0.1% resistors in parallel to form 6kΩ 0.1% resistances, so the R/2R ladder is in fact 6kΩ/12kΩ. This gives a divider impedance four times that of the earlier design, which used 1.5kΩ/3kΩ. This keeps the input impedance above 3kΩ at all times, making it easier to drive from an external source. The higher output impedance is partially solved by adding an optional buffer.

Using a single value means we benefit from the fact that resistors from the same batch are likely to be closer in value to each than their tolerance would otherwise suggest. In addition, they should also have closely matched temperature coefficients, so the division ratio should not drift much with temperature.

Another advantage of this scheme is that the actual resistor value is not critical. If the 12kΩ resistors become difficult to acquire or expensive, constructors can simply substitute 10kΩ or another similar value. As a bonus, you can take advantage of the volume discounts often available when buying 50 or more resistors of the same value.

Chopper-stabilised op amp

As well as the precision divider and voltage reference, we have added an op amp to provide reference voltage gain, to expand the range of available output voltages. This op amp uses a boosted supply so that the 5V USB input isn't a limiting factor.

For this, we need an op amp with a very low input offset voltage, to avoid prejudicing the accuracy of the reference, along with low drift, low noise and a very low input bias current, to avoid errors due to the divider's output impedance (when acting as a buffer).

We originally planned to avoid chopper-stabilised op amps because although they have a very low input offset voltage, they tend to have high noise due to the 'chopping' (switching) action. However, in the end, the op amp we found that best suited our needs at reasonable cost is of this type, albeit one with very low noise.

It's the ADA4522-4ARZ from Analog Devices, which has four op amps in one package, a maximum input offset of just 5µV, drift of just 2.5nV/°C, a low typical input bias current of 50pA (maximum 150pA @ 25°C) and very low noise at just 5.8nV/√(Hz). As a bonus, it will run off a supply voltage of up to 55V. We decided on 39V (since

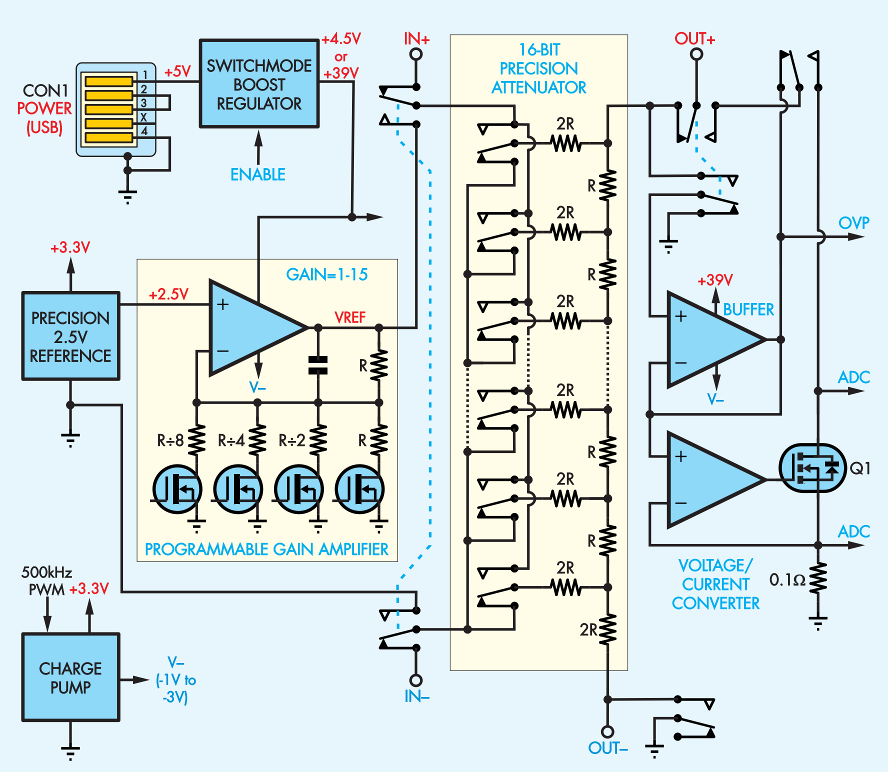


Fig.1: this diagram shows the basic concept of the *Programmable Voltage and Current Reference*. The output from a precision 2.5V reference is fed into a programmable gain amplifier (PGA) and the resulting reference voltage of 2.5-37.5V is then applied to a precision divider by a DPDT relay. The output of the divider can be accessed directly at the OUT+ terminal or optionally routed through either a buffer op amp or a voltage-to-current converter.

the boost regulator's internal MOSFET is rated at 40V peak), allowing reference voltages up to about 37.5V.

This quad op amp not only provides the gain stage, but also drives a voltage-to-current buffer, allowing the unit to sink or source a programmable current between 0.5mA and 5A (within certain dissipation limits). Another of its stages is used as an optional output buffer.

Operating principle

Block diagram Fig.1 shows the basic operation of the device. We're ignoring the *LCD BackPack* and its control logic, for the moment. At its heart is a 16-bit precision attenuator with all the switching done by relays. With the control relays in their off (default) states, the positive and negative input voltages for the precision attenuator come from an external voltage source via the IN+ and IN– banana sockets. Similarly, the divided voltage, with the attenuation ratio set by the state of the 16 relays in the R-2R ladder network, appears across the OUT+ and OUT– terminals. Normally, OUT– and IN– are both connected externally to GND.

A DPDT relay can switch the IN+ and IN– terminals out of the circuit and connect the input side of the attenuator to the output of the programmable gain amplifier (PGA) instead. This is fed from the 2.5V precision reference. With the four PGA MOSFETs off, the attenuator receives 2.5V and this can be divided into 65,536 discrete voltages at the OUT+ terminal; the OUT– terminal can be internally connected to ground via a relay, for convenience.

Should a voltage above 2.5V be required, the switchmode boost regulator can be enabled, raising the PGA op amp's supply voltage from USB 5V up to 39V. Its gain can then be increased to give a reference voltage from 5V to 37.5V, increasing the range of output voltages available from the divider.

A simple charge pump driven by the micro in the *LCD BackPack* provides a negative rail for the op amp that's typically 1-3V below ground, so that its outputs can reach 0V even when sinking several milliamps. This is a common issue with 'rail-to-rail output' op amps; while in theory their outputs can swing to the supply rails, in practice they usually fall a bit short.

A DPDT relay at the OUT+ terminal can insert one of these high-precision op amps in series with the output, to buffer the voltage. The relay shown at upper right switches the buffered output from voltage mode to current mode. In this mode, current from the OUT+ terminal passes through MOSFET Q1 to the OUT– terminal. An op amp varies Q1's gate voltage so that it sinks the programmed current, by monitoring the voltage across the 0.1Ω shunt and comparing it to the reference voltage from the divider.

Finally, the micro in the *LCD BackPack* uses its analogue-to-digital converter (ADC) to monitor the dissipation in Q1, along with its drain voltage and current, and the voltage at the output of the buffer op amp. It can then disconnect the output terminal from this circuitry should any of these be driven outside their design ranges.

Circuit description

Fig.2 shows the full circuit diagram of the *Precision Voltage and Current Reference*. The main 2.5V reference is provided by REF1, a MAX6071-2.5 with an initial accuracy of ±0.04%. Its power supply is derived from the regulated 3.3V rail of the *LCD BackPack* module via an RC low-pass filter (100Ω/4.7µF) to cut out switching hash from the microcontroller. We're using the 3.3V supply because it's likely to be less noisy than the unregulated 5V input.

The 2.5V output is fed to IC5a, which forms the PGA. By default, with outputs O4-O7 of IC3 in their high impedance state, the op amp's feedback is via the 12kΩ resistor and parallel 100nF capacitor (for stability and noise reduction) and this gives unity gain, ie, V_{REF} = 2.5V.

However, if IC3's output O4 switches low, this forms a 1:1 divider (ie, 12kΩ/12kΩ) and so the op amp gain becomes two, giving V_{REF} = 5V. The 0.1%-tolerance resistors ensure this value is close to ideal, but any error is automatically calibrated out, as explained later.

Similarly, if O5 switches low, the gain becomes four and V_{REF} = 10V. Various combinations of O4-O7 can be switched to give a gain of 1-19, resulting in a V_{REF} between 2.5V and 37.5V.

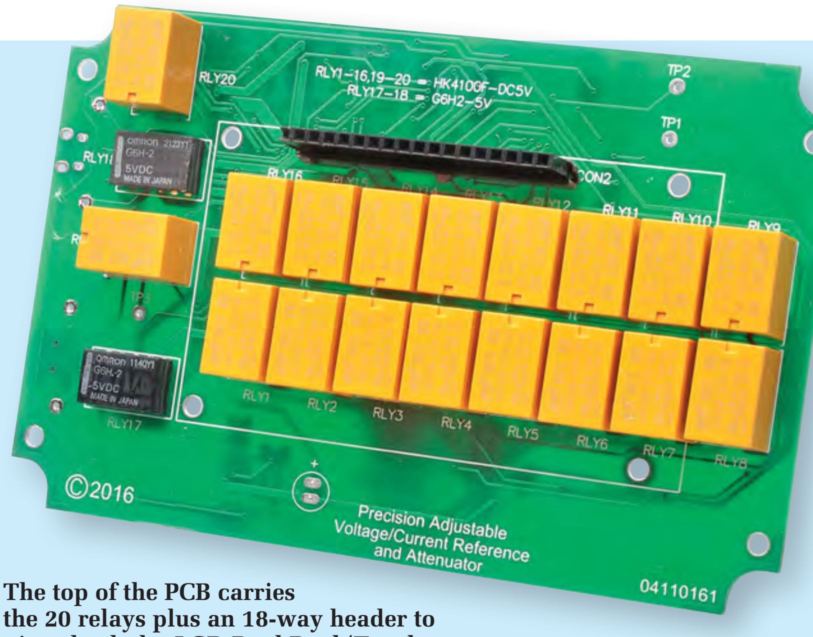
When V_{REF} = 2.5V, IC5a runs from the 5V supply via Schottky diode D1 and inductor L2, resulting in around 4.5V. Before the PGA gain is set above unity, pin 12 of CON2 is brought low, enabling boost regulator REG1. This lifts IC5a's supply voltage up to 39V [1.276V × (22kΩ ÷ 750Ω + 1)]. The operation of REG1 will be explained later.

Voltage divider

When relay RLY18's coil is energised, V_{REF} is connected to the top end of the R-2R divider ladder while the bottom end is connected to GND. On the PCB, the GND connection is routed so that no additional current will flow along this path, ensuring accuracy – just that passing through the ladder.

The ladder itself consists of 47 12kΩ 0.1%-tolerance resistors, chosen for the reasons explained earlier. Relays RLY1-16 connect various points in the R-2R ladder to either GND or V_{REF}. Depending on which combination of these relays are energised, the ladder output at TP3 ranges between GND and just a tiny bit below V_{REF}. For example, if RLY16 is energised and the other 15 are not, assuming all components are exactly the expected value, that will give V_{REF} × 32768 ÷ 65,535 or just slightly more than $V_{REF}/2$ at TP3.

When RLY17 is not energised, this voltage is available at the OUT+ terminal. Normally, RLY19 will be energised and so the OUT– terminal will be connected to GND.



The top of the PCB carries the 20 relays plus an 18-way header to piggy-back the *LCD BackPack/Touchscreen*.

Output buffering

When RLY17 is switched on, the voltage at TP3 is routed to the non-inverting input of op amp IC5c, another high-precision op amp. At the same time, this op amp's output is connected to the OUT+ terminal, via RLY20's normally-closed contact and a 47Ω resistor. This buffers the ladder output voltage, so that a few milliamps going into or out of the OUT+ terminal will have no effect on the voltage.

The 47Ω resistor prevents any capacitance at the OUT+ terminal from destabilising op amp IC5c. This would normally cause a voltage shift, however, this op amp stage actually has 'zero DC output impedance' due to the 10kΩ resistor between the output end of the 47Ω resistor and the inverting input. In other words, DC feedback comes from the output end of the 47Ω resistor. But AC feedback comes from the other end, via a 47pF capacitor, so the op amp still benefits from the stability improvement provided by the 47Ω resistor.

Current sink and source

In current reference mode, RLY20 is energised. The OUT+ terminal is then connected to the drain of N-channel MOSFET Q1 and its source is connected to GND (and then to OUT–) via a nominal 0.1Ω shunt. The voltage from this shunt is proportional to the current sunk by Q1 and this is fed back to the inverting input of IC5d, another precision op amp stage, via an RC filter.

The non-inverting input of this op amp, pin 12, is connected to the output of buffer stage IC5c via a 1kΩ resistor. So, as an example, let's say V_{REF} = 2.5V and the R-2R ladder is set up to divide this by 100, ie, with 25mV at TP3. This 25mV is applied to pin 12 of IC5d.

IC5d then controls the gate of MOSFET Q1 to sink enough current so that 25mV appears across the 0.1Ω shunt, ie, 250mA. Thus, the current through the shunt (in A) is equal to the voltage at TP3 (in V) multiplied by 10.

A series/parallel combination of three resistors between the 2.5V reference output and the drain of Q1 provides a minimum current flow. This prevents Q1 from being switched off fully when Q1's gate voltage drops, which could cause overshoot upon recovery.

Similarly, zener diode ZD1 keeps Q1 in linear operation during those times when Q1 cannot sink the programmed current from the external voltage source. Once its gate voltage rises above 5.6V or so, Q1 is already switched on fully and ZD1 pulls its inverting input (pin 13) up to prevent any further rise in the output voltage at pin 14. This allows it to reduce Q1's conductance more quickly when current regulation resumes.

The 2.2kΩ/47pF filter in its feedback arrangement compensates for the phase shift due to Q1's gate capacitance and turn-on/turn-off time. Without these, the output at pin 14 would oscillate rather than reach a steady level to sink the required current. Essentially, the 47pF capacitor forms an AC feedback path between the pin 14 output and pin 13 inverting input, reducing gain to unity at high frequencies while leaving DC feedback high for precise current control.

Note that the 0.1Ω shunt resistor tolerance of ±1% means that the current reference will initially be much less precise than the voltage reference. But, if the shunt's resistance can be accurately measured, this can be programmed into the unit and the error calibrated out. More on how to do this later.

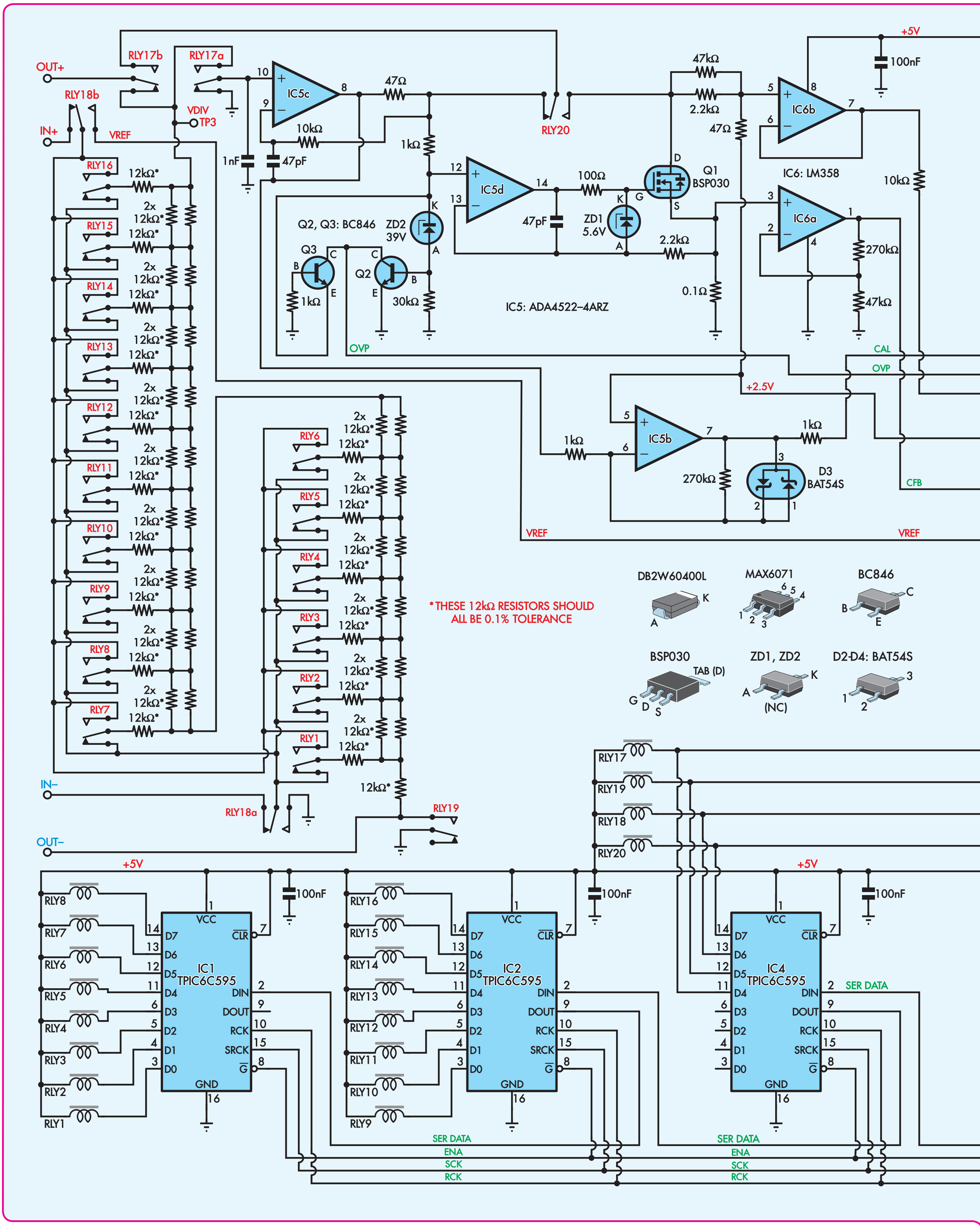
Note that while the circuit can only sink current, because the whole device is effectively floating (assuming the 5V supply is not earthed), it can just as easily be used as a current source, by connecting the OUT+ terminal to a positive voltage and then drawing current from the OUT– terminal. The circuit won't 'know' the difference.

Boost regulator

Before configuring the PGA to give a V_{REF} of 5V or higher, the PIC32 in the *Micromite LCD BackPack* brings pin 12 of CON2 high. This is normally held low by a 30kΩ pull-down resistor. When high, REG1 is activated. At first, nothing happens since its internal current source at pin 1 must charge a 1µF capacitor via Schottky diode D2. But once the voltage at that pin rises sufficiently, it will begin to periodically sink current from pin 8, with a frequency of around 560kHz and a duty cycle that starts very low and steadily increases.

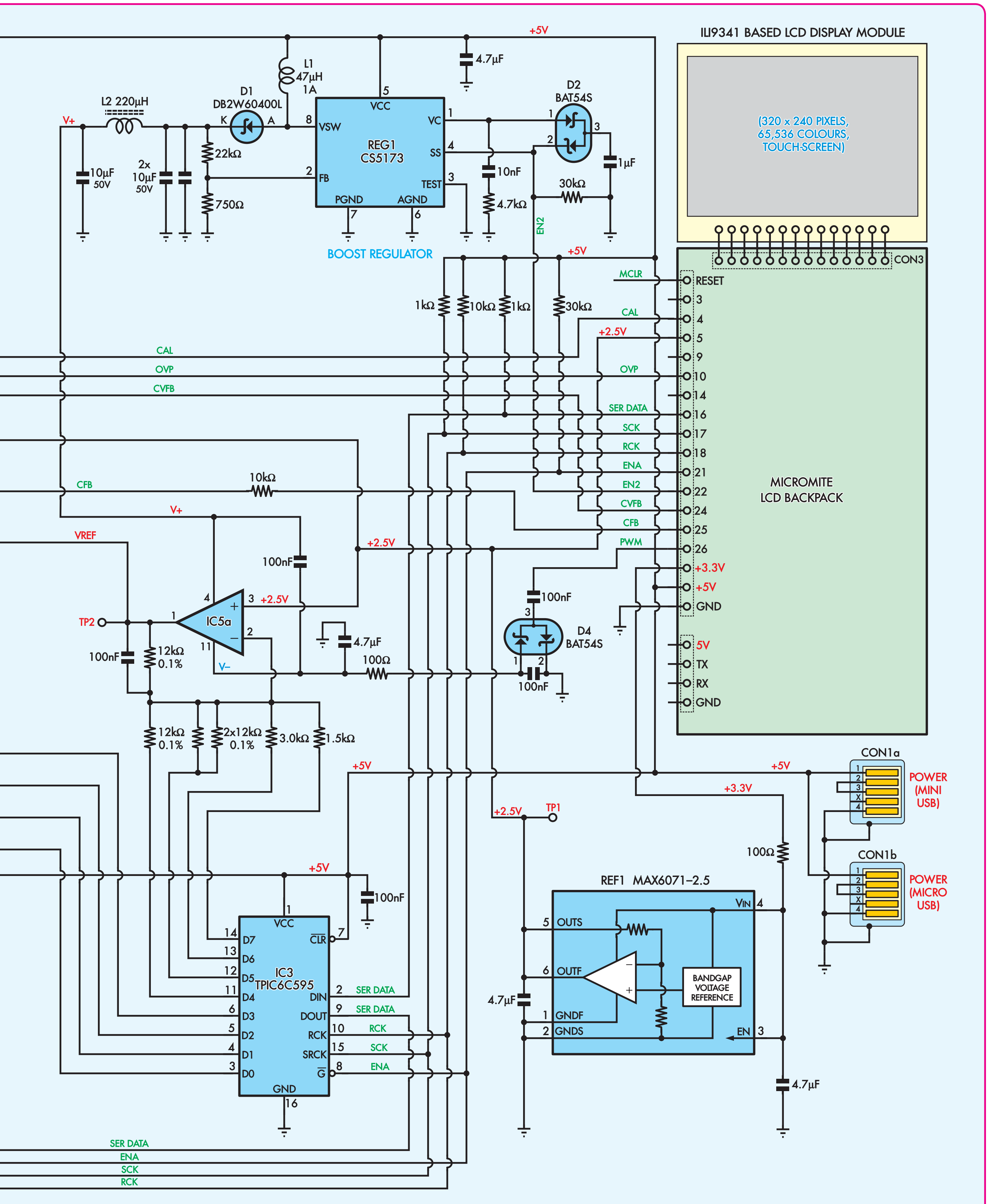
Each time REG1 brings pin 8 low, L1's magnetic field charges up. When it ceases sinking current from this pin, the voltage at pin 8 shoots up above the 5V supply, due to the magnetic field of L1 discharging. 2A, 60V Schottky diode D1 is forward-biased and the two parallel 10µF capacitors are charged up to a voltage which increases as the switching duty cycle builds.

Eventually, the voltage across these capacitors reaches 39V. The 22kΩ/750Ω divider across these capacitors results in a voltage of 1.276V at the feedback pin (pin 2) of REG1 for an output of 39V and when this is reached, REG1 dials back the duty cycle to keep



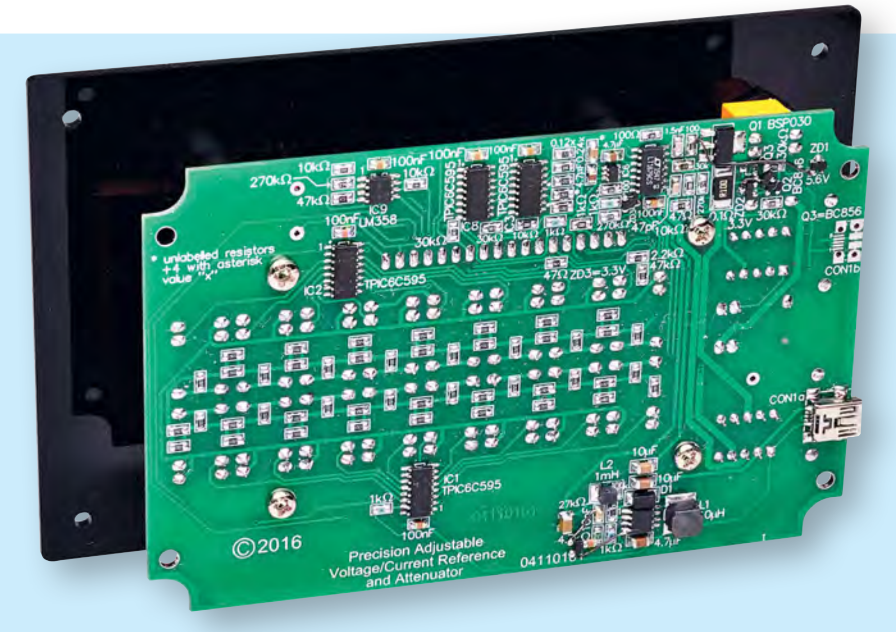
the output voltage steady. The 10nF capacitor and series 4.7kΩ resistor provide frequency compensation, to avoid oscillation in this voltage.

The 39V supply is filtered by 220µH inductor L2 and another 10µF capacitor, to remove as much of the switching residual as possible. Note that L2 has a DC resistance of around 17Ω, so it's effectively an RLC filter, ie, you can consider L2 as an ideal 220µH inductor with a 17Ω resistor in se-



PROGRAMMABLE PRECISION VOLTAGE & CURRENT REFERENCE

Fig.2: this is the complete circuit of the *Programmable Reference*, with the *LCD BackPack* and its associated PIC32 microcontroller shown in the upper-right corner. The precision attenuator (shown at left) is formed from 16 SPDT relays and 47 x 12kΩ ±0.1% resistors, with the control logic below. The switchmode boost converter, for reference voltages above 2.5V, is built around controller REG1, while the voltage reference is in the lower-right corner and the PGA above and to its left.



Most of the parts are mounted on the underside of the PCB (prototype board shown). Part 2 has the assembly details.

ries. This 39V supply powers quad op amp IC5 only.

Relay control

In addition to the 16 relays which are used in the R-2R divider ladder, four relays switch between the various modes; RLY17 and RLY18 are DPDT types, while RLY19 and RLY20 are the same SPDT types as used in the divider. All have 5V DC coils.

All 20 relay coils are driven directly from the 5V input supply rail and switched by one of three 8-way open-drain serial-to-parallel latches (IC1, IC2 and IC4). These are similar to the 74HC595, but have open-drain outputs rated to 33V/100mA with diode clamps to allow direct switching of inductive loads. Another identical IC, IC3, is used to switch the ground ends of the four PGA gain resistors. Note that while the coils of RLY17-20 are connected to outputs of both IC3 and IC4, only those outputs on IC4 are programmed to pull low by the software; the extra connections are simply there for PCB routing convenience.

While we're only using 24 of the 32 available outputs, we need four ICs rather than three. That's because if the same IC was used to switch relay coils and the PGA gain resistors, the ground shift caused by the much larger relay coil currents would affect PGA gain accuracy.

IC1-IC4 are daisy-chained with a single 3-wire SPI serial bus. Serial data is fed to pin 2 (D_{IN}) of IC3 and is shifted out eight clock cycles later at pin 9 (D_{OUT}). This signal is fed to IC4's D_{IN} and then on to IC2 and IC1 in a similar manner. Pin 15 of each IC is the data clock (SCK) and these are driven in parallel. Once 32 bits have been shifted through all four ICs, the parallel-connected RCK inputs (pin 10) are pulsed high, transferring that data to the output latches.

The fourth control line, $\overline{G}$ (pin 8) is also connected in parallel between the four ICs and this is pulled high initially by a 30kΩ resistor from the 5V supply, disabling all 32 outputs by default. It isn't until data is loaded into the output latches that the micro pulls this line low, enabling the ICs.

Since IC1-IC4 run off 5V and their inputs are not compatible with 3.3V logic levels, as used by the PIC32 micro, all four of these lines are driven by 5V-tolerant open-drain outputs on the micro, and each line has a pull-up resistor from the 5V supply. The lines driving the D_{IN} and SCK inputs have a 1kΩ pull-up resistor because these need to be switched at a much higher frequency than the other control lines (in other words, each is toggled up to 32 times when the relay and PGA states are to be updated, compared to once).

Protection circuitry

Several protection features prevent damage in case the device's outputs are back-driven by excessive voltages or currents, especially in current reference mode. If this happens, the outputs are disconnected by RLY17.

The maximum continuous current for Q1 is 5A, and in this case, the 0.1Ω 3W shunt dissipates $5A^2 \times 0.1\Omega = 2.5W$. But the dissipation in Q1 itself depends on both the current and its drain voltage. While it can handle more than 2.5W for short periods, in the long term, it can overheat.

The software keeps track of the drain voltage by monitoring the output of IC6b, which buffers a voltage derived from Q1's collector. The divider resistors at its pin 5 non-inverting input have an effective ratio of around 45 times and bias the result by 2.5V, allowing it to sense voltages from well below 0V up to about 36V.

This is important because if the drain is pulled below ground, Q1's parasitic diode could conduct a lot of current, quickly overheating it. So, if its drain goes below –0.5V or above its +30V rating, it is immediately disconnected.

The micro also monitors the current through Q1 via op amp IC6a, which amplifies the shunt voltage by a factor of 6.75, giving 675mV/A, allowing measurement of up to 5A. Again, should this limit be exceeded, the output will immediately be disconnected.

While operating as a current reference, the micro subtracts the implied shunt voltage (ie, 0.1Ω times the measured current) from the drain voltage and then multiplies this by the current to obtain the instantaneous dissipation. This is then integrated over time, with a thermal model allowing for heat to be radiated and conducted away from Q1.

The micro therefore continuously estimates Q1's junction temperature and can disconnect the output should it approach a dangerous level (>125°C). This allows relatively high dissipation to be maintained in Q1, for higher reference currents, as long as they are only brief tests. The user can safely connect the test load and allow the unit to disconnect before Q1 overheats. The estimated junction temperature is displayed on the TFT display while using the current reference mode.

Additional protection features operate when the buffered output is enabled. If OUT+ is pulled above 39.5V, zener diode ZD2 conducts and switches on NPN transistor Q2, pulling pin 10 on the Micromite low. It then switches off RLY17 to protect IC5. Similarly, if OUT+ is driven negative, Q3 switches on and also pulls pin 10 low.

Self-calibration support

The 2.5V reference's initial accuracy is good and it does not require calibration. However, should you have the equipment to accurately measure its output, the software will allow you to enter the exact measured reference voltage for improved precision.

Note that the PGA gain is not necessarily as accurate as REF1; it should be within ±0.25% with a V_{REF} of 5V, 7.5V or 10V due to the use of 0.1% resistors, but this is already worse than REF1's tolerance. At higher gains, the gain error could exceed 1%.

Fortunately, this can be automatically corrected by the software. It measures the actual PGA gain on each range the first time the unit is powered up and this can be repeated at any time, via the touchscreen user interface.

It works as follows. First, the PGA is set up for a gain of two, ie, V_{REF} = 5V. Then, relays RLY17, RLY18 and RLY19 are energised and the precision divider is set for a ratio as close to 2:1 as possible. In theory, this should result in a voltage very close to 2.5V at the output of IC5c, since the PGA's gain of two and the attenuator's gain of one-half should cancel out.

The difference in the output of IC5c and the output of REF1 is amplified by a factor of –271 by precision op amp IC5b and fed to pin 3 of CON2, which is connected to one of the Micromite's analogue inputs. Pin 4 of CON2 is connected to the 2.5V reference rail. The micro measures the voltages at pins 3 and 4 and compares them.

If the PGA's gain is actually greater than two then the output of IC5c will be more than 2.5V and so the output of IC5b will be below 2.5V (it's an inverting stage). The gain factor of 271 means that even though the micro's ADC only has 10-bit precision, the micro can accurately measure the error. It can then adjust the precision divider's ratio and re-measure, repeating this until the output of IC5c is as close to 2.5V as possible.

Then, by using the attenuation setting and the difference between the voltages at pins 3 and 4, the micro can calculate the exact voltage at V_{REF} when the PGA is set for a nominal gain of two. The software will then use this value to determine the correct divider ratio to get an accurate reference voltage between 2.5V and 5V.

This process is repeated for the other PGA gain settings; for example, PGA gain is set to three times (V_{REF} = 7.5V) and the attenuator is set to one-third; PGA gain is set to four times (V_{REF} = 10V) and the attenuator is set to one-fourth, and so on.

Note that this process takes a few seconds because the micro needs to wait for the output of the PGA to settle each time before performing measurements. The 100nF capacitor across its feedback resistor, required for stability and low-noise operation, does take a little time to charge (approximately one second).

Once all the PGA gain measurements are made, the results are stored in Flash memory for future use. They can be overwritten later if necessary. Similarly, if the user provides a more accurate measurement of REF1's output, this too is stored in Flash.

Changing the R/2R resistor ladder value

As mentioned in the text, the 12kΩ resistor value used in the divider ladder is not critical. If all the 12kΩ resistors are changed to another, similar value (eg, 10kΩ), you only need to change two additional components: the 3kΩ and 1.5kΩ resistors in the PGA. These should be as close as possible to 1/4 and 1/8 the ladder resistor value. For example, for 10kΩ ladder resistors, use 2.4kΩ and 1.2kΩ respectively.

Current mode calibration

The easiest way to calibrate the current sink is to use an accurate 4-wire resistance meter to measure the shunt's actual resistance and program this into the unit via the touchscreen. This is then stored in the micro's Flash memory and used to compensate the control voltage.

In theory, you could calibrate the unit by measuring the actual current sunk/sourced and adjusting the shunt value until it matches the set value. However, the average DMM only has a DC current measurement accuracy of ±1%, so that's a non-starter.

A more practical approach would be to purchase a 0.1% resistor of around 1kΩ. You would then check and possibly adjust your DMM's accuracy measuring 10V, using this unit. Next, set the unit to current mode and program it to sink 10mA, then apply 12V to OUT+ via the 1kΩ precision resistor. You can then adjust the unit's shunt value setting until you measure exactly 10V across this resistor (10mA × 1kΩ = 10V).

Part 2

In the December issue of *EPE* we'll describe how to assemble the PCB, attach the *Micromite LCD BackPack*, program it and mount it inside a box. We'll also show screen grabs and explain how to use it.

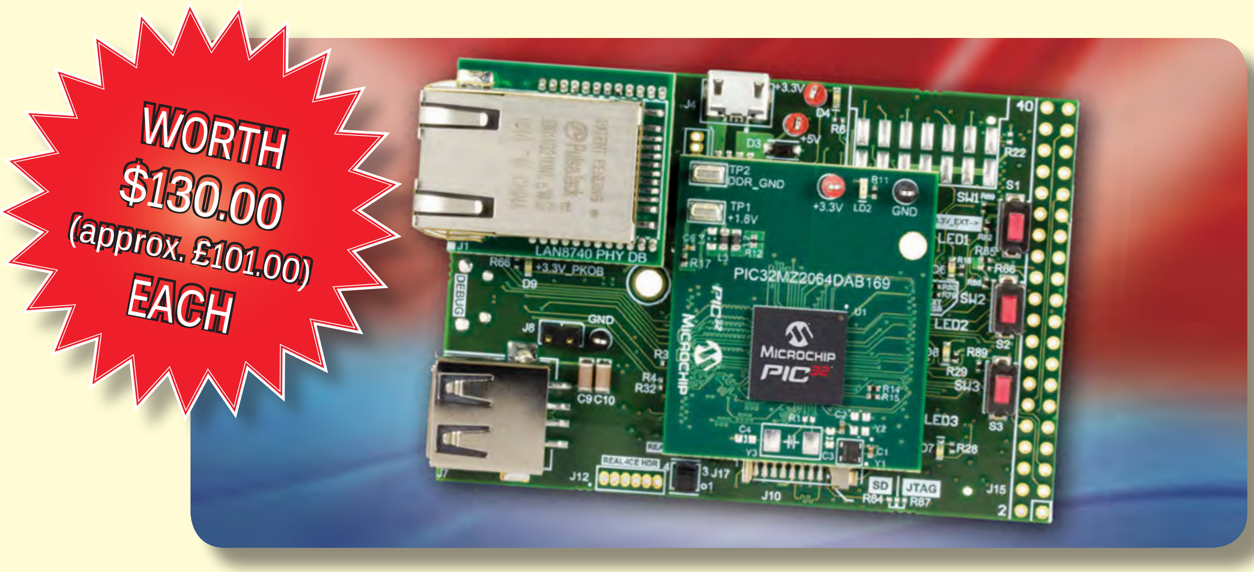
Win a Microchip PIC32MZ Embedded Graphics Starter Kit

EVERYDAY PRACTICAL ELECTRONICS is offering its readers the chance to win a Microchip PIC32MZ Embedded Graphics with Stacked DRAM (DA) Starter Kit (DM320010). This PIC32MZ Starter Kit provides the easiest and lowest-cost method to experience the high performance and advanced graphics integrated into the PIC32MZ DA MCUs. Microchip's PIC32MZ DA microcontroller family is the industry's first MCU with an integrated 2D Graphics Processing Unit (GPU) and up to 32MB of integrated DDR2 memory. This combination gives designers the ability to increase their application's colour resolution and display size (up to 12 inches) with easy-to-use MCU-based resources and tools. This kit provides an excellent board for development and testing of USB and Ethernet-based applications with graphical user interfaces.

The PIC32MZ DA family is supported by Microchip's MPLAB Harmony Integrated Software Framework, MPLAB X Integrated Development Environment (IDE), MPLAB XC32 Compiler for PIC32, MPLAB ICD 3 In-Circuit Debugger and MPLAB REAL ICE In-Circuit Emulation System. The PIC32MZ DA series, with its integrated graphics controller, graphics processor and 32MB of available on-chip DDR2 DRAM, lifts graphical user interface (GUI) designs to performance and quality levels not yet seen in embedded microcontroller applications. Developers that use the PIC32MZ DA in their designs should expect microprocessor-like graphics quality while still enjoying the ease of design of an MCU. And with MPLAB Harmony Graphics 2.0, designers can finish and display GUI design faster than ever thought possible.

The PIC32MZ Embedded Graphics with Stacked DRAM Starter Kit features a socket that can accommodate 10/100 Ethernet transceiver (RJ-45) plug-in connectors from various vendors for prototyping and development.

Package contains: • PIC32MZ DA Starter Kit board • LAN8740 PHY daughter board • Ethernet patch cord • Standard-A to micro USB cable.



HOW TO ENTER

For your chance to win a Microchip PIC32MZ Embedded Graphics with Stacked DRAM Starter Kit visit **www.microchip-comps.com/epe-pic32da** and enter your details in the online entry form.

CLOSING DATE

The closing date for this offer is 30 October 2017.

June 2017 ISSUE WINNER

Mr Marin Dolinar, from Karlovac, Croatia

He won a Microchip Dual Mode PICtail Board, valued at £70.00

Since the original Currawong amplifier was published in November and December 2015 and January 2016, it has created quite a deal of interest and those who have built it have been most enthusiastic. However, it had a complicated power supply employing two transformers – so now we present a much simplified circuit using a single power transformer, which also saves on the overall cost.

By
Leo Simpson

New Power Transformer for
The Currawong
2 x 10W Stereo Valve Amplifier

All electronic design work involves maximising performance from the cheapest, readily available components.

That certainly applied to the power and output transformers used in the *Currawong Stereo Valve Amplifier*. Each output transformer used in both channels was actually a 100V audio line transformer with the multi-tapped 100V windings being used to provide an (almost) ultra-linear connection to the plates and screens of the 6L6 beam tetrodes.

It works surprisingly well for a cheap transformer.

And while we would have preferred to use a single transformer in the power supply, the fact was, there simply wasn't a suitable unit available at the time.

So we ended up using two toroidal power transformers, rated at 160VA and 80VA. We had their secondary windings connected to provide 114VAC for the HT supply and 12V for the series-connected tetrode heaters and the 12V regulated DC rail. This rail runs the heaters for the 12AX7 dual triodes, relay speaker switching and remote control circuitry.

The new 160VA transformer from Altronics. Note that this is a pre-production sample and lead colours in the stock item may be quite different.

New transformer

But the original 160VA transformer has since been discontinued, so we have now arranged with Altronics Distributors (who stock the *Currawong* amplifier kit) to source a new single transformer, which will do the job by itself.

It is a 160VA toroidal unit (altronics.com.au – part MA5399) with two 115VAC 0.5A windings, two 6.3VAC 1A windings and a single 12.6VAC 2A winding. While that may seem like more windings than we actually need to run the *Currawong*, we have arranged it this way so that the transformer can be used in other applications, of which there are several (see panel).

However, the main game is to run it in the *Currawong*, as you can see from the power supply circuit shown in Fig.1.

Apart from the transformer connections and the connection for LK6, this circuit is identical

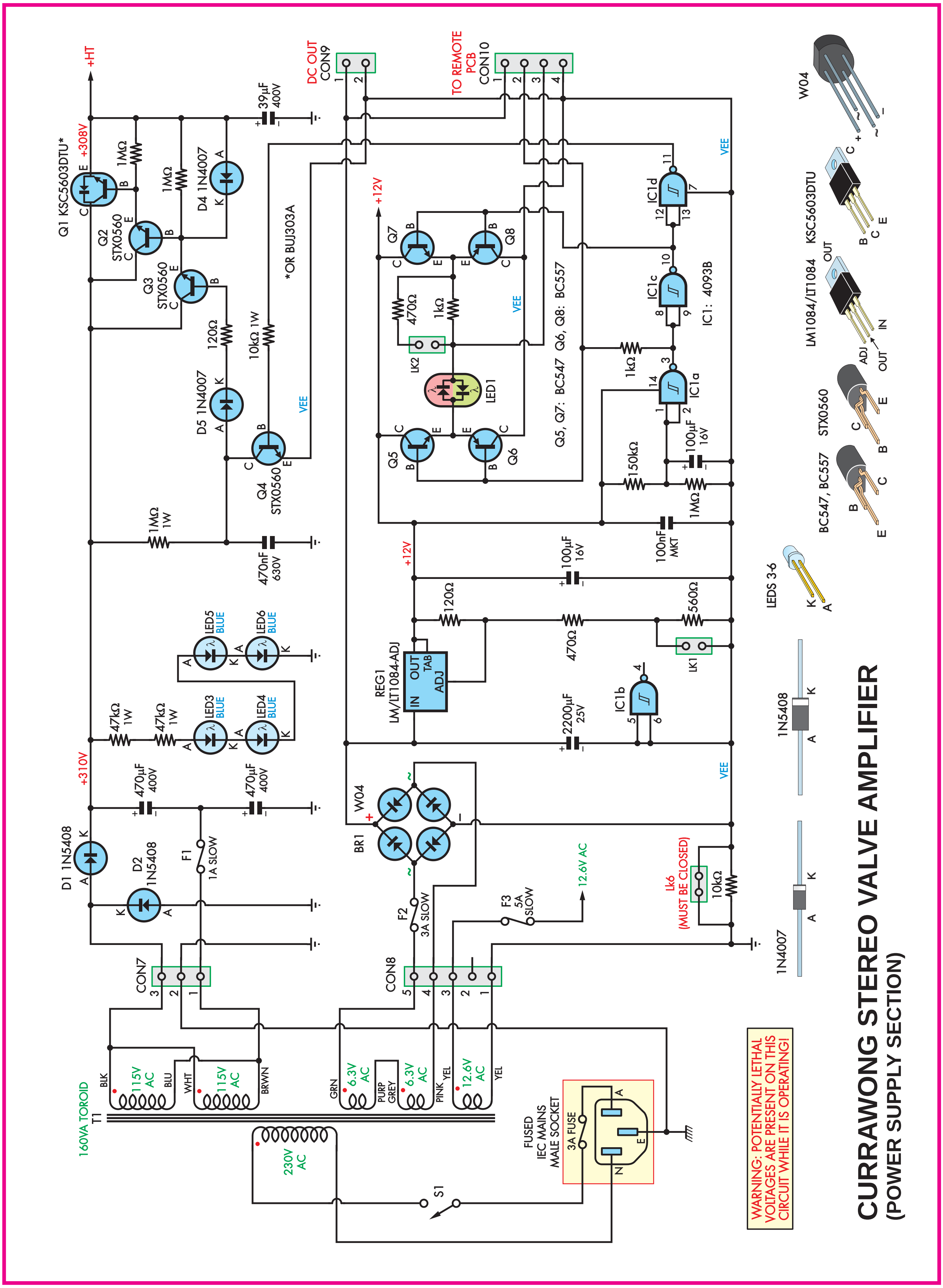


Fig.1: the 115VAC secondaries of transformer T1 are connected in parallel and rectified using a voltage doubler to produce a 310V HT rail. Most of the ripple is filtered out by a capacitance multiplier comprising high-voltage transistors Q1-Q3 and a 470nF polyester capacitor. T1's 12.6VAC secondary drives the 6L6 filaments directly in a series/parallel configuration. The two 6.3VAC windings are connected in series to drive bridge rectifier BR1, a 2200µF filter capacitor and linear regulator REG1 to produce a regulated 12V rail to run the 12AX7 filaments. IC1 provides an HT turn-on delay and soft start.

The new transformer mounted inside the same plinth which held the original two transformers. Again, ensure that any exposed mains wiring (for example, the IEC mains input socket) is properly covered, as shown here.

to the original version published in the November 2015 issue on page 16.

If you make comparisons between the two diagrams you will see that the connections for the new transformer are considerably simplified.

The two 115VAC windings are connected in parallel to pins 1 and 3 of CON7 and thence to the voltage doubler rectifier comprising diodes D1 and D2, together with the two 470µF 400V electrolytic capacitors.

The two 6.3VAC winding are connected in series and go to pins 4 and 5 of CON8 and then via a 3A slow-blow fuse F2 to bridge rectifier BR1. The single 12.6VAC winding is connected to pins 1 and 3 of CON8 and then via slow blow-fuse F3 to power the series-connected heaters of the 6L6 beam power tetrodes.

No change needs to be made to the componentry on the main PCB except for the fact that link LK6 must be fitted (the 10kΩ resistor that it shorts out can be omitted if you wish).

Wiring it up

Fig.2 shows the much simplified wiring inside the timber base of the *Currawong*, and you should compare it with the photo on page 42 of the December 2015 issue, which shows the same details.

The transformer should be located as shown in the wiring diagram and in the photo. Leave enough room between the transformer and rear panel so that you can later reach behind the main PCB as it's being slid in, and plug the various connectors into the underside (this requires more clearance than is available above the transformer).

We suggest a gap of no less than 60mm between T1 and the rear of the case. In practice, this means positioning the transformer mounting bolt so that it is approximately 120mm from the back edge of the plinth (ie, about 100mm from the inside rear edge).

Mount the transformer using the supplied rubber mounting washers, metal plate and washers via a 6mm hole drilled in the bottom of the plinth, but do not tighten the nut at this stage.

Then position the 9-way terminal block, as shown in Fig.2. Use two 12mm self-tapping screws to hold it in place.

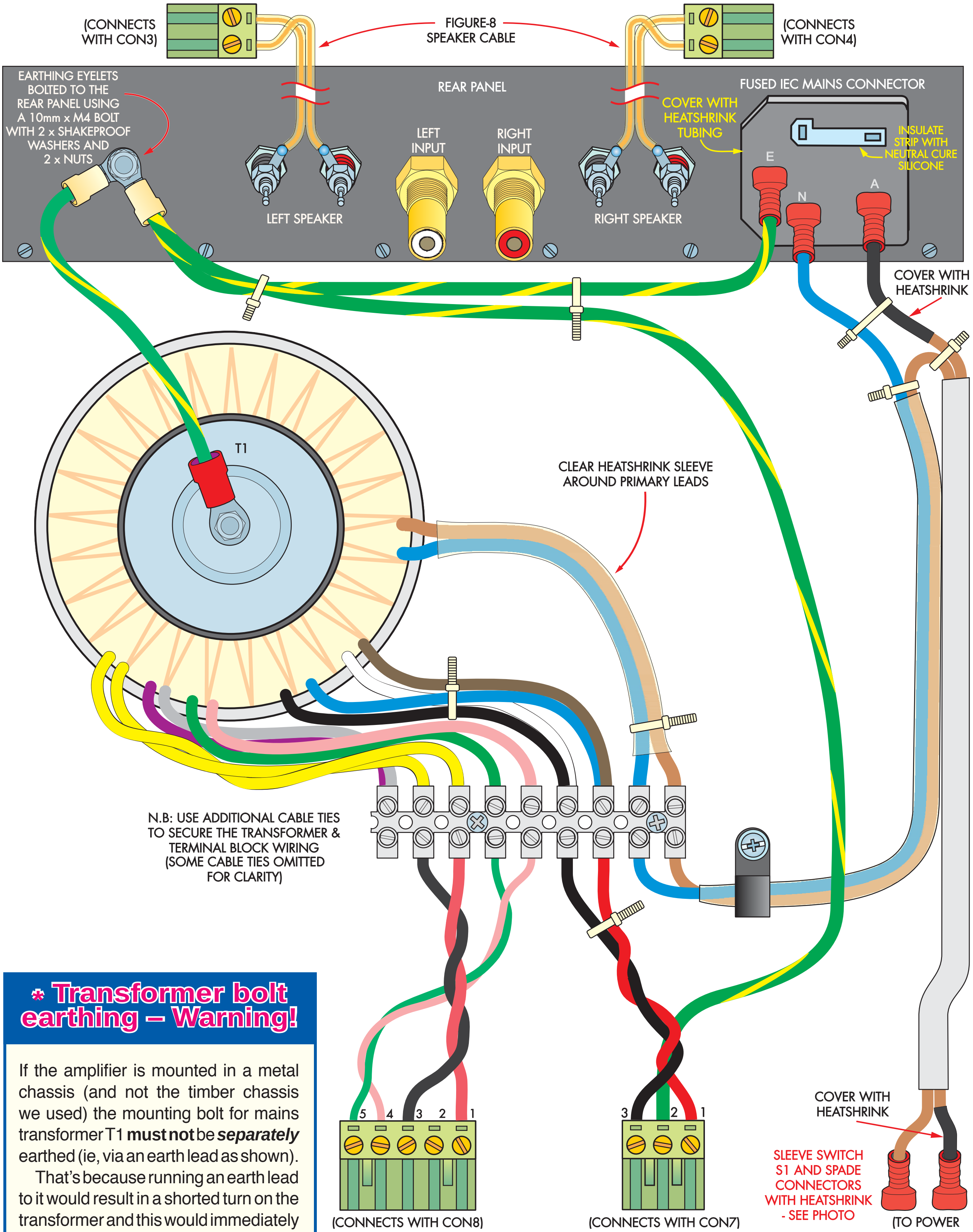
Wiring colours

It is important to note that the colours of the transformer connection wires shown in Fig.1 and Fig.2 are those on our pre-production transformer. It is likely that these may change in the production transformers. So while we refer to particular colours in this article, to match those shown in the photo, it is important to look at the labelling of the supplied transformer to identify the particular winding colours.

For example, although our prototype transformer had two red wires for the 230VAC primary winding, it is likely (and preferable) that the production version will have blue and brown wires.

With that in mind, cut a length of 5mm-diameter clear heatshrink tubing to cover the entire length of the primary winding wires, except for about 10mm at the ends. Then shrink the tubing down. Bend the wires so they run as shown on the wiring diagram and terminate them in the terminal block.

Now, twist the four 115VAC secondary wires together (black/blue and white/brown). This will help to minimise the radiated hum and buzz fields. Join the black and white wires together and connect them to one of the terminals of the 9-way terminal block. Then do the same with the blue and white wires. Doing it in this way means that both 115V windings have the starts and finishes connected together. If you don't do this right, one winding will effectively short the other and the transformer would very rapidly overheat and (hopefully) blow the fuse.



* Transformer bolt earthing – Warning!

If the amplifier is mounted in a metal chassis (and not the timber chassis we used) the mounting bolt for mains transformer T1 **must not** be ***separately*** earthed (ie, via an earth lead as shown).

That's because running an earth lead to it would result in a shorted turn on the transformer and this would immediately blow the fuse in the IEC socket.

The mounting bolt does **not** have to be insulated from the metal chassis if no earth lead is run.

Fig.2: the *Currawong* wiring diagram with a single power transformer. Compare it closely with the transformer wiring in the circuit of Fig.1. Note that the IEC socket must be covered with heatshrink tubing (see photo). This diagram assumes a *timber* cabinet as per our prototype – see warning above earthing if a metal chassis is used.

On the other side of the 9-way terminal block, the 115VAC red and black wires are terminated at pins 1 and 3 of the green connector, which mates with CON7 on the main PCB.

Now twist the four 6.3VAC wires (green, purple grey and pink) together in the same way and connect to the 9-way block. The green and pink wires provide 12.6VAC to pins 4 and 5 of the green connector, which mates with CON8 on the main PCB. Then twist the yellow 12.6VAC wires together and connect to the 9-way block. These provide 12.6VAC to pins 1 and 3 on the same green connector.

Once all the wires are in place, measure the resistance between pins 1 and 3 on the CON7 connector.

You should get a reading of about 5Ω. There should be an infinite reading between pins 1 and 2 and pins 2 and 3.

Similarly, between pins 1 and 3 and pins 4 and 5 on the CON8 connector, you should get a very low value; less than 1Ω.

Any higher readings than these suggests at least one wire is not making good contact in the terminal block, so go over them again.

From this point on, you can follow the original wiring and assembly instructions which were explained in the *Currawong* article in the December 2015 issue of *EPE*.

However, before making connections to the main PCB via CON3, 4, 7 and 8, we suggest that you connect power to the transformer and check the voltages present at the green connectors for CON7 and CON8.

Remembering that the transformer has no load at this stage, and assuming a mains input voltage of 230VAC, you should have about 127VAC at pins 1 and 3 of CON7 and 13.7VAC or thereabouts at pins 1 and 3 and 4 and 5 of CON8.

What else can you use this transformer for?

As described in the main article, the main application of this new 160VA toroidal transformer is to power the ***Currawong Stereo Valve Amplifier***. But it's quite a versatile transformer, offering a variety of other applications – nothing to do with the ***Currawong!*** Some of its possible uses include:

Isolation transformer

Fig.3(a) shows it with the two 115VAC windings connected in series so it can be used as a standard isolation transformer (ie, where you need to keep the device isolated from the mains supply) with a rating of about 150VA.

Stepdown transformer for 115V equipment

Fig.3(b) shows it with the two 115VAC windings connected in parallel so it can be used as a 230VAC to 115VAC transformer to run equipment rated up to about 150VA.

Voltage adjustment for high (or low) mains

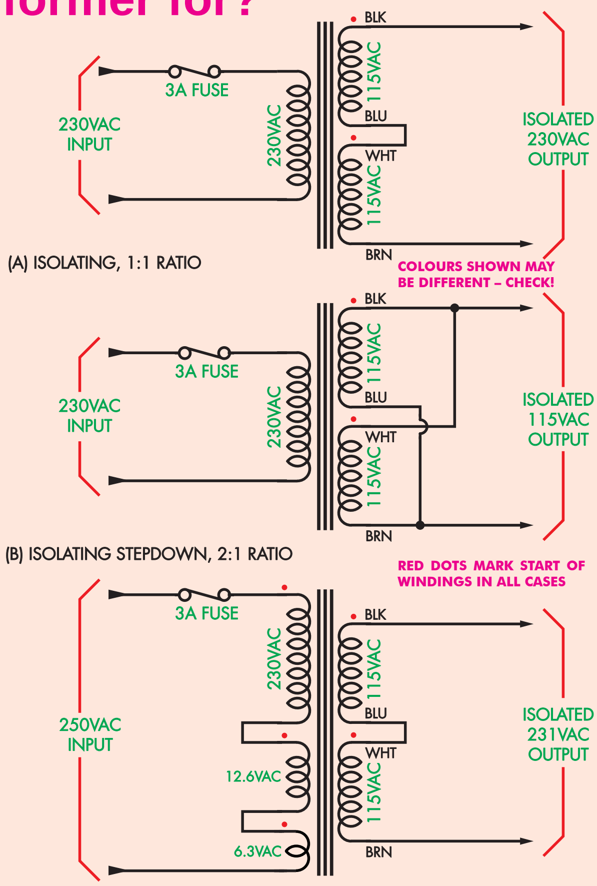
Fig.3(c) shows it with one 12.6VAC winding and one 6.3VAC winding connected in series across the incoming mains (primary) winding and with the two 115VAC windings connected in series.

You would use this connection if your mains voltage is very high at around 250VAC or more and you want to improve the reliability of connected equipment by running it at a much safer 230VAC, or thereabouts.

This arrangement can yield other voltages, eg, by using only one of the 12.5VAC or 6.3VAC windings in series with the primary (to yield a slightly higher output voltage than shown here) or connecting one or more of the low-voltage windings in series with the 115VAC secondaries to step up the output voltage (eg, if you have a consistently low mains voltage).

However, you must ALWAYS check (carefully!) that you have the phasing of the windings correct – if the transformer gets hot or hums loudly, chances are they're wrong!

Above all, remember that you are dealing with lethal voltages!



The transformer's Altronics catalogue number is MA5399.

Micromite Plus Explore 100

Part 2:
By Geoff Graham

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

THE ASSEMBLY of the *Explore 100* is straightforward, with all parts mounted on a 4-layer PCB, measuring 135 × 85mm. This board mounts on the back of a 5-inch touchscreen LCD panel and plugs directly into a matching pin header on this panel.

Other LCD panels of various sizes can also be used, but some of these have to be connected to the *Explore 100* via a flat ribbon cable, as described later.

Fig.2 shows the parts layout on the PCB. There are only four surface-mount parts: the Micromite Plus PIC32 microcontroller, its core filter capacitor, reverse-polarity protection MOSFET Q1 and the USB socket. The remaining parts are all through-hole mounting types.

A complete kit (minus the LCD) is available from **micromite.org**, as are various individual parts. You can also purchase the PCB separately (with or without the SMDs pre-soldered).

The PIC32 chip has a pin spacing of 0.5mm and can be soldered with a standard soldering iron. The recommended soldering technique was described for the *Explore 64* in the August issue, so we won't repeat it here. Just remember to use plenty of flux and keep only a very small amount of solder on the iron's tip.

Following the microcontroller, you should then solder the IRF9333 MOSFET (Q1), the mini USB connector and the 10µF SMD capacitor. The recommended technique for all of these was also described in August.

If you aren't fitting Q1 then bridge the solder pads, which would normally be underneath it. This will directly connect the 5V input to the rest of the *Explore 100*.

When fitting the remaining components, use the normal approach of inserting and soldering the low-profile components first (ie, starting with the resistors) and then working up to the taller items such as the header sockets.

When you come to crystal X1 you should mount it one or two millimetres off the PCB so that there is no danger that the metal case could short out the PCB's solder pads. Alternatively, use a plastic mounting pad for the crystal as we did.

Regulator REG1 can be attached to the PCB using an M3 × 6mm machine

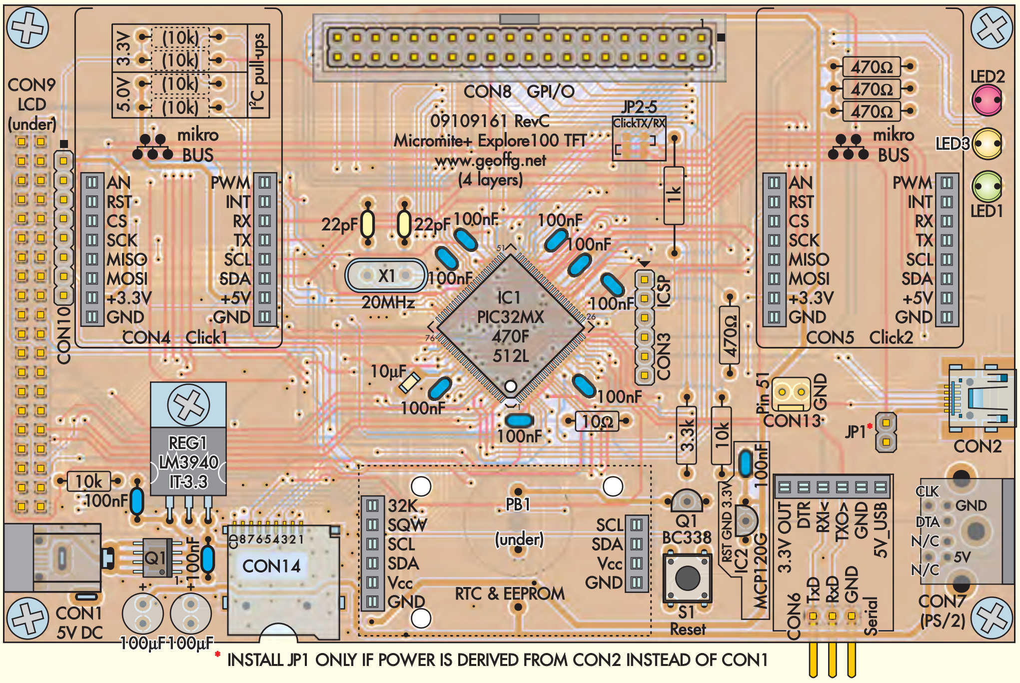
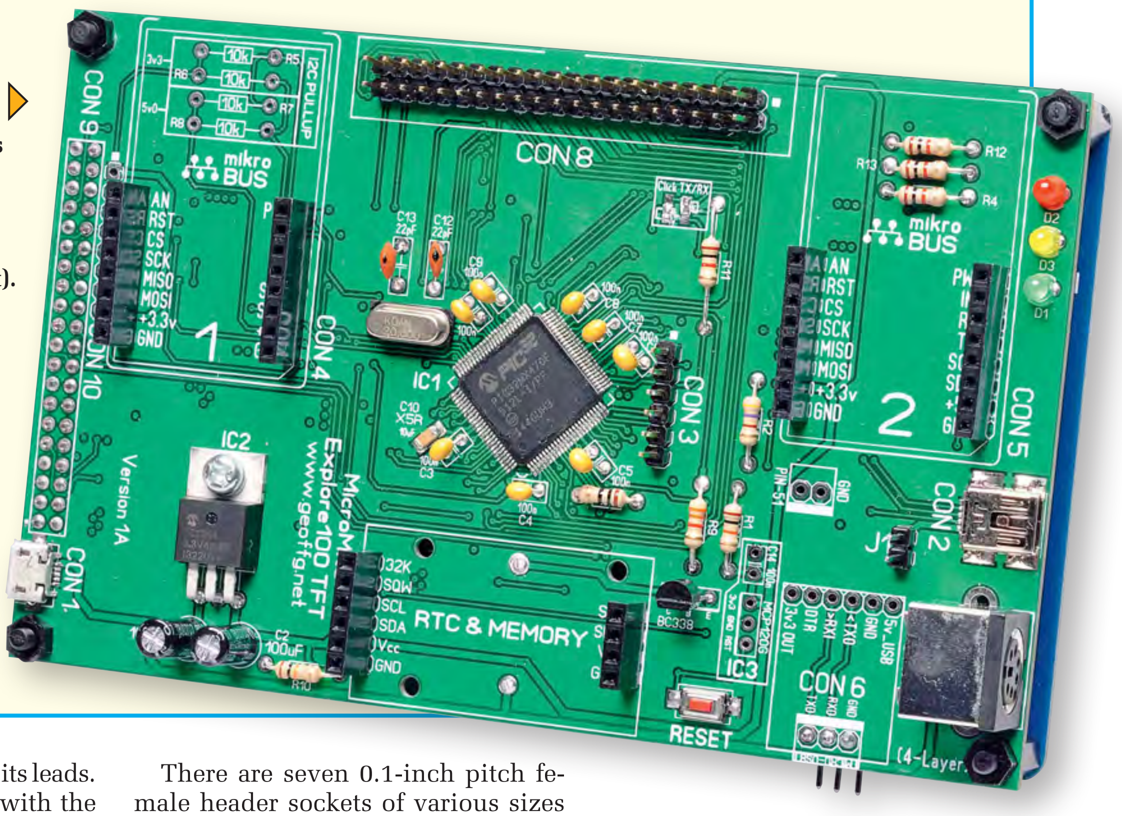


Fig.2: follow this parts layout diagram to build the PCB. *The Explore 100* uses mostly through-hole components, with just four surface-mount parts (including the PIC32 micro). Note that the diagram to the left shows a protoype. The version supplied from micromite.org will not include CON14. Constructors who wish to use an SD card (when not using the E100 with a TFT) can directly plug in an optional SD card module to CON10, also available from micromite.org



This photo shows an early prototype version of the *Explore 100*. The PCB uses four copper layers and was designed by Graeme Rixon of Dunedin, NZ. Be sure to install the PIC32 microntroller first (see text).

screw and nut before soldering its leads. It should be in good contact with the PCB, so that the top copper layer acts as a heatsink.

There are a group of closely-spaced pads on the PCB marked 'Click TX/RX' (JP2-5). These pads allow you to reverse the serial Tx and Rx lines for Click boards. **Normally though, you will want the two pairs of pads joined which are marked with brackets, so solder across these pads initially.**

The piezo buzzer mounts on the underside of the PCB. There is provision for two different types: a large 23mm buzzer for noisy locations and a smaller 14mm device for normal use.

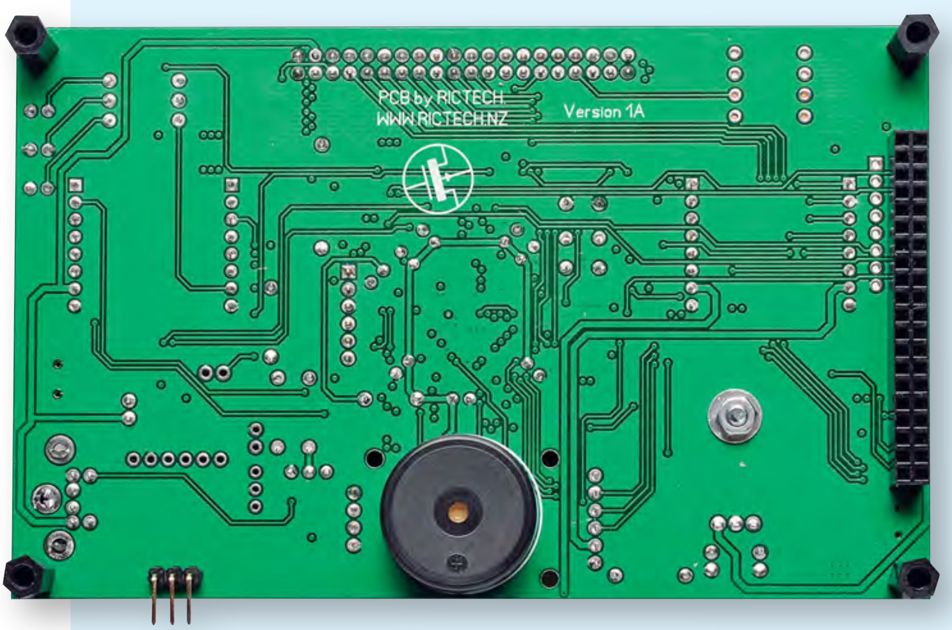
There are seven 0.1-inch pitch female header sockets of various sizes on the board. They can be sourced individually but it is simpler to use the more readily available 50-pin single row header sockets and cut them to size. This can be done using a pair of side-cutters to cut the middle of one pin (thereby sacrificing that pin). The resultant jagged ends can be smoothed with a small hand file.

The Microchip MCP120 reset supervisor is only required as a protection against power supply issues, so it and its associated 100nF capacitor are optional. The specified MCP120 is in a TO-92 package, so be careful to not confuse it with the BC337/338 transistor, which is also in a TO-92 package.

Real-time clock module

The *Explore 100* has provision for a real-time clock (RTC) module. This is optional but we strongly recommend it, since without it, the time setting of the Micromite Plus will be lost on power-up or reset.

Use a module that's based on the Maxim DS3231 IC as these are accurate and low in cost. They are available from places like eBay, AliExpress and **Banggood.com**. Search for 'DS3231'. If you are purchasing online, make sure that the module matches our photograph so that it will fit the footprint on the PCB.



The piezo buzzer and the 40-way connector for the LCD panel mount on the rear of the PCB. The connector plugs directly into a matching pin header on the back of the 5-inch LCD panel (see photos and page 37, August 2017).

To prepare the module for the *Explore 100*, you need to solder a 4-pin header to the underside of the module at one end and a 6-pin header at the other end. Some modules come with a pin header soldered to the top of the module and that will need to be removed first. Also the small diode next to the RTC chip must be removed. With these modifications complete, it's then just a case of plugging the module into the socket and running the configuration commands listed later in this article. Alternatively, a pre-prepared RTC module is available from **micromite.org**

Display mounting

If you are planning on using a 5-inch display, you should solder a 40-pin dual-row female header socket **on the underside** of the board at the position marked CON9 (see photo above). Then, the *Explore 100* can mount on the back of the display using either four M3 ×12mm tapped spacers and eight M3 × 6mm machine screws, or four 12mm untapped spacers and four M3 × 16mm machine screws and nuts.

This is the RTC module that the *Explore 100* is designed to use. It employs the Maxim/Dallas DS3231 which can keep the time to better than ±2ppm and its battery back-up facility will retain the time during power outages. Note that the existing pin header has to be removed and two straight pin headers soldered to the underside of the PCB at both ends of the module.

The *Explore 100* will also plug directly into a 4.3-inch or 7-inch display, but the mounting holes for the display will not line up. If you want to use one of these displays, a better solution would be to mount the display panel separately from the PCB and then use a 40-way ribbon cable fitted with IDC connectors to join them.

If you are using a ribbon cable, you will need to use a 40-pin male header plug for CON9. Incidentally, the required cable is the same as the old IDE hard disk cables used in old PCs, so you might already have a suitable cable ready to go. This cable should be as short as possible, ideally under 120mm. This is because the LCD panel can draw a lot of current (up to 750mA) and a large voltage drop in the ground wire can upset the logic levels seen by the LCD and the Micromite.

Testing and fault-finding

The test procedure described in the August 2017 issue for the *Explore 64* also applies to the *Explore 100*, so we'll just summarise the steps required. First, if not already programmed, the microcontroller must be programmed with the Micromite Plus firmware using a PIC32 programmer such as the PICkit 3. You then connect a USB-to-serial converter to the console (see August issue) and check that you can get the MMBasic command prompt.

Fig.3: When you have configured the *Explore 100* as a stand-alone computer (OPTION LCDPANEL CONSOLE), pressing the Reset Button should reward you with the MMBASIC start-up banner, along with the command prompt, being shown on the LCD panel.

If you do not see this prompt, the fault could be with the Micromite or your connection to the console. First measure the current drawn by the *Explore 100* without the display or any Click boards attached. It should be 90-100mA after IC1 has been correctly programmed with the Micromite Plus firmware. Anything greatly more or less will indicate that you have a problem.

For example, a current drain of less than 15mA indicates that the MMBasic firmware has not been loaded or is not running.

Basic fault finding essentially involves checking that the correct power voltages are where you expect to see them, that the 10µF SMD capacitor (connected to pin 85) is present and correct, the crystal and its associated capacitors are correct and that all of IC1's pins have been correctly soldered. Also, make sure that you have properly programmed the firmware.

If the current drain is about right, then the fault is almost certainly with the USB-to-serial converter that you are using and its connections to the *Explore 100*. Again, refer to the August issue for the fault-finding procedure.

Configuring the touch-screen

Micromite Plus features can be enabled or disabled via OPTION commands which are saved in non-volatile memory inside the chip and automatically re-applied on start-up. These commands must be entered via the console (serial or USB).

With the command prompt displayed in the terminal emulator window, the first step is to configure the display. Enter the following command at the prompt:

```
OPTION LCDPANEL SSD1963_5,
LANDSCAPE, 48
```

This tells the Micromite that a 5-inch display is connected in landscape orientation and that pin 48 is used for backlight control. Other options are available for the LCD panel size, orientation and backlight control. Please refer to the *Micromite Plus User Manual* for details.

You can now test the LCD panel by entering the command:

GUI TEST LCDPANEL

This will continuously draw a sequence of overlapping coloured circles. To terminate the test, press the spacebar.

The next step is to configure the touch interface. Even if you are not going to use the touch facility in your programs, you will still need to set it up. That's because the touch controller will interfere with access to the SD card if it is physically present but not configured. To set this up, enter the following command:

OPTION TOUCH 1, 40, 39

This specifies that pin 1 is used for the touch controller's chip select line, that pin 40 is used for the IRQ (interrupt request) signal and that pin 39 controls the buzzer. The touch sensing then needs to be calibrated and this is done with the following command:

GUI CALIBRATE

The screen will display a target in the top left corner. Using a pointy but blunt stylus, press on the exact centre of the target. After a second, the display will blank and then present the next target on the top right. Work around all four corners in this manner to calibrate the display.

When you have finished, the Micromite should respond with 'Done. No errors' or you might get a message indicating that the calibration was not accurate. You can ignore this if you wish, but it would be better to redo the calibration, taking more care the second time. You can test the touch feature with the command:

GUI TEST TOUCH

This will blank the LCD and when you touch it, the Micromite will draw a dot at the location that it has determined you touched. If your calibration was accurate, the dot should appear directly under the spot that you touched. Press the spacebar on the console's keyboard to return to the command prompt.

Configuring the SD card

The next step is to configure the *Explore 100* to use the SD card socket that's mounted on the LCD panel. The required command is:

OPTION SDCARD 47

This specifies that pin 47 is connected to the chip select signal. **Alternatively, if you are using the external SD card module (plugged into CON10), the chip select will be pin 52 instead.** CON10 has pin 53 connected to the Card Detect switch, so you can also specify this if desired. CON10 also provides a connection to pin 17 for the Write Protect/read-only (WP) pin, if used. Refer to the circuit and to the *Micromite Plus User Manual* for more details.

To test the SD card, use the **FILES** command which will list all the files and directories on the card.

If you have installed a real-time clock (RTC), this must also be made known to MMBasic. The command to do this is:

OPTION RTC 67, 66

The command defines the I/O pins used by the RTC and instructs MMBasic to automatically get the correct time from the RTC on power-up or restart. You then need to set the time in the RTC, as follows:

RTC SETTIME year, month, day, hour, min, sec

Note: time must be in 24-hour format.

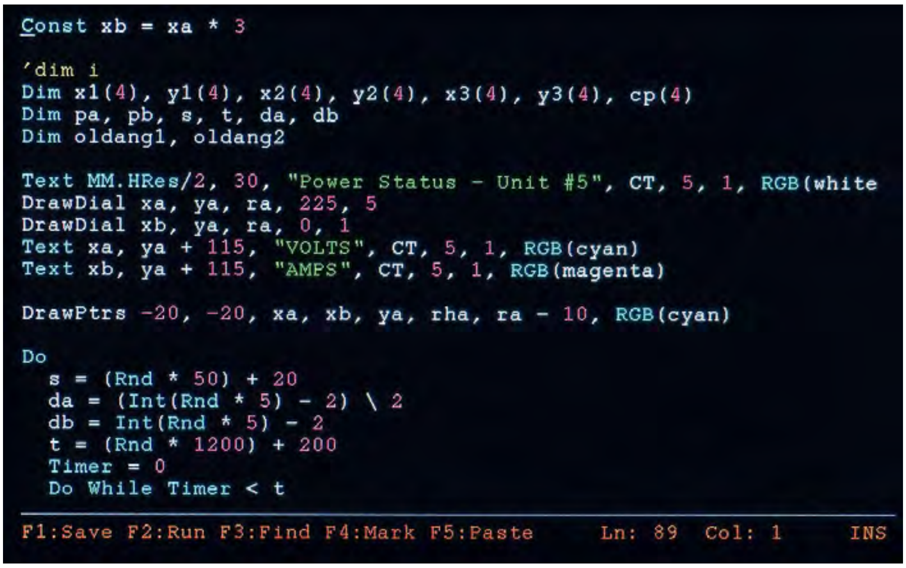


Fig.4: a nice feature of the Micromite Plus is the in-built program editor. This can edit a program in one session and its use will be familiar to anyone who has used a standard editor (eg, Notepad in Windows). As shown, it colour-codes your program; with keywords in cyan, numbers in pink, comments in yellow and so on.

Self-contained computer set-up

Before you can use the Micromite Plus as a self-contained computer, you will need to run some more configuration commands. The first is to tell the Micromite Plus to echo all console output to the LCD panel. The command to do this is:

OPTION LCDPANEL CONSOLE

Following this command, you should see the command prompt (>) appear on the LCD panel. If you now try typing something on your terminal emulator, you will see that these keystrokes are echoed on the LCD screen.

Next, you need to tell the Micromite Plus that a PS/2 keyboard is connected using the following command:

OPTION KEYBOARD UK

At this point you should be able to type something on the keyboard and see the result on the LCD screen. For example, try entering PRINT 1/7 and MMBasic should display 0.142857.

When you set up the keyboard, you also have the choice of a number of different keyboard layouts. The command above specifies the UK layout, but other layouts that can be specified are United States (US), French (FR), German (GR), Belgium (BE), Italian (IT) or Spanish (ES).

All these configurations are saved in non-volatile (Flash) memory and will be automatically recalled on power-up or reset.

Now disconnect the serial console and cycle the power. The unit will start up and display the MMBasic banner and copyright notice on the LCD, followed by the command prompt.

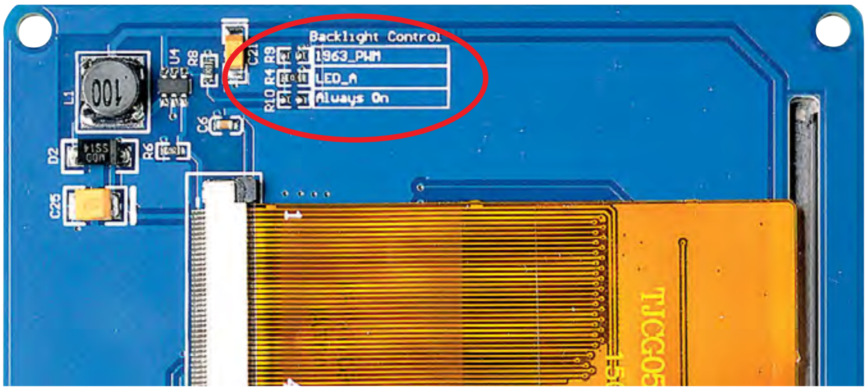
You might wonder if the USB interface needs setting up – this is not necessary. The Micromite constantly monitors the USB socket and if it detects that it is connected to a host, it will automatically change its configuration to suit.

Further options

Some of the above configuration commands have additional options. These are not important but we list them here in case you want to experiment with them. The command for directing the console output to the LCD panel has four optional parameters. The full command is:

OPTION LCDPANEL CONSOLE font, fc, bc, blight

- 'font' is the font to be used on power-up. The Micromite Plus has five



As explained in the text, if you move the 0Ω resistor from position 'LED_A' to '1963_PWM' you will be able to control the display's brightness in 1% steps. This photograph shows the back of a 5-inch display, but the other display sizes each have a similar set of jumper positions.

suitable fonts built in and numbered 1 to 5, with the larger numbers designating a larger-sized font. If the font is not specified then it will use font number #2.

- 'fc' and 'bc' are the default foreground and background colours to be used on power-up. If you like yellow letters on a blue background (ugh), this is how you do it. Refer to the MMBasic User Manual for details on the RGB() function that can be used to specify colours.
- 'blight' is the LCD brightness setting to be used on power-up. By default, the Micromite Plus will set the LCD's backlight to full brightness, but this can consume a lot of power (up to 500mA). Reducing it will only make a small difference to the perceived brightness but will considerably cut the display's power consumption.

The backlight's power requirement can be important if you are building a portable computer using the Micromite Plus. Setting the brightness to one third (ie, 'blight' set to 33) will almost triple the battery life while still being bright enough for normal use.

LCD backlight

The LCD panels used with the *Explore 100* have two methods of regulating the backlight intensity. Both methods use a pulse-width modulated (PWM) signal to rapidly switch the backlight on and off. The first requires the Micromite to generate this signal on the pin marked 'LED_A' on the LCD's interface connector. The second requires the Micromite to send a command to the SSD1963 display controller, requesting it to generate the required PWM signal.

Either will work, but the advantage of using the SSD1963 to do it is that it can vary the brightness with a finer degree of resolution (1% steps), whereas the Micromite-generated signal has a coarse control (5% steps). The difference is not normally noticeable but it can be important if you want to smoothly vary the brightness up or down for a special effect.

By default, the LCD panel will be configured for the Micromite control but you can change it with a soldering iron. As shown in the above-left photo, the LCD panel will have an area on its PCB marked 'Backlight Control'. To use the SSD1963 for brightness control, the 0Ω resistor should be moved from the pair of solder pads marked 'LED-A' to the pair marked '1963_PWM'.

Fig.5: Explore 100 I/O pin allocations (CON8)

	Pin No.	Pin No.	
Ground		97	5V
5V Output		96	5V
3.3V Output (200mA max.)		95	5V
Count - Wakeup - IR - ANA	78	92	5V
ANA	77	91	5V
Count - ANA	76	90	5V
ANA	44	88	5V - COM1 Rx
COM1 Enable - ANA	43	81	5V - Count
ANA	41	80	5V
ANA	35	79	5V - PWM 1C
Count - ANA	34	74	5V - PWM 1A
ANA	33	72	5V – SPI OUT (MOSI)
ANA	32	71	5V – SPI IN (MISO)
COM3 Rx - ANA	26	70	5V – SPI Clock
COM3 Tx - ANA	25	68	5V – PWM 1B
COM1 Tx - ANA	24	67	5V - I^{2}C DATA
COM2 Rx - ANA	22	66	5V - I^{2}C CLOCK
ANA	21	61	5V
COM2 Tx - ANA	20	60	5V
ANA	14	59	5V

(1) Pin No. refers to the number used in MMBasic to identify an I/O pin.
(2) All pins are capable of digital input/output and can be used as an interrupt pin.
(3) ANA means that the pin can be used as an analogue input.
(4) 5V means that the pin is 5V input tolerant.
(5) COUNT means that the pin can be used for counting or frequency/period measurement.

Programming the I/O pins

Fig.5 shows the pin allocations for CON8, the 40-pin I/O connector. Each pin can be independently set as an input or an output and any pin can generate an interrupt to the running program on a rising or falling signal, or on both. Note that the I^{2}C, SPI and COM3 serial interfaces are shared with the Click boards, if one of these is installed.

The connection between a Click board and the *Explore 100* is via two eight-pin headers which carry the three communications interfaces (I^{2}C, SPI and serial), some general-purpose signals (analogue, PWM, interrupt) and 3.3V and 5V power. The Click boards require either a 3.3V or 5V power supply, and the *Explore 100* supplies both. In addition, the outputs from the Click boards connect to 5V-tolerant inputs on the PIC32, so you can use 3.3V or 5V click boards without concern.

Fig.6 shows the I/O pin allocations for the two Click board sockets. The I^2C, SPI and serial buses are common between the two sockets, while the other signals (analogue, PWM) are separate.

As previously mentioned, the PCB includes a set of solder pads which can be used to reverse the serial signals used for the Click boards. These are marked 'Click TX/RX' and normally you should jumper the solder pads marked on the silk screen with brackets. However, there is a chance that some Click boards will have their transmit (Tx) and receive (Rx) signals swapped and you can accommodate these by moving the solder blob to the other solder pads.

When it comes to programming for the Click boards, it is normally a case of consulting the data sheets for the device on the board. MikroElektronika often offer one or more example programs written in their mikroBasic language and these can easily be converted to MMBasic for the *Explore 100*.

Another feature of the PCB is the two general-purpose indicator LEDs described earlier. The yellow LED (LED3) is controlled by Micromite pin 38 and the red LED2 by pin 58. Note that the BASIC program needs to set the output low to illuminate these LEDs. On power-up, these pins will be in a high impedance state so the LEDs will default to off.

We hope you enjoy assembling and using the extremely powerful *Explore 100* module. If you do run into any issues then the team at **micromite.org** will be happy to help you out. Simply drop them an email to: **epe@micromite.org**, with the subject 'HELP'. Have fun!

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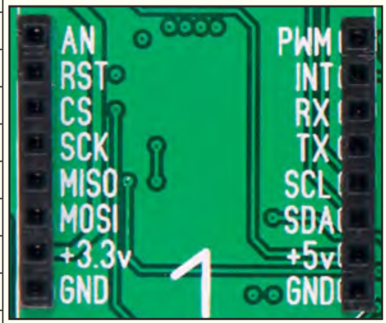
Fig.6: Click board pin assignments

Click Board 1 Socket

	Pin No.	Pin No.	
ANA	23	82	5V – PWM 2A
	29	8	5V
	28	26	COM3 Rx
SPI Clock – 5V	70	25	COM3 Tx
SPI In (MOSI) – 5V	71	66	5V – I^2C Clock
SPI Out (MOSI) – 5V	72	67	5V – I^2C Data
3.3V			5V
Ground			Ground



Click Board 2 Socket

	Pin No.	Pin No.	
ANA	27	9	5V – PWM 2B
	73	7	5V
5V	69	26	COM3 Rx
SPI Clock – 5V	70	25	COM3 Tx
SPI In (MOSI) – 5V	71	66	5V – I^2C Clock
SPI Out (MOSI) – 5V	72	67	5V – I^2C Data
3.3V			5V
Ground			Ground

(1) Pin No. refers to the number used in MMBasic to identify an I/O pin.
(2) All pins are capable of digital input/output and can be used as an interrupt pin.
(3) ANA means that the pin can be used as an analogue input.
(4) 5V means that the pin is 5V input tolerant.
(5) COUNT means that the pin can be used for counting or frequency/period measurement.

Sourcing parts

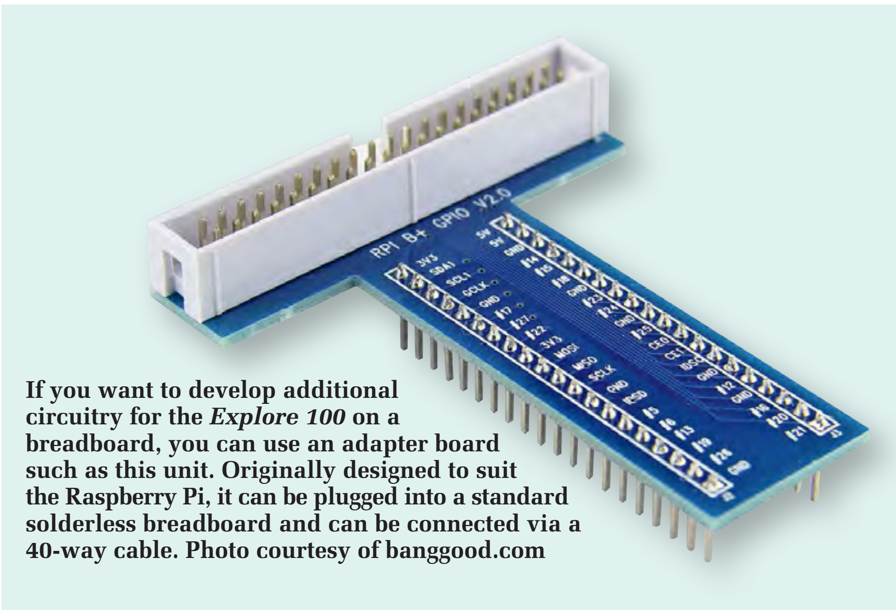
IMPORTANT!

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

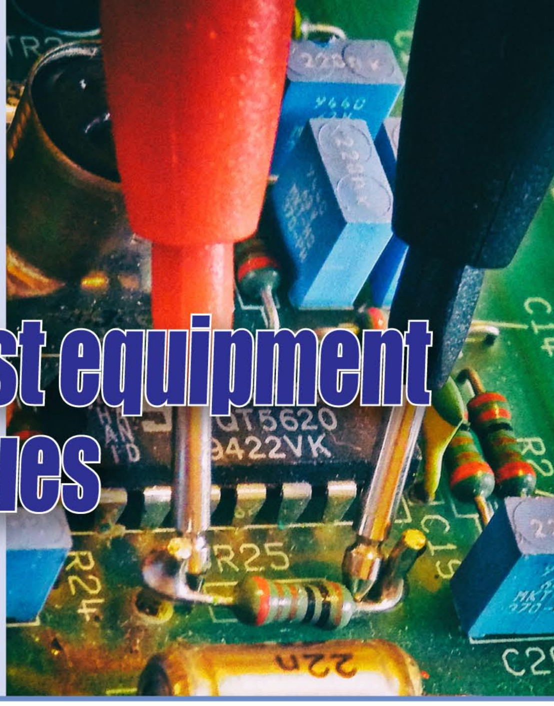
Many of the PCB designs come from Graeme Rixon in New Zealand, and now there is a UK online shop for all things Micromite-related, run by Phil Boyce at: **micromite.org**

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

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



If you want to develop additional circuitry for the *Explore 100* on a breadboard, you can use an adapter board such as this unit. Originally designed to suit the Raspberry Pi, it can be plugged into a standard solderless breadboard and can be connected via a 40-way cable. Photo courtesy of banggood.com



Teach-In 2018

Get testing! – electronic test equipment and measurement techniques

Part 1: Multimeters

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).

Electronic testing

Forty years ago, my very first teaching job involved designing and running a new course for electronic technicians and test engineers employed in the field of 'electronic testing'. This course looked at a wide variety of test equipment and its use in an equally wide range of applications, from avionics to industrial control, and from consumer electronics to telecommunications. Significantly, this course combined both analogue and digital instrument technologies, and students were encouraged to carry out measurements using the widest possible range of test equipment. Selecting the right test equipment for the job coupled with an ability to make reliable inferences from the measurements was paramount. This rationale is just as valid now as it was then, and this principle underpins this current *Teach-In* series. Put simply, there is little point in making measurements unless you know how to use the results.

Testing to specification

Testing to verify a quoted specification is important in a number of situations, just like tests to make refinements and improvements to a circuit during its development. By measuring parameters such as current, voltage, frequency, pulse width, and rise-time you will be able to analyse the performance of a circuit and arrive at an understanding of why it does what it does. With this in mind, we've incorporated the following features in the *Teach-In 2018* series.

In theory

Our 'In theory' feature will provide you with the essential underpinning knowledge relating to electronic testing and measurement. We will assume that you have a basic understanding of electronic circuits and that you can recognise symbols as well as the physical appearance of common parts such as resistors, capacitors, inductors, transformers, diodes, transistors, and integrated circuits. We'll look at the principles behind a wide variety of measurements and examine the limitations imposed by accuracy, resolution and repeatability of the techniques and equipment used.

Gearing up

This is about choosing and using test gear – what to look for, what to avoid and what to pay. We'll examine typical specifications and how these impact on the quality and reliability of measurements. We will explain how to improve the accuracy and reliability of your measurements and when you should treat readings and indications with some caution. For those on a limited budget, we'll also look at second-hand equipment as a means of acquiring a range of laboratory-standard equipment for minimal outlay.

Get it right!

We've included some useful hints and tips that highlight the best practice when using common items of test equipment. These hints and tips have arisen from

***Fig.1.1.** Our* **Test gear** *projects will provide you with a variety of useful test gear accessories*

hard-won experience and they may well save you time and unwanted expense.

Check it out

Our 'Check it out' feature provides you with practical examples of tests and measurements made on a variety of different electronic circuits. We aim to demystify the process of carrying out tests and measurements, and explain what the indications actually mean in terms of the performance of the equipment under test. We will also introduce simple fault-finding techniques that will not only save time but also improve the accuracy and reliability of fault diagnosis.

Test gear project

Each month we will feature a simple but useful practical project. These projects will include calibrators, probes and range extenders, as well as some devices that can be used as stand-alone items of test equipment; for example, signal sources and tracers (see Fig.1.1). Several of our projects are designed to extend the features, ranges and usability of existing items of test equipment and most of them can be built for less than £10.

This month

In this month's instalment, *In theory* will introduce DC measurements of voltage, current and resistance. *Gearing up* deals with multimeters, both analogue and digital types, and *Get it right!* provides some important tips on using them. Finally, the first of our *Test gear projects* will show you how to construct a simple device that can be used to check the DC voltage, current and resistance ranges of a multimeter. This handy gadget provides an accurate source of voltage, current and resistance that will come in handy for checking that your trusty meter is telling you the truth.

In theory: DC measurements

Straightforward direct current (DC) measurements of voltage, current and resistance can provide useful information on the state of almost any circuit. We will begin by explaining the principles that

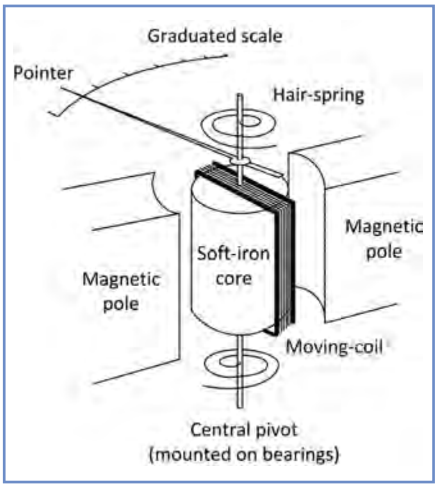


Fig.1.2. Key components and layout of a moving-coil meter movement

Fig.1.3. Internal arrangement of a typical moving-coil meter

underpin basic analogue and digital measuring instruments, starting with the humble moving-coil meter.

Analogue meters

Analogue meters use a moving-coil meter movement to which a pointer is attached that sweeps over a graduated scale. Moving-coil movements tend to be delicate and they can be rather expensive. However, it is still possible to purchase a meter based on such a device and despite the shortcoming that we discuss later, an analogue instrument can actually be preferred in some applications.

The basic construction of a moving coil meter movement is shown in Fig.1.2. This consists of a coil wound on a rectangular former suspended in a permanent magnetic field where the flux is radially concentrated in the air gap in which an axially pivoted coil is free to rotate. When a small current flows in the coil the resulting magnetic force produces a deflecting torque which works against a restoring torque produced by the two hairsprings. This results in movement of the coil and the attached pointer moves across a graduated scale, resting at a deflection where the deflecting torque balances that of the restoring torque. Since the deflecting torque is directly proportional to the current flowing in the coil, the position of the pointer will be directly proportional to the applied current. Fig.1.3 shows the internal arrangement of a typical moving coil meter. Note the suspension and hairsprings.

Multipliers and shunts

To use a moving coil meter as the basis of a voltmeter (ie, a device for reading voltage) all that is needed is

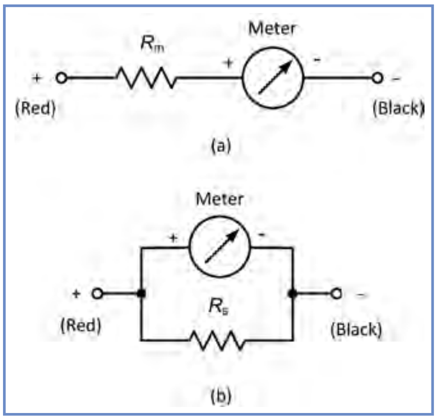


Fig.1.4. Voltmeters and ammeters

a series resistor (commonly known as a 'multiplier'). The multiplier resistor reduces the current extracted from the circuit under investigation to a relatively small value that will produce a modest deflection of the pointer.

To use a moving coil meter as the basis of an ammeter (ie, a device for reading current) all that is needed is a parallel resistor (commonly known as a 'shunt'). The shunt resistor diverts current so that once again the current extracted from the circuit under investigation is reduced to a relatively small value that will produce a modest deflection of the pointer.

Voltmeter and ammeter circuits

Figs. 1.4(a) and 1.4(b) respectively show the circuit of a simple voltmeter and a simple ammeter using a moving-coil movement. Each instrument is based on the moving-coil indicator shown in Fig.1.2. The voltmeter consists of a multiplier resistor connected in series with the basic moving-coil movement, and the ammeter consists of a shunt resistor wired in parallel with the basic moving-coil instrument.

When determining the value of multiplier or shunt resistances (R_m and R_s respectively in Fig.1.4) it is important to remember that the coil of the moving coil meter also has a resistance. We have shown this as resistor r, in series with the moving coil. The value of this resistance is typically in the range 100Ω to 1kΩ, and the current required to produce full-scale deflection of the meter movement (I_m) is often less than 100µA.

In the voltmeter circuit shown in Fig.1.5(a):

$$V = I_m R_m + I_m r$$

from which:

$$I_m R_m = V - I_m r$$

Thus:

$$R_m = \frac{V - I_m r}{I_m}$$

In the ammeter circuit shown in Fig.1.5(b):

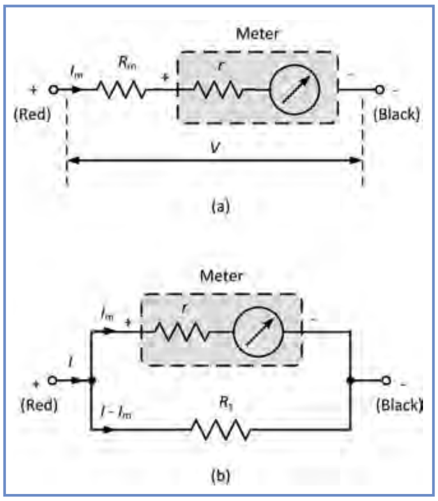


Fig.1.5. Multiplier and shunt resistance calculations

$$(I - I_m)R_s = I_m r$$

from which:

$$R_s = \frac{I_m r}{I - I_m}$$

Note that the resistance seen between the two input terminals of a voltmeter should ideally be infinite, but in fact is R_m in series with r; ie, $(R_m + r)$. In the case of an ammeter, the resistance that appears between the two input terminals should ideally be zero, but is actually R_m in parallel with r – ie, $(R_s \times r) / (R_s + r)$. This resistance can have a significant effect on the accuracy that we can place on the readings obtained.

Example 1

A moving-coil meter has a full-scale deflection current of 100µA. If the meter coil has a resistance of 500Ω, determine the value of multiplier resistor for the meter if it is to be used as a voltmeter reading 10V full-scale deflection.

Using $R_m = \dfrac{V - I_m r}{I_m}$ gives:

$$R_m = \frac{10 - \left(100 \times 10^{-6} \times 500\right)}{100 \times 10^{-6}} = \frac{10 - 0.05}{100 \times 10^{-6}}$$

$$= 99.5 \times 10^3 = 99.5\text{k}\Omega$$

Example 2

A moving coil meter has a full-scale deflection current of 1mA. If the meter coil has a resistance of 100Ω, determine the value of shunt resistor if the meter is to be used as an ammeter reading 0 to 30mA.

$R_s = \dfrac{I_m r}{I - I_m}$ gives:

$$R_s = \frac{1 \times 10^{-3} \times 100}{30 \times 10^{-3} - 1 \times 10^{-3}} = \frac{100 \times 10^{-3}}{29 \times 10^{-3}} = \frac{100}{29} = 3.45\ \Omega$$

Ohmmeters

The circuit of a simple ohmmeter based on a moving coil is shown in Fig.1.6. The battery is used to supply a current that will flow in the unknown resistor (R_x) which is indicated on the moving-coil meter. Before use, the variable resistor (RV1) must be adjusted to produce full-scale deflection (corresponding to zero on the ohms scale). Zero resistance thus corresponds to maximum indication. Infinite resistance (ie, when the two terminals are left open-circuit) corresponds to minimum indication. The ohms scale is thus reversed when compared with a voltage or current scale. The scale is also very non-linear, as shown in Fig.1.7.

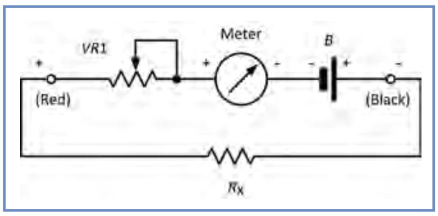


Fig.1.6. An ohmmeter based on a moving coil indicator

Fig.1.7. Scale of a typical analogue multimeter showing non-linearity of the resistance range (outer green scale marked 'OHMS')

Digital voltmeters

Digital voltmeters use analogue-to-digital converters (ADC) and liquid crystal displays (LCD) to indicate measured values. There are several different types of ADC, but one of the most common is the dual-ramp integrating ADC, as shown in Fig.1.8. This type of ADC employs an input range selector followed by an electronic switch. The output of the switch is taken to an integrating circuit, the output of which is fed to a zero-crossing detector. The dual-ramp ADC has a high-stability clock that is gated into a counter. During the conversion process, pulses are fed via the gate into the counter. When the conversion is complete, the count is stopped and the result is passed via the display driver to the LCD. The number of pulses counted is directly related to the applied input voltage.

To understand how the dual-ramp ADC works, let's first assume that the electronic switch is in position 1. The (assumed positive) input voltage will then be applied to the input of the integrator. As a result, the output of the integrator will ramp downwards during the fixed integration period, t_1. During this period the output of the integrator will be negative and, as a result, the output of the zero-crossing detector will be high and the transmission gate will be open, allowing clock pulses into the counter. Note that the fixed integration period is equivalent to a fixed number of clock cycles and the period will be the same for any value of input voltage.

At the end of the fixed integration period, the electronic switch will move to position 2, disconnecting the input voltage and replacing it with a fixed negative reference voltage, V_{ref}. At this point, the output of the integrator will begin to ramp upwards until it eventually reaches zero at the end of the variable measurement period, t_2. During this period, the output of the zero-crossing detector will remain high and clock pulses will continue to be fed via the gate into the counter. When the output of the integrator eventually reaches zero, the output of the zero-crossing detector will fall to zero and the gate will close, preventing any further clock pulses from being counted. The number of pulses fed into the counter during the variable measurement period will be directly proportional to the applied input voltage (V_{in}) and independent of the values of C and R used in the integrator, as we will now show.

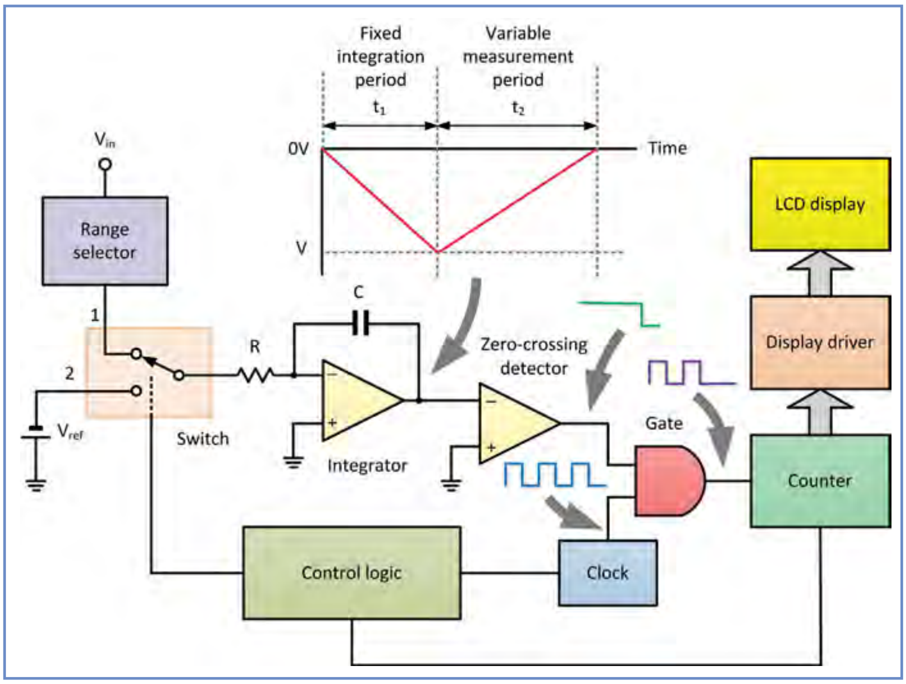


Fig.1.8. Basic arrangement of a digital voltmeter based on a dual-ramp integrating ADC

At the end of the fixed integrating period the output of the integrator will be given by:

$$V = -V_{in} \frac{t_1}{CR}$$

During the variable measurement period:

$$V = -V_{ref} \frac{t_2}{CR}$$

From which we can infer that:

$$V_{in} \frac{t_1}{CR} = V_{ref} \frac{t_2}{CR}$$

Hence:

$$V_{in} = V_{ref} \frac{t_2}{t_1}$$

If n_1 clock pulses are used during the fixed integration period, and n_2 pulses are counted during the variable measurement period then we can conclude:

$$V_{in} = V_{ref} \frac{n_2}{n_1}$$

Where V_{ref} and n_1 are constants. Hence the number of pulses counted is directly proportional to the input voltage. In other words:

$$n_2 \propto V_{in}$$

Multimeters

For practical measurements on electronic circuits we invariably combine the functions of a voltmeter, ammeter and ohmmeter into a single instrument (known as a multi-range meter or simply a multimeter). In a conventional multimeter as many as eight or nine measuring functions may be provided, with up to six or eight ranges for each measuring function. Besides the normal voltage, current and resistance functions, some meters also include facilities for checking transistors and measuring capacitance. Most multi-range meters normally operate from internal batteries and thus they are independent of the mains supply. This leads to a high degree of' portability, which can be all-important when measurements are to be made away from a laboratory or workshop. Fig.1.9 shows typical mid-range instruments with an analogue multimeter shown on the left and a comparable digital multimeter shown on the right.

Analogue multimeters

Analogue meters employ conventional moving coil meters (see earlier) and the

Fig.1.9. Comparable mid-range analogue and digital multimeters

Fig.1.10. Reading the scale of an analogue multimeter

display takes the form of a pointer moving across a number of calibrated scales, depending on the range selected. This arrangement is not as convenient to use as that employed in digital instruments because the position of the pointer is rarely exact and will often require interpolation. Analogue instruments do, however, offer some advantages, not least the fact that it is very easy to make adjustments on a circuit while observing the relative direction of the pointer; a movement in one direction representing an increase and in the other a decrease. Despite this, the principal disadvantage of many analogue meters is the rather cramped, and sometimes confusing scale calibration. To determine the exact reading requires first an estimation of the pointer's position and then the application of some mental arithmetic based on the range-switch setting.

Fig.1.10 shows an example of how a reading is taken using a typical analogue multimeter. The instrument is switched to the 30V DC range and the pointer crosses the 30V DC scale just above the scale mark corresponding to 17V. The pointer is slightly to the right of the 17V scale mark but to the left of the next (and slightly larger) scale mark corresponding to 17.5V. We can estimate the measured voltage at somewhere between 17.1V and 17.2V. Note that we really cannot be more precise than this!

The accuracy of an analogue multimeter is usually expressed as a percentage of the full-scale reading on the currently selected range. Typical values are ±5%, ±3%, and ±2% of full-scale deflection (FSD) for basic, mid-range and laboratory-grade instruments when used on the DC ranges. Accuracy on the AC ranges will often be worse than this, and on the resistance range may be ±10% at best.

When used on the voltage ranges an ohms-per-volt rating is often quoted for an analogue multimeter. This indicates the amount of loading, in terms of resistance, that will be imposed by the meter on the circuit to which it is connected. In some cases, particularly in high-impedance circuits, this can be very important as it may lead to significant errors.

The ohms-per-volt rating is, in effect, the resistance presented by the meter when switched to the 1V range. It can be calculated from the inverse of the basic sensitivity of the moving coil used in the instrument. So, for example, an analogue instrument that uses a 50µA meter movement would have a resistance of 20kΩ when used on the 1V range. On the 10V range it would have a resistance of 200kΩ and on the 100V it would have a resistance of 2MΩ. From the above we can conclude that:

$$\text{Meter f.s.d.} = \frac{1}{\text{ohms-per-volt}}$$

or

$$\text{Ohms-per-volt} = \frac{1}{\text{Meter f.s.d.}}$$

Clearly, the higher the ohms-per-volt value, the less likely we will be subject to potential errors caused by the loading effect of a voltmeter. With digital instruments, this problem does not arise because they generally have a constant, high-input impedance (usually 10MΩ).

Get it right!

Digital multimeters

Compared with analogue instruments, digital meters are easy to read and have displays that are clear, unambiguous, and capable of providing a very high resolution. It is thus possible to distinguish between readings that are very close. This is just not possible with an analogue instrument.

Low-cost digital multi-range meters have been made possible by the advent of mass-produced LSI devices and liquid crystal displays. A 3½-digit display is the norm and this consists of three full digits that can display '0' to '9' and a fourth (most-significant) digit which can only display '1'. Thus, the maximum display indication, ignoring the range switching and decimal point, is 1999; anything greater over-ranges the display and an appropriate warning will be displayed.

The resolution of the instrument is the lowest increment that can be displayed and this would normally be an increase or decrease of one unit in the last (least-significant) digit. The sensitivity of a digital instrument is generally defined

Fig.1.11. Two low-cost autoranging digital multimeters

Get it right when using an analogue multimeter!

- Always ensure that you have selected the correct range and measuring function before attempting to connect the meter into a circuit
- Select a higher (less-sensitive) range than expected and then progressively increase the sensitivity as necessary to obtain a meaningful indication
- Remember to zero on the ohms range before attempting to measure resistance
- Switch the meter to the 'off' position (if one is available) whenever the instrument is not being used and always before attempting to move or transport the meter
- Check and, if necessary, replace the internal batteries on a regular basis
- Always use properly insulated test leads and probes (see Fig.1.12)
- Never attempt to measure resistance in a circuit that has power applied to it
- Don't rely on voltage readings made on high-impedance circuits (the meter's own internal resistance may have a significant effect on the voltages that you measure)
- Use caution when measuring voltages and currents in circuits where high frequency signals or pulse waveforms are present (in such cases an analogue meter may produce readings that are wildly inaccurate or misleading)
- Avoid subjecting an instrument to excessive mechanical shock or vibration (this may damage the delicate moving coil meter movement)

as the smallest increment that can be displayed on the lowest (most sensitive) range. Sensitivity and resolution are thus not quite the same. To put this into context, consider the following example:

A digital multi-range meter (DMM) has a 3½-digit display. When switched to the 2V range, the maximum indication would be 1.999 V and any input of 2V or greater would produce an over-range indication. On the 2V range, the instrument has a resolution of 0.001V (or 1mV). The lowest range of the instrument is 200mV (corresponding to a maximum display of 199.9mV) and thus the meter has a sensitivity of 0.1mV (or 100µV).

Nearly all digital meters have automatic zero and polarity indicating facilities, and some also have autoranging. This feature, which is only found in more expensive instruments, automatically changes the range setting so that maximum resolution is obtained without over-ranging. There is no need for manual operation of the range switch once the indicating mode has been selected. This is an extremely useful facility since it frees the user from the need to make repeated adjustments to the range switch while measurements are being made.

Unlike the accuracy of an analogue instrument, which is expressed as a percentage of the full-scale reading, the accuracy of a digital multimeter is expressed as a percentage of the measured reading as well as the uncertainty in the least-significant digit (LSD) of the display. This uncertainty is usually expressed in terms of the number of counts that might be in error. This might sound a little complicated, so here is an example. Let's suppose that a particular 3½-digit DMM is quoted as having an accuracy of ±1% + 2 digits. If the DMM is switched to the 20V DC range and it is indicating a reading of 4.59V then the uncertainty in the reading would be calculated as follows:

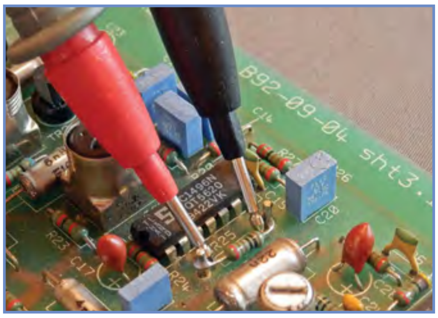


Fig.1.12. A set of properly insulated test probes is essential when making measurements on live circuits

±1% of 4.59V – this amounts to ±0.05V when rounded to the nearest digit (we do this because the 3½-digit meter only has a resolution of 10mV on the 20V DC range)

+2 digits – this implies an uncertainty of ±0.02V (ie, 20mV which is twice the resolution of the instrument on the 20V DC range).

From this we arrive at a total uncertainty of ±0.07V, or 70mV. Thus, the measured voltage should strictly be taken to be 4.59V ±0.07V. In other words, the measured voltage is within the range 4.52V to 4.66V.

Get it right when using a digital multimeter!

- Always select the appropriate measuring function before attempting to connect the meter into a circuit
- Unless the multimeter is an autoranging instrument, check that you have selected the correct range before attempting to connect the meter into a circuit
- When starting a measurement, select a higher range than expected and then progressively increase the sensitivity as necessary to obtain a meaningful indication
- Always switch the meter to the 'off' position when not in use. This will help conserve battery life
- Check and, if necessary, replace the internal battery on a regular basis
- Always use properly insulated test leads and probes (see Fig.1.12)
- Check that a suitably rated fuse is fitted to protect the current ranges (this often fails if the instrument is set to read current and misconnected to a voltage source)
- Never attempt to measure resistance in a circuit that has power applied to it
- Don't rely on voltage and current readings made on circuits where high frequency signals or pulse waveforms may be present (as with analogue instruments, digital meters may produce readings that are wildly inaccurate or misleading in such circumstances)
- Exercise caution when making measurements on circuits where voltage/current is changing or when a significant amount of AC may be present superimposed on a DC level.

Check it out!

To put this all into context, let's look at how a digital multimeter can be used to verify the operation of the audio amplifier shown in Fig.1.13. The circuit operates from an 18V DC supply (not shown in Fig.1.13) so the first step should be checking that the supply is functioning and that the supply voltage is at, or close to 18V.

Step 1 – First check the supply rail voltage. This can be done by setting the digital multimeter to the 20V DC range and connecting the positive (red) test lead to the +18V terminal and the negative (black) test lead to the 0V terminal. If more convenient, we could connect the positive test lead to the end of the supply fuse (F1) or simply connect the test meter across the large value electrolytic capacitor (C9) as shown in Fig.1.13. A supply voltage of 18.23V is measured and this is reasonably close to the expected value.

Step 2 – Having established that we have a DC supply connected and present on the board the next step is checking the supply current. Since the board is fitted with a fuse we can simply remove the fuse and in its place insert the meter, switched to the 200mA DC current range. The positive (red) test lead is taken to the supply input and the negative (black) test lead is connected to the positive supply rail. A supply current of 63.5mA is indicated and this is reasonably close to the 70mA quoted in the manufacturer's specification.

Step 3 – Next, we will check the quiescent (no-signal) current flowing in the output stage comprising the complementary pair, TR3 and TR4. The manufacturer has provided a 'service link' on the board so that this measurement can be easily carried out. Simply remove the link, set the multimeter once again to the DC 200mA range, and insert the meter in place of the link. The positive (red) lead goes to the supply rail end of the service link while the negative (black) test lead is taken to the other end of the link, which is connected to the collector of TR4. The measured current is 51.8mA, which is just a littler greater than the 50mA specified by the manufacturer (note that this current can be adjusted with RV2).

Step 4 – If no service link is provided, an alternative method of measuring the quiescent current flowing in TR3 and TR4 is that of measuring the voltage drop across the low-value emitter resistor (R11) of TR4 and using the indicated value to calculate the current flowing. Set the multimeter to the 200mV range and connect the positive (red) test lead to the more positive end of R11 and the negative (black) test lead to the more negative end of R11. The value measured is 54mV and since R11 has a resistance of 1Ω we can infer that a current of 54mA must be flowing in it. This value of current will be slightly greater than that measured by removing the service link because the current flowing in R1 will be the sum of the collector and base currents flowing in TR4. This value is, in any event, reasonably close to the expected value.

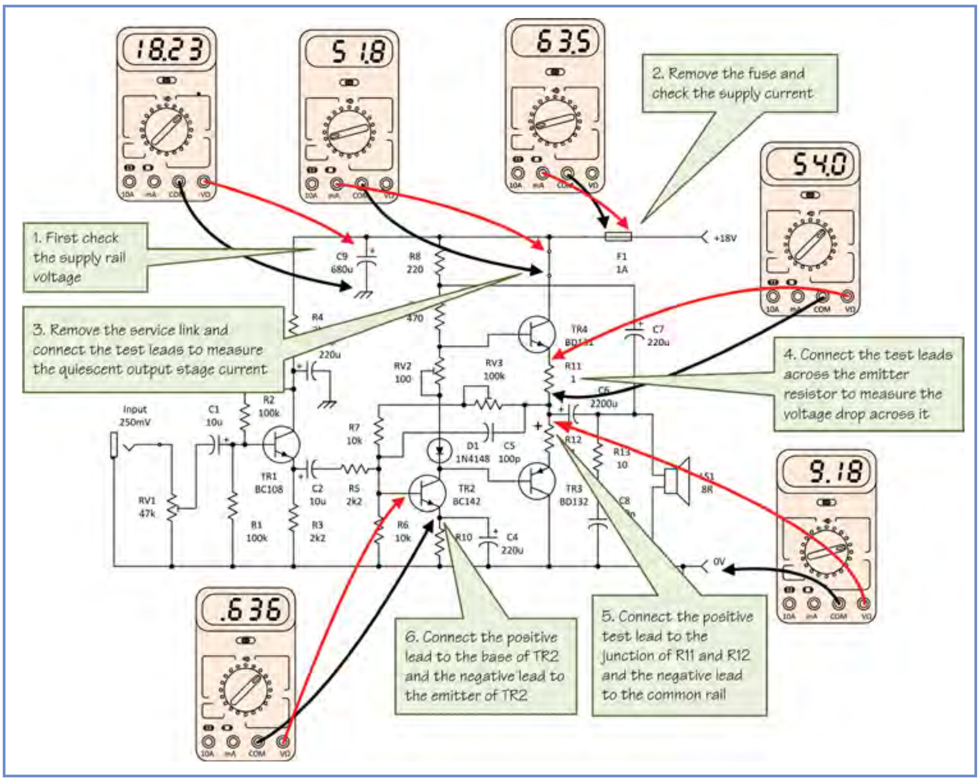


Fig.1.13. Checking the DC voltages and currents present in an audio power amplifier

Step 5 – To check the symmetry of the output stage we need to verify that the supply voltage (nominally 18V) is shared equally between the two output transistors, TR3 and TR4. Switch the multimeter to the 20V DC range, connect the positive (red) test lead to the half-supply point (junction of R11 and R12) and the negative (black) test lead to the 0V rail. The indicated value is 9.18V, which is close to the ideal 9V value.

Step 6 – In some cases (and in the event that we might have diagnosed a fault condition), it might be necessary to measure bias voltages present in the circuit. For example, to measure the base-emitter voltage for TR2 we would set the multimeter to the 2V DC range with the positive (red) test lead connected to TR2's base and the negative (black) test lead connected to TR2's emitter. The voltage indicated is normal for an NPN silicon device, such as a BC142, and is indicated as 0.636V.

Gearing up: multimeters

The most basic – and arguably – the most useful of all electronic test instrument is the multimeter. So, if you only have sufficient funds to purchase just one instrument then this should be it. Fortunately, it is also likely to cost less than almost any other piece of test equipment in your workshop.

Your trusty multimeter will allow you to carry out basic measurements of DC and AC current and voltage, as well as resistance, continuity, capacitance and frequency on more sophisticated (and expensive) instruments. There are several types of multimeter available, and it is important to choose an instrument that is right for your future needs as well as your current requirements. Here are a number of features that you might want to look for.

DC voltage and current

It should go without saying that you will need several DC voltage and current ratings. The voltage ranges should extend from at least 200mV to 200V and the current ranges from 200µA to 2A. More sophisticated (and usually more expensive) instruments will provide you with more ranges. For example, many budget-priced multimeters dispense with an internal 10A shunt resistor and are only capable of only reading up to 199.9 mA. It can also be useful to measure AC voltages up to about 750V. Beyond this you should consider a more specialised instrument with a matching high-voltage probe.

AC voltage and current

It is important to be able to measure RMS values of voltage and current at the mains supply frequency (50Hz or 60Hz). It can also be useful to have an instrument that can reliably measure audio signals – do note that many digital multimeters are severely limited in terms of frequency response and are often only usable from around 40Hz to 400Hz. This is inadequate for most audio frequency measurements; however, a future *Test gear project* will provide you with a means of overcoming this limitation in the form of a handy accessory that will allow you to accurately measure RMS AC voltages from 5Hz to well over 100kHz.

Resistance

You will need several resistance ranges, extending from 200Ω to at least 20MΩ. Note that *analogue* meters can be very problematic when used to measure high values of resistance and they should not usually be relied upon for values much in excess of 50kΩ to 100kΩ.

Diodes and transistors

Some digital multimeters incorporate diode junction tests and they may also have a basic transistor testing capability. These features can be extremely useful and are well worth the additional cost, particularly if you have a stock of unmarked and untested semiconductor devices.

Capacitance

Modern instruments often have a capacitance testing facility, but it is likely to be somewhat limited in range. It is useful to have the ability to measure values ranging from less than 2nF to at least 200µF. The Vici VC99 mid-range auto-ranging DMM (currently available for well under £30) will read capacitance with a resolution of 10pF up to 40nF and, at the other extreme, with a resolution of 1µF up to 2000µF.

Frequency

An ability to measure frequency can also be useful but, once again, the measuring range might be somewhat limited. The Vici VC99 DMM (mentioned above) measures frequency from 10Hz to 60MHz at resolutions of 0.01Hz to 10kHz, respectively. Other instruments may not provide you with such a wide measuring range, 20kHz being typical of budget instruments.

Auto-ranging

Once restricted to top-of-the range instruments, auto-ranging is a feature that is increasingly being found on lower-cost digital multimeters. Once set to a particular function (eg, AC voltage or DC current) auto-ranging will free you from the need to manually select your measurement range. The instrument will automatically set the range without the need for operator intervention. This can be a very useful feature and can greatly speed up measurements, but you need to be aware that the instrument will take a finite time to set itself to a suitable range and this can add to a delay when taking a series of measurements. Each time you transfer the test leads to a different test point you may have to wait for the instrument to auto-select an appropriate range for the measurement.

Fig.1.14. A laboratory-grade Fluke bench multimeter

Auto-power off

Auto-power off is another feature that was once only found in more expensive instruments. Auto-power off is important if you all too easily forget to switch off an instrument after a period of use.

Bench multimeters

Bench multimeters (see Fig.1.14) are larger multi-range instruments that generally only operate from an AC mains supply. Such instruments usually offer a significantly higher degree of accuracy and for this reason they are often more expensive than portable instruments. On older instruments, displays were often based on a number of seven segment LEDs, while newer versions use four- or five-digit LCDs, similar to those fitted to handheld meters.

What to pay

A digital multimeter with a reasonable specification need not cost more than about £30. For this you can expect to have an instrument with standard features, such as DC and AC voltage, current and resistance ranges, as well as limited range capacitance and frequency measurement and basic diode/transistor checking. DC current can usually be measured at up to about 10A and DC/AC voltage up to around 750V. This will be adequate for practically all basic test and measurement situations. There may also be a handy audible continuity check, as well as auto-ranging and an auto-power off. In the £20 to £40 price range an instrument should be supplied with a decent set of probes and will usually have a carrying case or protective holster. Unless you are working on a very restricted budget it is sensible to avoid most of the cheaper instruments because these usually offer fewer features, limited ranges and reduced accuracy.

Buying new

You will have little difficulty in finding an instrument to meet your requirements and available budget, but the sheer range of equipment can sometimes be baffling! Many of our regular advertisers carry stocks of suitable instruments but, although it is possible to purchase a digital multimeter for well under £10, such instruments should generally be avoided as they invariably offer only a limited specification and can have displays that can be difficult to read. Their build quality can also be rather poor, so it is best to

Fig.1.15. Model 8 Avometer

choose a known brand and expect to pay up to £30. This will get you an instrument with features and range that will cope with a wide range of eventualities and serve you well over the coming years.

Buying second-hand

Good quality, second-hand laboratory-grade instruments are frequently available from various electronic suppliers and also from on-line sources such as eBay. Such an instrument can be a useful investment if you need to carry out highly-accurate measurements or if you need specialist features, such as a high-voltage probe or extended current ranges. You can expect to pay around £50 for a quality second-hand instrument, but do note that it may not be supplied with a calibration certificate so your first job should be that of checking the instrument's calibration. In this case appropriate documentation such as a user-manual or service-manual can be a good investment. This will describe the calibration procedures as well as telling you how to dismantle the equipment and how to make any necessary adjustments.

Classic instruments

Classic instruments, such the Model 8 Avometer shown in Fig.1.15 are regularly available at prices of around £50 to £100 from on-line auction sites such as eBay. Condition can vary considerably and a meter in 'mint' condition will invariably cost more. The disadvantage of such instruments is that they can be rather bulky and may be prohibitively expensive to repair. It is also important to be aware that an analogue voltmeter has a relatively low input resistance on the voltage ranges. For example, a Model 8 Mark 5 instrument has an ohms-per-volt rating of 20kΩ per volt on the DC voltage ranges and a mere 2kΩ per volt on the AC voltage ranges above 10V. This means that, if set to the 10V DC range the meter will offer a resistance of only 200kΩ, while on the 30V AC range it will only exhibit a resistance of 60kΩ. These values are very

Table 1.1 Comparison of instrument performance

Instrument	Quoted specification	Check (see this month's Test gear project)		
		5V	5mA	1kΩ
Vici VC99 mid-range auto-ranging DMM	±0.5% + 3 digits DC V ±1.2% + 5 digits DC I	4.991V	4.96mA	999Ω
Velleman DV890 mid-range DMM	±0.5% + 1 digit DC V ±0.8% + 1 digit DC I	4.98V	4.93mA	998Ω
Fluke 8012A bench DMM	±0.1% + 1 digit DC V ±0.3% + 1 digit DC I	4.98V	4.92mA	1000Ω
Crenova/Hyelec MS8233D low-cost auto-ranging DMM	±0.5% + 2 digits DC V ±1.5% + 3 digits DC I	4.98V	4.91mA	999Ω
Fluke 8012A bench DMM	±0.1% + 1 digit DC V ±0.3% + 1 digit DC I	4.98V	4.92mA	1000Ω
Avometer Model 8 analogue multimeter	±1% of full-scale DC V ±1% of full-scale DC I	4.9V	4.7mA	975Ω
Marconi TF1041B valve voltmeter	±2% FSD	4.9V	n.a.	1000Ω

Fig.1.16. Valve voltmeter

much less than the 10MΩ typical of digital instruments on all the DC and AC voltage ranges.

Valve voltmeters

As the name implies, a valve voltmeter is an instrument that uses a thermionic valve, invariably in conjunction with a moving coil meter movement – see Fig.1.16. Now considered obsolete, such instruments are often designed for both AC and DC voltage measurements as well as resistance, and they offer high input resistance resulting from the use of a valve rather than a semiconductor input device. Despite their age, such instruments can still be a useful addition to the range of test equipment in your workshop. So, if you are lucky enough to spot one at a reasonable price, it can be a very worthwhile (and fun!) investment.

Typical instrument performance

As an indication of what can be expected, we tested a representative selection of commonly available multi-range instruments using the 5V/5mA/1kΩ calibration accessory described in this month's *Test gear project*. The results that we obtained are shown in Table 1.1.

Test gear project: a handy multimeter checker

Our *Test gear projects* have been designed to be both low-cost and easy to construct. They use no more than a handful of commonly available components and are assembled using a small piece of inexpensive strip board. The aim is to keep the cost under £10, although some of our later probe-fitted *Test gear projects* are a little more expensive to construct due to the more specialised enclosure.

Our first project is one of the simplest so let's get started!

It is important to check the calibration of a multimeter, particularly if you have any concerns or questions over its accuracy – for example, if you bought it second hand. This can be done using a supply of known voltage, but will invariably require the use of a second meter of known accuracy to check the calibrating voltage before the measurement is carried out. Our first *Test gear project* overcomes this problem by providing an accurate 5V, 5mA and 1kΩ calibration source. We chose these values of voltage, current and resistance because they are well within the range expected in most simple electronic circuits. The checker is small, inexpensive, easily constructed and will typically work to an accuracy of ±2%, or better.

The complete circuit of our *Test gear project* is shown in Fig.1.17. It is based on a TL431 precision programmable voltage reference. This chip produces a constant voltage output determined by two external resistors (R2 and R3) that form a voltage divider. The TL431 has a typical output impedance of 0.2Ω and its internal 2.5V reference is accurate to within ±2%. The circuit is powered from a standard PP3 9V battery. The 5mA calibration output is available from SK2 via a 1kΩ resistor connected in series with the precision 5V output provided by SK1. Note that the three 1kΩ resistors (R2, R3 and R5) must all be ±1% tolerance high-stability types, which are available from most component suppliers at a cost only slightly more than standard tolerance types.

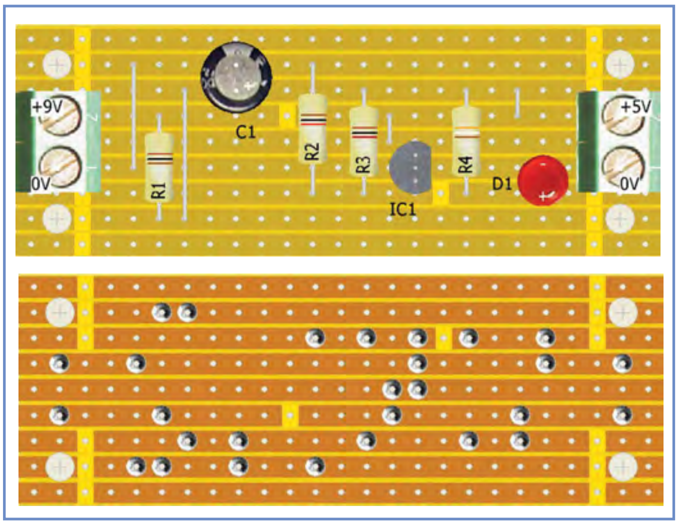


Fig.1.18. (top) Stripboard layout of the multimeter checker and (bottom) underside of the stripboard showing track breaks

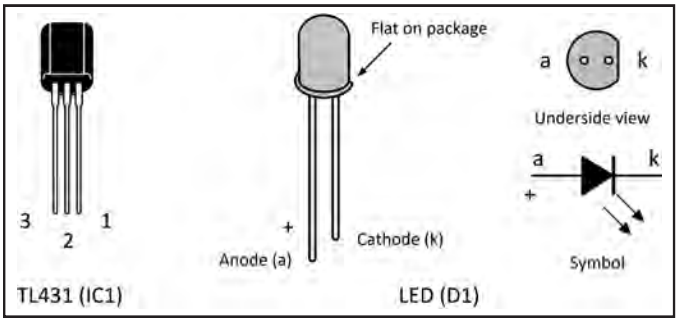


Fig.1.19. Semiconductor pin connections

You will need

Perforated copper stripboard (9 strips, each with 25 holes)

2-way terminal blocks (2)

ABS case with integral battery compartment

9V PP3 battery clip

9V PP3 battery

Miniature DPDT toggle switch (S1)

2mm red banana sockets (SK1 and SK2)

2mm black banana socket (SK3)

TL431 precision voltage reference (IC1)

5mm red LED (D1)

1 100Ω resistor (R1)

3 1kΩ 1% tolerance resistors (R2, R3 and R5)

1 390Ω resistor (R4)

1 220µF 16V radial lead electrolytic capacitor (C1)

Assembly

Assembly is straightforward and should follow the layout shown in Fig.1.18 – do note that the underside view of the board is *not* an 'X-ray view'. The '+' symbol shown on D1 indicates the more

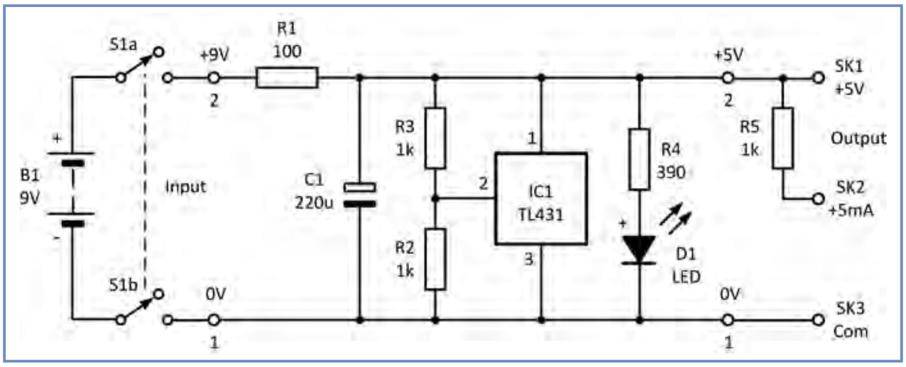


Fig.1.17. Complete circuit of the multimeter checker

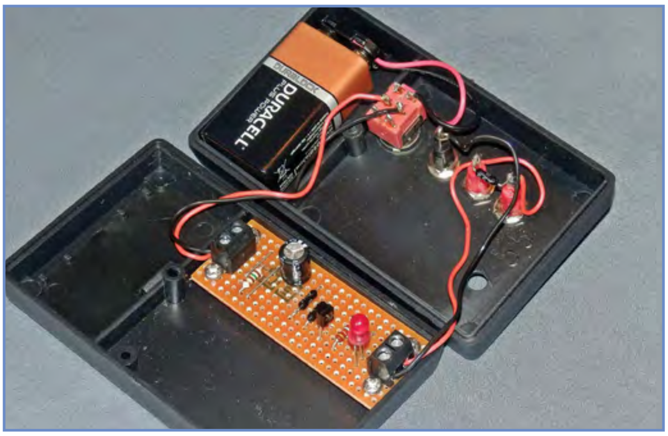


Fig.1.20. Internal wiring of the multimeter checker

positive (anode) terminal of the LED. The pin connections for the two semiconductor devices are shown in Fig.1.19. Note that there is a total of 14 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 four links to be made with tinned copper wire of a suitable diameter or gauge (eg, 0.6mm/24SWG). When you've finished soldering, it is important to carry out a careful visual check of the board, especially track side, checking for solder splashes and unwanted links between tracks.

Setting up

No setting up is required after assembly – all you need to do is to connect a PP3 battery and switch on. D1 should become illuminated; if not, check the battery and circuit connections carefully.

If your multimeter is not an autoranging instrument, select the DC 10V or 20V range and connect the multimeter's test leads between +5V (positive or red test lead to SK1) and Com. (negative or black test lead to SK3). The multimeter should indicate a value that is very close to 5V, as shown in Fig.1.23.

Next, select the DC 10mA or 20mA range and connect the multimeter's test leads between +5mA (positive or red test lead to SK2) and Com. (negative or black test lead to SK3). The multimeter should indicate a value that is very close to 5mA, as shown in Fig.1.24.

Finally, to check the resistance (ohms) range of your multimeter, simply switch off the power, select an appropriate range and move the test leads to the appropriate terminals. Connect the multimeter's test leads to +5V (positive or red test lead to SK1) and +5mA (negative or black test lead to SK2). Your meter should indicate very close to 1,000Ω, as shown in Fig.1.25. Table 1.1 shows the values we obtained from some representative analogue and digital instruments.

Fig.1.21. Rear panel wiring

Fig.1.22. External appearance of the finished multimeter checker

Next month

In next month's *Teach-In 2018* we will be looking at oscilloscopes and our practical project will feature a handy calibrator that will provide you with a useful signal source, allowing you to check your 'scope's performance.

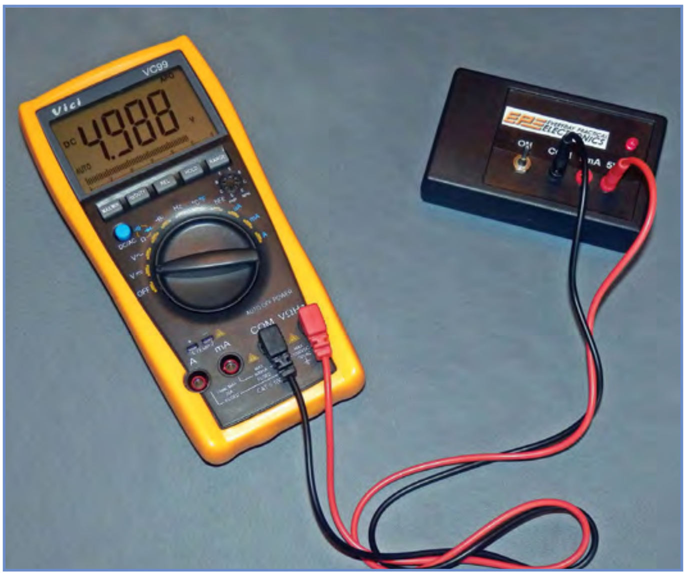


Fig.1.23. Checking the DC voltage function with the multimeter checker

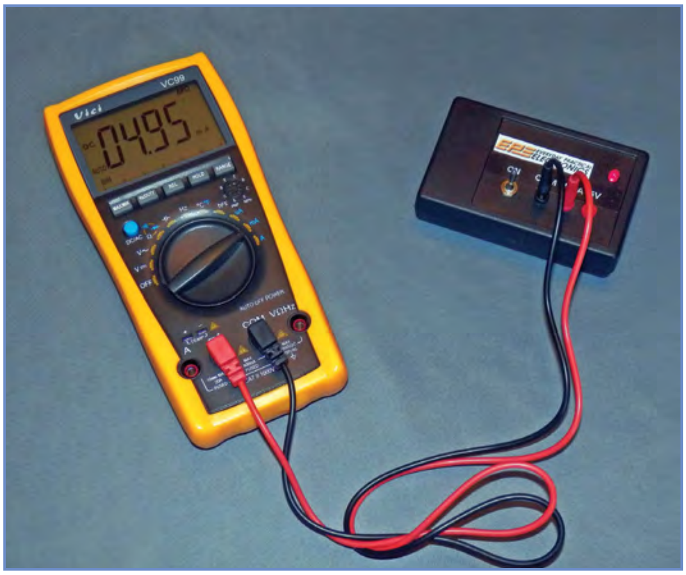


Fig.1.24. Checking the DC current function with the multimeter checker

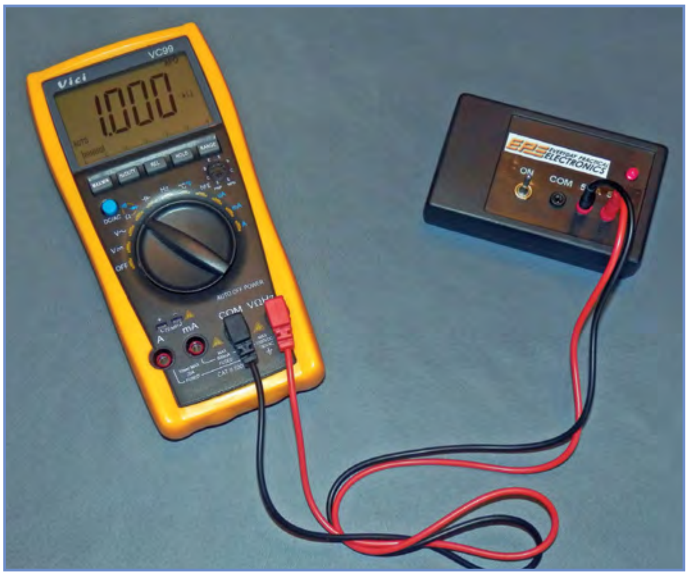


Fig.1.25. Checking the resistance function with the multimeter checker

WIN A Micromite E100 module!

micromite

SIMPLE · INTERACTIVE · FUN

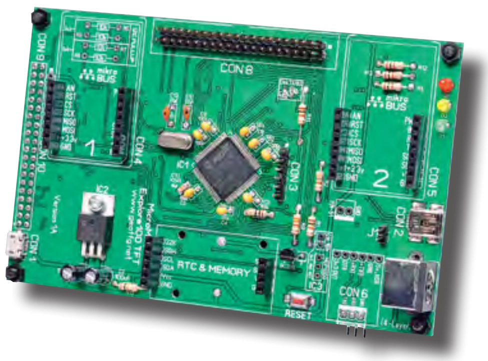
Another fantastic Micromite prize is up for grabs this month thanks to the team at: **micromite.org**

- A Fully Assembled Explore100 Module (E100) (RRP £75.00)

This month we are holding an online Raffle for our *EPE* readers.
To enter, simply send an email to **epe@micromite.org**
with the subject **E100Raffle**

Closing date for entry is **30th September**.

Look out for future competitions to win other fantastic Micromite products



(**PLEASE NOTE:** TFT Screen or Click Modules are not included)

Good Luck!

We are pleased to announce the winners from the August 2017 issue of *EPE*:

David Burton (from Manchester) wins the Micromite BackPack Module with 2.8" TouchScreen (BP28): with his 'Mobility Scooter Dashboard'

Ken Horton (from Warrington) wins the Micromite Explore64 Module (E64): with his 'Vivarium'

Well done to David & Ken

T&Cs

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

NET WORK

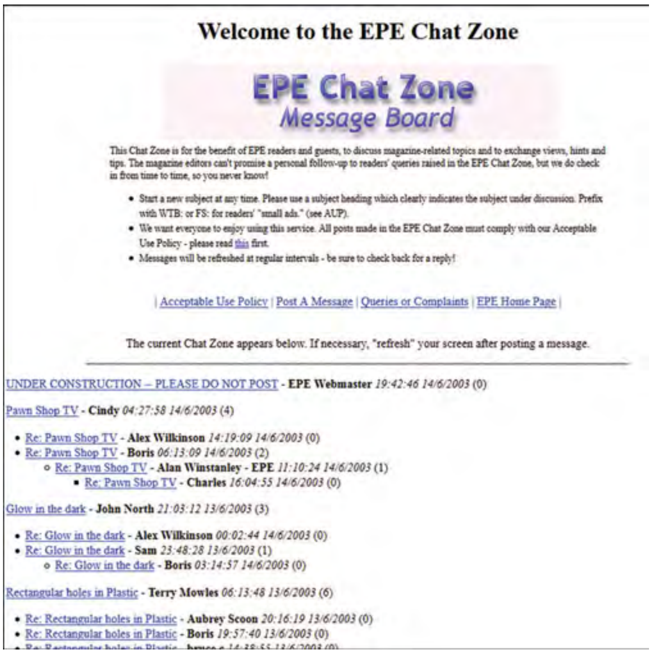
by Alan Winstanley

Chat Zone news

THIS MONTH'S *Net Work* brings the sad announcement that after much deliberation, it has been decided that the current *EPE Chat Zone* forum (**www.chatzones.co.uk**) is reaching its end of life and we will be switching it to 'read-only' mode from October. This has been a very difficult decision to take because we know that a number of regular users treat it as their online 'home'. The *EPE* forum contains many an interesting tale of readers' electronic exploits, victories, queries and conundrums dating back to the time it was first launched in 2005, and we continue to marvel at your great ingenuity, skill and dogged persistence in tackling thorny electronics-related problems!

The forum also plays host to much input by the late John Becker, *EPE's* technical editor who created a vast array of PIC-powered designs and really helped to shape the market at that time. (John once told me that it was typical to get 80 or more emails over a weekend when his latest PIC project appeared, and he would answer them all individually.) The forum provided a new and more interactive medium in which to share hints and tips with fellow electronics enthusiasts. We have always endeavoured to manage the forum with a light touch, and we are proud to have successfully fostered a spirit of friendliness and cooperation among our electronics fraternity – most of the time anyway!

The original *EPE Chat Zone* was launched in the late 1990s when the web was young and *EPE* was dipping its toes into the online arena for the first time. It is hard to believe today, but the original forum was a simple 'threaded' one, where anybody could post anything. This interaction was a new experience for many *EPE* readers, and many enjoyed its simplicity, but so did Russian hackers who broke the forum after learning how to use bots to post spam links automatically. Sadly, our first *EPE Chat Zone* (based on Matt's free wwwboard script) became inoperable after being spammed to death and it was put out of commission for a period.


Welcome to the EPE Chat Zone

EPE Chat Zone
Message Board

This Chat Zone is for the benefit of EPE readers and guests, to discuss magazine-related topics and to exchange views, hints and tips. The magazine editors can't promise a personal follow-up to readers' queries raised in the EPE Chat Zone, but we do check in from time to time, so you never know!

- Start a new subject at any time. Please use a subject heading which clearly indicates the subject under discussion. Prefix with WTB: or FS: for readers' "small ads." (see AUP).
- We want everyone to enjoy using this service. All posts made in the EPE Chat Zone must comply with our Acceptable Use Policy - please read this first.
- Messages will be refreshed at regular intervals - be sure to check back for a reply!

| Acceptable Use Policy | Post A Message | Queries or Complaints | EPE Home Page |

The current Chat Zone appears below. If necessary, "refresh" your screen after posting a message.

UNDER CONSTRUCTION – PLEASE DO NOT POST - **EPE Webmaster** *19:42:46 14/6/2003* (0)

Pawn Shop TV - **Cindy** *04:27:58 14/6/2003* (4)

- Re: Pawn Shop TV - **Alex Wilkinson** *14:19:09 14/6/2003* (0)
- Re: Pawn Shop TV - **Boris** *06:13:09 14/6/2003* (2)
  - Re: Pawn Shop TV - **Alan Winstanley - EPE** *11:10:24 14/6/2003* (1)
    - Re: Pawn Shop TV - **Charles** *16:04:55 14/6/2003* (0)

Glow in the dark - **John North** *21:03:12 13/6/2003* (3)

- Re: Glow in the dark - **Alex Wilkinson** *00:02:44 14/6/2003* (0)
- Re: Glow in the dark - **Sam** *23:48:28 13/6/2003* (1)
  - Re: Glow in the dark - **Boris** *03:14:57 14/6/2003* (0)

Rectangular holes in Plastic - **Terry Mowles** *06:13:48 13/6/2003* (6)

- Re: Rectangular holes in Plastic - **Aubrey Scoon** *20:16:19 13/6/2003* (0)
- Re: Rectangular holes in Plastic - **Boris** *19:57:40 13/6/2003* (0)

The original EPE Chat Zone *from 1998 was fatally flawed: anyone could post a message, including spammers*

In 2005, we launched the new *Chat Zone*, a Perl-based system based on DiscusWare. It brought us new features including user logins and despite its outward simplicity, unlike any other forum system, its powerful mark-up language allowed users to post messages containing precise scientific notation and equations.

A lot of round-the-clock, routine maintenance has gone on behind the scenes, including one time when the writer was managing some very difficult threads using his smartphone, literally while pushing a shopping trolley around Tesco! Over the past dozen years, the DiscusWare forum has proven to be resilient and robust, if not quirky. From the writer's point of view the software has never missed a beat, a testimony to its original programmer. That is more than could be said for many popular forum systems that require constant maintenance, patching and upgrades. Our excellent ISP, Swift Internet in Birmingham, also helped us maintain server compatibility with this ageing software by rolling back some server updates, as well as restoring from the odd backup or two! More than once we thought the forum must surely be on its last legs, but Swift Internet saved the day.

Long gone

In the event, the software vendor DiscusWare disappeared without trace just as we ordered an upgrade, an early warning sign that the writing was perhaps on the wall. This left us with a forum without any technical support and no way of upgrading it, but we have continued to manage it carefully while crossing our fingers, curating readers' posts and systematically archiving them. Spammers have once again learned to use bots to automatically apply for user accounts; and while there has never been a problem with spam itself, the need for constant vigilance has become a burden. Even today, applications for user accounts from spammers continue to drip-feed their way into the admin system… as I type this issue of *Net Work*!

Bringing matters up to the present time, it would be true to say that the volume of traffic has dwindled dramatically compared with the forum's halcyon years of the mid-late-2000s. Now, only a smattering of posts appears every week, burdening us with maintaining the forum for the benefit of a handful of regular users. This partly reflects the fact that readers move on to other interests, of course, but there is now tremendous competition from Facebook and other forums as well. Users tend to blip in and blip out again, en route to some other online destination. More issues have surfaced that finally led us to decide to switch this forum to read-only mode; utmost in our minds is the need for upholding data security and we feel that this legacy forum is outclassed, judging by current expectations, and would only ever become more vulnerable, which is why we have also decided to remove users' private details from the server in due course.

Messages capture the spirit of the time, but become less relevant as time moves on. It's our desire and intention to keep the forum running for as long as is technically feasible to act as a reference resource. The ongoing need for server updates and the lack of software upgrades means there is always the possibility that one day in the future it may prove impossible to maintain the forum and its contents may finally be lost for ever.

Looking ahead

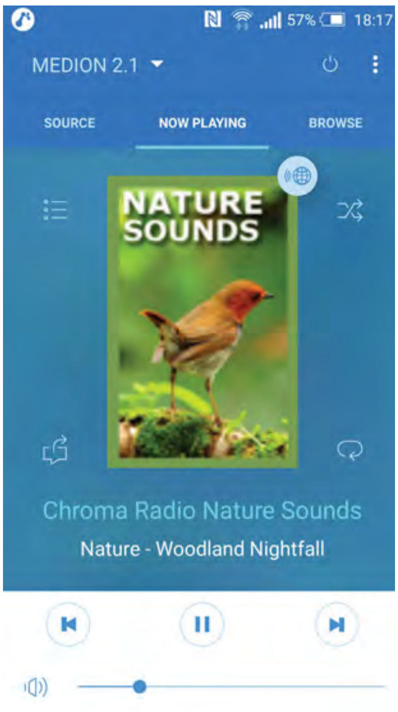
Putting the disappointment to one side, we want to re-assure readers that at the time of writing we are still weighing up some options to give *EPE Chat Zone* users a new home under the *EPE* 'umbrella'. We fully intend to support our group of loyal users and keep them together! We expect to have our own special group on the highly respected and renowned EEWeb electronics forums. Apart from having a new home, there is also the option of a closed Facebook group for those who use Facebook regularly. We will post news into the forum and, as always, help from *EPE* is only ever an email away.

There's no doubt the *EPE Chat Zone* has hosted some exciting and rewarding times over the past dozen years, and it has been an important part of enthusing our readership, but as the saying goes, it's better 'to wear out than rust out', and we will certainly be keeping readers posted with new developments in the *Chat Zone*, of that you can be assured.

If you're in a reminiscing mood, recall that we also publish summaries of all our projects with photos dating back to the year 1998, which can be viewed online at **www.epemag.com/projects-legacy.html**. Source codes for legacy PIC projects, including John Becker's famous PIC Toolkit TK3 are preserved for retro-compatibility on a separate website that I maintain, see **www.epemag.net**

Medion Internet Radio

Talking of trying to keep things going, even when seemingly reaching their end of life, in June's issue of *Net Work* I bemoaned the fact that my near-ten-year-old Pure Evoke Internet radio was becoming a bit bothersome. (Recall that Pure was hived off by owners Imagination Technologies last year.) I tune in to various Internet stations as a routine and the faithful radio keeps me company when I'm beavering away here in my worklab. Its OLED display had started to lose its luminance to the point that the super-vivid yellow digital readout was virtually blank. The only UK supplier of a spare, RS Components, silently cancelled my order, and searching online for a new Bolymin OLED display has proved fruitless, unless I want to buy 5,000 from Hong Kong. Regrettably, it was time to pension off another familiar favourite. I was gutted!



Medion's 2.1 Android app allows source, favourites and volume to be managed on a smartphone

The German brand Medion is probably best known to UK readers for its range of laptops, PCs and other IT peripherals, but they also quietly market a very interesting range of AV and domestic home electronics in Britain. One product that previously caught my eye was the Medion 2.1 Wireless LAN Internet Radio, a small-ish radio whose specifications looked extremely appealing. Not only does it have stereo twin speakers, but also the '2.1' alludes to the bonus of a small woofer mounted on top. The radio is rated at 2 × 4W + 1 × 12W RMS, which is very respectable for a small cabinet. Digging deeper into the Medion specs, I found this radio has built-in 2.4/5GHz Wi-Fi, as well as an RJ45 port for Ethernet, so you could hard-wire it to a LAN if Wi-Fi won't reach.

The Medion 2.1 Internet Radio has stereo speakers, a modest colour LCD, 2.4/5GHz Wi-Fi, RJ45 LAN, DAB+, FM, DLNA, IR and smartphone remote control, and to round it all off, a very reasonable woofer

In addition to the radio's Internet awareness, it includes a DAB+, an FM radio tuner, and a USB port for hosting, say, MP3 or WMA files on a memory stick. It also has a 2.4-inch colour LCD, plus headphone, stereo line-in and line-out sockets. There's more: the radio is DLNA-compatible, so it will play music hosted on a compatible home network. The tabletop radio does not have battery-powered portability (nor a carrying handle) but, unusually these days, a separate power on-off rocker switch is provided on the rear.

All the usual digital alarm clock functions are included: two alarms, snooze and sleep timers. An IR remote control is supplied and there's more: an app is available allowing the radio's basic functions to be controlled using a smartphone. Sold!

Sprechen sie Englisch?

It wasn't long before this radio was in my hands, thanks to Medion's super-efficient delivery. The first job was to select an English display because the radio receiver shows German by default. Helped by my schoolboy German and a menu flowchart included in the substantial manual, the LCD was reconfigured for English commands. It was straightforward to hook it to my Wi-Fi or tune into DAB stations almost immediately; the start-up 'boot' period is very fast. The app took a bit of fiddling with, but not much, and soon the remote control app was working on my Android phone – this provides just a basic on-off control, as well as selecting the radio's basic function or favourites, but it also shows program information (eg, what's playing). It works commendably well for the writer, but one or two users have grumbled about it. The radio also found my network music on my Synology NAS straight away.

The colour LCD display is somewhat low-rent and of the sort found on a DECT cordless phone. It would never match the Pure's OLED display for luminance or clarity, and it has quite a narrow (but acceptable) viewing angle. The sound output I found to be terrific! The addition of a woofer makes all the difference and the radio receiver fills a room with a sound that belies its small size (235×129×130mm).

The Medion2.1 Internet radio has all the features you need in a tabletop radio and I hope to be able to give readers an update in another ten year's time. A two-year warranty is provided and it can be bought direct from Medion at: **http://tinyurl.com/ybw54s3c**. Here's a tip: it's a good idea to set up an online account first, and then set up a 'Wish Price' target of £49.99 to be alerted of the best possible price, as these vary periodically.

That's all for this month's *Net Work*. The writer can be contacted by email to **alan@epemag.net**

EPE EVERYDAY PRACTICAL ELECTRONICS BACK ISSUES

CATCH UP ON WHAT YOU HAVE MISSED

We can supply back issues of *EPE* by post, most issues from the past five years are available. An *EPE* index for the last five years is also available at **www.epemag.com**. Where we are unable to provide a back issue a photocopy of any one article (or one part of a series) can be purchased for the same price. Issues from Jan. 99 are available on CD-ROM or DVD-ROM – and back issues from recent years are also available to download from **www.epemag.com**. Please make sure all components are still available before commencing any project from a back-dated issue.

OCTOBER '16

PROJECTS • Arduino-Based USB Electrocardiogram • 5-Element Yagi Antenna • Compact Hybrid Switchmode 100W Bench Supply – Part 2 • **FEATURES** • Techno Talk • Teach-In 2016 – Exploring The Arduino – Part 9 • Net Work • PIC n' Mix • Circuit Surgery • Audio Out • Electronic Building Blocks • Practically Speaking •

NOVEMBER '16

PROJECTS • Fingerprint Access Controller • Cheap Programmer For The PIC32 Microcontroller • Compact Hybrid Switchmode 100W Bench Supply – Part 3 • Ingenuity Unlimited • **FEATURES** • Techno Talk • Teach-In 2016 – Exploring The Arduino – Part 10 • Net Work • PIC n' Mix • Circuit Surgery • Audio Out • Electronic Building Blocks • Interface • Max's Hot Beans •

DECEMBER '16

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PROJECTS • High-Performance Stereo Valve Preamplifier – Part 1 • High Visibility 6-Digit LED GPS Clock – Part 1 • 5-Element Yagi Specifically For DAB Radio • **FEATURES** • Techno Talk • Teach-In 2016 – Exploring The Arduino – Part 12 • Interface • Net Work • PIC n' Mix • Circuit Surgery • Audio Out • Electronic Building Blocks • Max's Hot Beans

FEBRUARY '17

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MAY '17

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JULY '17

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PROJECTS • Touch-Screen Boat Computer With GPS • Fridge/ Freezer Alarm • Micromite Plus & The Explore 64• **FEATURES** • Techno Talk • Teach-In 2017 – Introducing The BBC micro:bit – Part 3 • Net Work • PIC n' Mix • Circuit Surgery • Audio Out • Max's Cool Beans

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M10/17

PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

Simple PIC Sinewave Generator – Part 2

LAST MONTH, we looked at the hardware for the *Simple PIC sinewave generator*, and I hope by now your circuit is built and waiting to be programmed. If not, check out last month's article for details on how to build the circuit and what components are needed – it's just four LEDs, a potentiometer, button switch, PIC16F1829 and a passive RC filter circuit feeding a buzzer.

This simple hardware doesn't involve very much – the magic is all in the software. Some of the concepts and maths are a little complicated, so we'll break them down into manageable chunks.

I explained last month that I want to use as much as possible from the *Beginner's Guide*, including PWM, the PIC's ADC, button debounce, interrupts and look-up tables. (I know we recently looked at EEPROM, but there's no real use for it in this project, so that will not be included in this project.)

Our aim is to output three different waveforms: a sinewave, a square wave and a triangle wave. The LEDs will indicate which waveform is currently being output. The potentiometer will allow us to alter the frequency within a specific range. The buzzer will output the different waveforms, allowing us to hear the tonal difference between each one.

The filter

The PIC16F1829 doesn't have a DAC (digital-to-analogue converter), so there is no way to output anything other than a digital high or low voltage value. This means we have to find another way to produce a sinewave. Using the PWM module in the PIC it is possible to output a signal that can then be filtered in order to obtain a sinewave. The PWM normally operates around 20kHz up to 50kHz, which ensures that it is outside the audible range.

We're looking to output a signal around 1kHz so we can hear it on a buzzer or transducer. We use an external analogue filter that passes the 1kHz output signal, but blocks the 20kHz to 50kHz PWM signal. By modulating the duty cycle on the PWM, it is possible to produce an analogue signal in a much lower frequency. The filter effectively averages the PWM signal so that individual pulses can no longer be seen.

Fig.1 shows the filter's schematic, and you can see it's a three-stage low-pass filter. Low-pass filters allow any frequency below a certain value and attenuate (or block) any signal above that frequency.

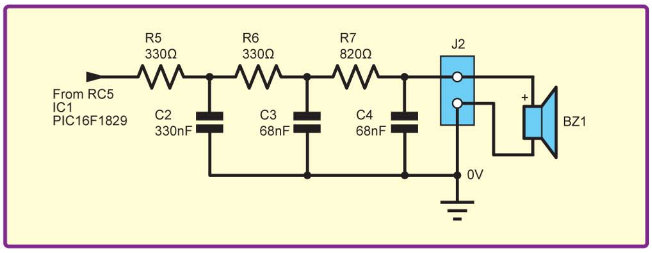

Fig.1. Schematic of the 1kHz analogue filter

R5 and C2 form the first stage of the filter, passing signals below around 1kHz. Using the illustrated component values we can calculate the cut-off frequency (f_c):

$f_c = 1/2\pi RC$

$f_c = 1/2 \times 3.141 \times 330 \times 330 \times 10^{-9} =$ 1462Hz

Here, R = R5 and C = C2. This means our signal will be attenuated (reduced) by 3dB at 1462Hz (the signal will be halved at this frequency). Any frequency above this value will be seen at the input of the filter, but is blocked by the filter and barely seen on the output. It may still be just visible, but it's only a small fraction of its original voltage.

The second stage of the filter with R6 and C3 works out as:

$f_c = 1/2 \times 3.141 \times 330 \times 68 \times 10^{-9} =$ 7096Hz

The third stage of the filter with R7 and C4 is calculated as:

$f_c = 1/2 \times 3.141 \times 820 \times 68 \times 10^{-9} =$ 2855Hz

The second and third stages filter out higher harmonics. The key thing to understand about single-stage filters is that they filter a specific frequency, but when placed together in a ladder formation as in Fig.1 they interact with each other. The maths does get complicated, but it's safe to say in this case, the cut-off frequencies of the second and third stages don't change that much, so we won't worry about these interaction effects.

Look-up tables

We mentioned the use of look-up tables in order to shape the sinusoidal waveform. As we will see later in the code section, this is an array of pre-calculated values. These values were calculated using Microsoft Excel (spreadsheet). What we need is a range of values that gives us a percentage duty cycle from 0% to 100%.

The equation used in Excel is as follows, where `X` ranges from 1 to 50:

```
=(100*(SIN((X/50)*2*π))+100)/2
```

Looking at this equation, it takes the sine of a fraction of 2π, which represents 360 degrees in a circle. We set a timer in the PIC to 20µs, which triggers an interrupt, at which point the duty cycle on each pulse is changed. A period of 20µs means a frequency of 50kHz for the PWM. To produce a 1kHz signal with a period of 1ms, the PWM frequency must produce 50 pulses during each 1ms period.

For the look-up table, this means finding 50 values to cycle through in each period. In the equation above, we want 50 points in the circle so we multiply 2π by `X/50`, where `X` ranges from 1 to 50, giving us 50 points. The `SIN` function produces values in the range from 1 to –1. We need to scale this up, so we multiply each value by 100, producing a range from 100 to –100. To make all the values positive, we add 100 to the result, creating a range from 0 to 200. Finally, the results are divided by 2, to produce a nice, neat range from 0 to 100. As an example, let `X` = 25:

```
=(100*(SIN((25/50)*2*π))+100)/2
=(100*(SIN(π))+100)/2
=(100*(0.05) +100)/2
=(5+100)/2
=105/2
=52.5
```

It's easier to work with integers with the PIC, so anything after the decimal point is ignored. We can now draw a single sinewave through 360 degrees with 50 points. (We could increase the number of points on the wave to improve the shape of the waveform.) Each of the calculated values represents the percentage duty cycle – from 0% to 100% – to be used with the PWM when the values are loaded into the CCPR1L register.

The potentiometer

We've used potentiometers in previous months for digital control, and this circuit is no different. The potentiometer is wired between VCC and ground, with the wiper connected to an ADC pin on the PIC.

So how does this change the frequency? The value captured on the ADC pin is used as the control value. This value is loaded into the PR2 register, which is the Timer2 Period Register. (Here, the period is defined as the distance between the peaks of a repeating wave.) Remember that period is the inverse of frequency, so when we change the period, we in turn change the frequency. This register is how the PIC determines the output frequency of the PWM.

The ADC value captured by the module in the PIC is 10 bits long; however, the PR2 register is only 8 bits long. The ADC result is therefore split between two registers – the higher ADRESH and the lower ADRESL. Since the ADC result is left aligned (selected in the code below), the ADRESL register will contain the two least-significant bits. If we ignore this register, we can simply copy the contents of the ADRESH register straight into the PR2 register. This will give us complete control of the minimum and maximum period.

Using this approach, the frequency range we can achieve is 200Hz to 1kHz. (However, once the PR2 register value goes very low, the PWM module doesn't work very well with the output filter.)

Looking at the code

Let's take a look the actual code used to produce the various outputs to the filter/buzzer. Fig.2 shows a flowchart describing the initial setup of the code before entering the main `while` loop. Fig.3 shows the flow of the code in the main `while` loop. First, we set the LED based on which mode (sinewave, triangle or square) has been selected. Then we enter the selected mode and stay there until the mode is changed. In each mode, the duty cycle will be continually altered as the loop steps through the selected values in the mode-specific look-up table.

```
#include <htc.h>
#define _XTAL_FREQ 500000
#define DOWN 0
#define UP   1
#define SWITCH   PORTAbits.RA2
#define PULL_UPS
```

The above piece of code includes the 'htc' header file, which is the Hi-Tech C Compiler for PIC16 MCU's. The code

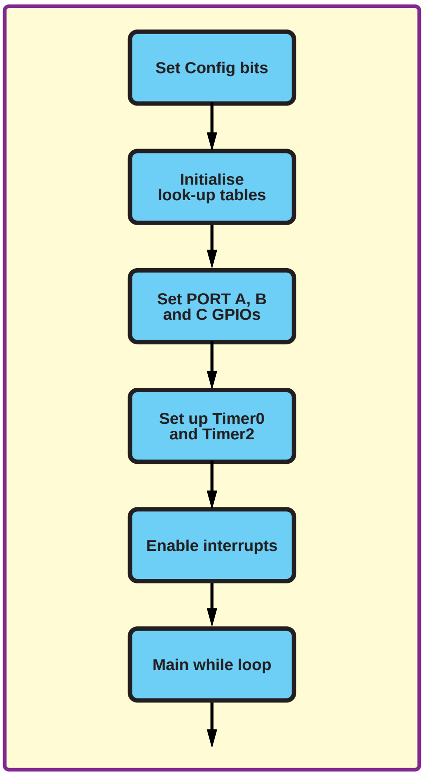

Fig.2. Flowchart of the software flow for the PIC initialisation

also defines the value `_XTAL_FREQ` frequency as 500kHz. This definition is used to calculate any delays in the code. Next, we define a few variable names that will make the code easier to understand. The `SWITCH` definition

```
#define SINE_WAVE    0
#define SQUARE_WAVE  1
#define TRI_WAVE 2
```

is mapped to the state of Port A2. Next, values for each mode of operation are defined. These will later be mapped to the LEDs to indicate which mode is currently selected.

```
__CONFIG(FOSC_INTOSC & WDTE_
OFF & PWRTE_OFF & MCLRE_OFF
& CP_OFF & CPD_OFF & BOREN_ON
& CLKOUTEN_OFF & IESO_OFF &
FCMEN_OFF);
__CONFIG(WRT_OFF & PLLEN_OFF
& STVREN_OFF & LVP_OFF);
```

We've looked at these lines before in the *Beginner's Guide*. These are the configuration bits to set up the basic behaviour of the PIC. See Part 3 of the *Beginner's Guide* for a better understanding of what these mean and how they work.

```
unsigned char pwmstep;
unsigned char pwmval;
unsigned char debounce;
unsigned int pwmMode = 0;
```

Now we setup a few variables that will be used later in the code.

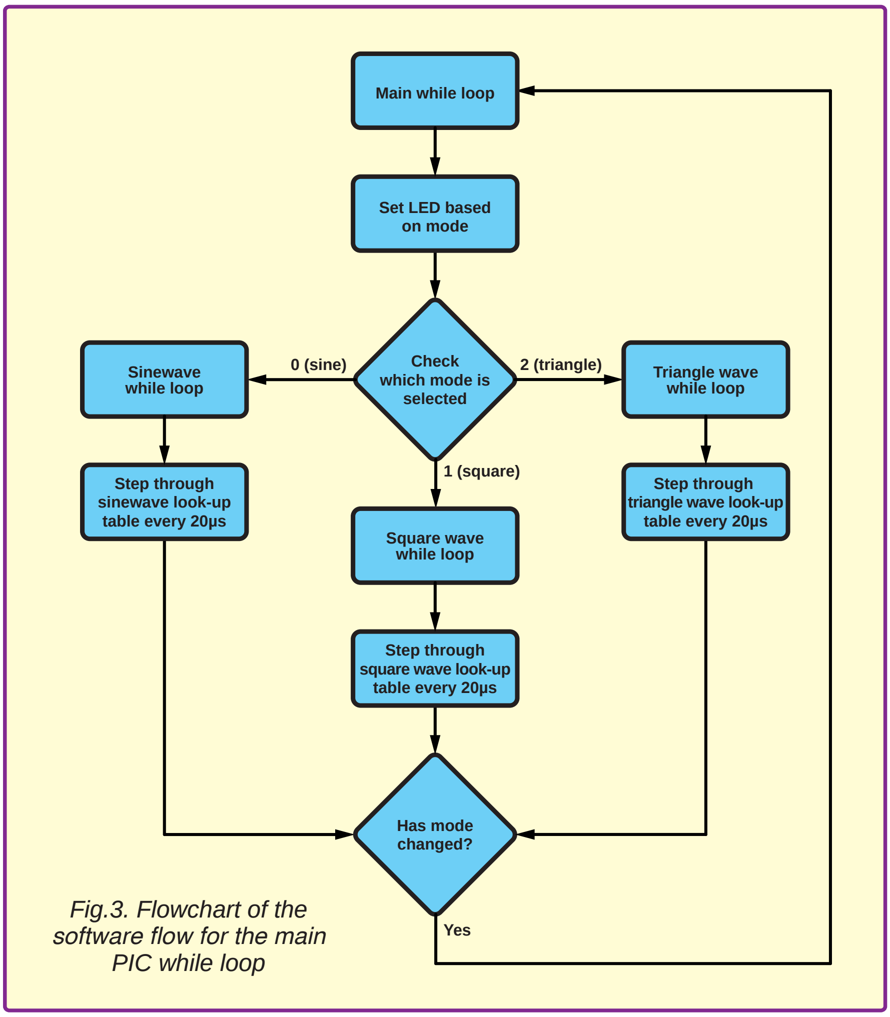

Fig.3. Flowchart of the software flow for the main PIC while loop

```
const unsigned char sine[50] = {56,62,68,74,79,84,88,92,95,97,
                                99,99,99,99,97,95,92,88,84,79,
                                74,68,62,56,49,43,37,31,25,20,
                                15,11,7,4,2,0,0,0,0,2,
                                4,7,11,15,20,25,31,37,43,50};

const unsigned char square[50] = {0,0,0,0,0,0,0,0,0,0,
                                  0,0,0,0,0,0,0,0,0,0,
                                  0,0,0,0,0,
                                  100,100,100,100,100,100,100,100,100,100,
                                  100,100,100,100,100,100,100,100,100,100,
                                  100,100,100,100,100};

const unsigned char triangle[50] = {0,4,8,12,16,20,24,28,32,36,
                                    40,44,48,52,56,60,64,68,72,76,
                                    80,84,88,92,96,100,96,92,88,84,
                                    80,76,72,68,64,60,56,52,48,44,
                                    40,36,32,28,24,20,16,12,8,4};
```

The above code shows the three look-up tables, which are assembled from constant unsigned 'chars'. This indicates these values will not be changed throughout the course of the program execution. The calculation of the sinewave values was discussed earlier. As can you might expect, the square wave values are simply on / off (0 or 100). The triangle look-up table rises and falls in a linear fashion throughout the 50 points.

```
void main() {

    C1ON = 0;
    C2ON = 0;
    PORTA =     0b00000000;
    TRISA =     0b00000100;
    ANSELAbits.ANSA2 = 0;
    PORTB =     0b00010000;
    TRISB =     0b00100000;
    ANSELBbits.ANSB5 = 1;
    PORTC =     0b00000001;
    TRISC =     0b00000000;
```

These next few lines set up the GPIOs on the PIC. `C1ON` and `C2ON` turn off the comparators. These aren't really necessary, but are included as a precaution. Port A2, which represents the button switch state is made digital using `ANSELAbits.ANSA2 = 0;`

The input from the potentiometer on Port B5 is an analogue pin, so it is selected using `ANSELBbits.ANSB5 = 1;`

```
OSCCON = 0b00110000;
ADCON0 = 0b00101101;
ADCON1 = 0b00010000;
```

These lines set the internal oscillator to 500kHz and set up the ADC module. The ADC module is assigned to `AN11` (also known as Port B5) and is enabled.

```
#ifdef PULL_UPS
    WPUA2 = 1;
    nWPUEN = 0;
#endif
```

Most of the above code should be familiar to you, but the next piece of code is new. The `#ifdef` statement checks to see if the variable `PULL_UPS` is defined. If it is defined, it will set the internal pull-ups on Port A2 using `WPUA2`. Next, `nWPUEN` enables individual pull-ups defined in the `WPU` latch values.

As we saw in the code earlier, `PULL_UPS` is defined, so the internal pull-ups on Port A2 (which is connected to our button) are enabled. By commenting out the definition for `PULL_UPS`, we can disable the pull-ups. (This is a handy way to make changes to the program without having to find the specific lines of code again.)

```
OPTION_REG = 0b00000111;
INTCONbits.TMR0IE = 1;
INTCONbits.IOCIE = 1;
IOCANbits.IOCAN2 = 1;
GIE = 1;
```

Next, we need to define the prescaler rate select bits in the `OPTION_REG` register. This is set to 1:256. Then we initialise the interrupts for `Timer0` and interrupt on change for Port A2. Once these have been completed, global interrupts are enabled.

```
  T2CON = 0b00000100;
    PR2 = 0x80;
    __delay_ms(300);
    pwmstep = 0;
    debounce = 0;
```

Timer2 is specifically used for the PWM module. `T2CON` sets the prescaler to 1 and enables the timer. Next, we set the period in the `PR2` register to 128.

```
 while(1) {
        if(pwmMode == SINE_WAVE) {
            PORTC = 0b00000001;
        } else if (pwmMode == SQUARE_WAVE) {
            PORTC = 0b00000010;
        } else if (pwmMode == TRI_WAVE) {
            PORTC = 0b00000100;
        } else if (pwmMode == CAL_WAVE) {
            PORTC = 0b00001000;
        } else {
            pwmMode = 0;
            PORTC = 0b00000001;
        }
```

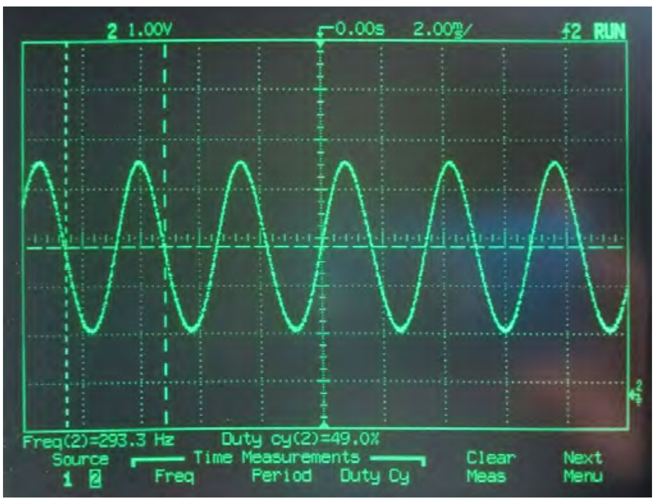

Fig.4. Oscilloscope capture of the output sinewave

Then we enter the `while` loop. This piece of code, checks to see which mode is currently selected and sets the output of Port C accordingly. From our schematic last month, Port C is connected to the three LEDs.

```
if(pwmMode == SINE_WAVE) {
       CCP1CON = 0b00001111;
       while(pwmMode == SINE_WAVE) {
           while(!TMR2IF);
           CCPR1L = pwmval;
           TMR2IF = 0;

           pwmstep++;
           if(pwmstep >= 50) pwmstep = 0;
               pwmval = sine[pwmstep];
       }
   } else if(pwmMode == SQUARE_WAVE) {
       CCP1CON = 0b00001111;
       while(pwmMode == SQUARE_WAVE){
           CCP1CON = 0b00001111;
           while(pwmMode == SQUARE_WAVE) {
               while(!TMR2IF);
               CCPR1L = pwmval;
               TMR2IF = 0;
               pwmstep++;
               if(pwmstep >= 50) pwmstep = 0;
                   pwmval = square[pwmstep];
           }
       }
   } else if(pwmMode == TRI_WAVE) {
           CCP1CON = 0b00001111;
           while(pwmMode == TRI_WAVE) {
               while(!TMR2IF);
               CCPR1L = pwmval;
               TMR2IF = 0;
               pwmstep++;
               if(pwmstep >= 50) pwmstep = 0;
                   pwmval = triangle[pwmstep];
           }}}}}
```

Now we look at the code that does all the magic. Each selection is exactly the same. First we check to see which mode we are in. Then we enable the PWM output using the CCP1CON control register. A `while` loop then steps through the look-up tables every time the Timer2 interrupt flag is set. When the flag is set, the last value of `pwmval` is loaded into the CCPR1L register to be used for the next pulse. The interrupt flag is reset, the `pwmstep` is then incremented to the next value in the look-up table, and if less than 50, it is loaded into the `pwmval` variable to be loaded into the CCPR1L register the next time the Timer2 interrupt is set.

```
void interrupt ISR(void) {
    if (IOCAF) {
        IOCAF = 0;
        __delay_ms(300);
        if (SWITCH == DOWN) {
            pwmMode++;
            if(pwmMode > 2) {
                pwmMode = 0;
            }
        }
    }
    if (INTCONbits.T0IF) {
        INTCONbits.T0IF = 0;
        __delay_us(5);
        GO = 1;
        while (GO) continue;
        PR2 = ADRESH;
    }
}
```

The last part of the code is the interrupt service routine (ISR). We actually have three interrupts, but we only manage two of them here. `IOCAF` looks for a change on Port A2, which is connected to the button. When the button is pressed, we clear the flag, then add a 300ms button-debounce delay. Next, we check if the `SWITCH` is still down and increment the `pwmMode` to the next setting.

The second interrupt is the `Timer0` interrupt, which does an ADC conversion and then loads the contents of `ADRESH` into the `PR2` period register. This is how the potentiometer is used to alter the frequency of the output.

The third is actually Timer2. The interrupt flag is not serviced in the ISR. It is actually controlled in the mode-select loops mentioned above. This goes to show not all interrupts need to be serviced immediately, which is what the ISR will do. The Timer2 interrupt flag could be set a little longer, until it is seen by the code. This doesn't cause problems with the Timer, although it is important to note that the Timer2 value will contain the maximum value and will not be counting anymore until the flag is reset.

Last, but not least, I almost forget to mention you can download all the code for this project from the *EPE* website.

Operation

Once the PIC has been programmed, it should be possible to hear the three different outputs on the buzzer. The sinewave should produce a clear tone. Fig.4 shows what the output looks like on an oscilloscope. It is possible to see some ripple, but it is very small. The square wave sounds like old PC games tone. Fig.5 shows what the output of this looks like. Notice how the filter rounds the top of the corner on the rising edges. Using mathematics (Fourier analysis) you can show that a true square wave will contain high-frequency harmonics and of course the low-pass filter has removed anything over 1kHz. The result is the distorted square wave seen on the scope trace.

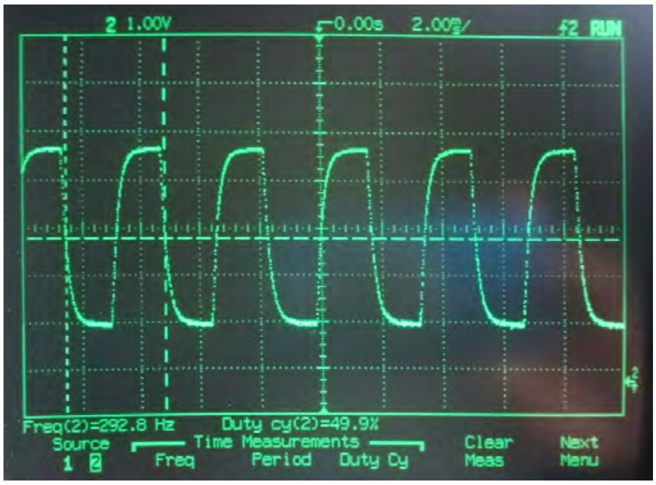

Fig.5. Oscilloscope capture of the output square wave

The triangle wave sounds a little less harsh than the square wave. Fig.6 shows what this looks like when captured on an oscilloscope. Again, the filter has removed higher harmonics and the result is a respectable, but

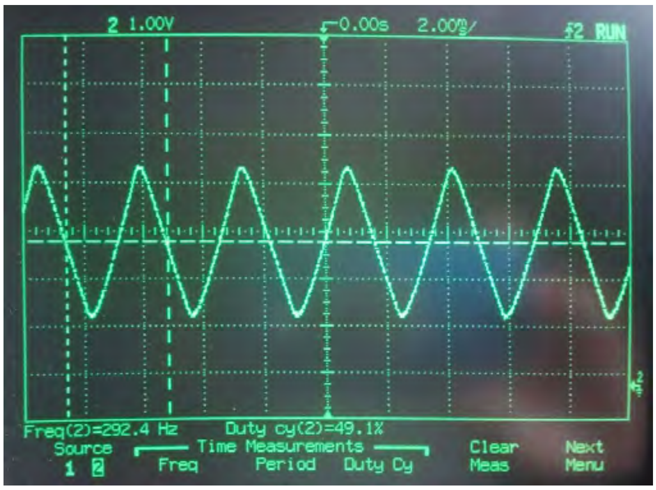

Fig.6. Oscilloscope capture of the output triangle wave

distorted signal. It does look reasonably straight, but it is a little rounded at the top and bottom.

Conclusion and acknowledgement

This circuit was not designed to replace your trusty signal generator, but to demonstrate how even a simple PIC circuit with some carefully designed code can produce useful results. What we have achieved here is actually quite interesting. Using just a PWM-modulated digital waveform we have managed to produce some respectable variable-frequency analogue waveforms – no DACs were used! With a little ingenuity you should be able to produce your own waveforms – sawtooth, rectified sinusoids and so on.

Last, but not least, I must thank the designer/constructor at the website **www.romanblack.com/onesec/Sine1kHz.htm**. He had already made a fixed-frequency, sinewave-only version of what I was aiming for, so I used his circuit and code as inspiration for my variable-frequency, triple-waveform design. There are similarities between our two designs, but I did make a lot of modifications to his code. It's always a good idea to hunt around online for ideas, hints and clues, but if you publish your work, even if only on your own website, then do make sure you acknowledge other people's work.

My thanks to ***james***, who commented on *Chat Zone*, 'There are a couple of gremlins for Part 1 of the Simple PIC Sinewave Generator. First, LEDs 1 to 4 are listed in a different order in the schematic (Fig.2.) to that shown in the build diagram (Fig.3.). This wouldn't really matter except that LED1 is specified as a green LED and the others are red.' Well spotted ***james***! The LEDs are indeed in a different order on the schematic (Fig.2) compared to the veroboard diagram (Fig.3). The veroboard diagram has the correct numbering for the LEDs. In the schematic, D1 should be swapped with D4, D2 should be swapped with D3. D4 is the green LED and is used to indicate that the board is powered. D1, D2 and D3 are all red LEDs and are used to indicate which mode is selected.

'Second, resistors R1 to R4 are specified as 220R on the schematic (Fig.2.) but as 1kΩ on the component list.' Within reason, it doesn't make too much difference if a little extra (or a little less) LED current flows, but inconsistency in text and diagrams is always to be avoided. There is no harm in using a 1kΩ resistor, and if your LEDs are not bright enough then simply drop the resistance – perhaps first to 470Ω, and then lower if necessary

Next month

That concludes the *Simple PIC sinewave generator*. We might return to it at a later time with a better PIC using a DAC and an NCO to output much greater frequencies with a greater resolution. Next month, I'd like to take a closer look at some of the extra features in the MPLAB X IDE; for example, Microchip's Code Configurator, which can ease some of the GPIO setup at the start of any project.

Digital signal syntax and temperature sensors

WE RECEIVED an email from Richard Phillips asking about the nomenclature of the digital signals used in the article *Logic Timing and Timing Diagrams* in the May 2017 issue of *EPE*. He writes: 'Please refer to Fig.2 on page 52 (repeated and expanded here as Fig.2). I am not sure how to interpret the label on the third waveform from the top which is labelled `Value<3:0>`. Also, on Fig.2, `Q<3:0>` on the fourth line from the top. In Fig.1 (repeated here as Fig.1), the `D` inputs of the presettable counter has `Value<2:0>`. I had thought that the numbers inside the `<*:*>` may refer to the number of input and output paths or maybe the decimal value of possible binary values. I am not sure. Please explain.'

First, there is a minor error on the timing diagram in the original article in that `Value` and `Q` are designated `<3:0>`, but they should be `<2:0>` to match the schematic (corrected in Fig.2 here). Apologies for any confusion caused by this.

Signal index

The `<n:m>` format is short hand for the set of index values for a multi-bit signal (commonly referred to as a bus). For example `Q<2:0>` refers to *three* wires, signals, or I/O connections with the individual names `Q2`, `Q1` and `Q0`, or more correctly, following this format, `Q<2>`, `Q<1>` and `Q<0>`. Single-bit signal wires are given names without any index syntax, for example `Load` and `Clock` in the figures. Fig.2 here is expanded with respect to the original article to show the individual signals of `Value` and `Q` in addition to their collective values.

Signal naming formats like these are commonly used in computer-aided design tools, such as logic simulators, although they do not all use the same syntax. Other examples include `Q[2..0]` and `Q[2:0]` for a multi-bit signal and correspondingly `Q[2]`, `Q[1]`, `Q[0]` for the individual wires (in both cases). This approach allows one line or I/O port to be drawn on a schematic and labelled in such a format to represent many wires. This is particularly efficient for signals with many bits – eg, `DATA<31:0>` for a 32-bit value.

This labelling format is related to computer code syntax – it is similar to the idea of an array index in a programming language like C. Syntax like this also occurs in Hardware Description Languages (HDLs) such as Verilog and VHDL. HDLs typically provide the means to define the required behaviour of a circuit (what it should do) as well as structure (how its components are wired up). A behaviour description is used by a synthesis tool, which automatically creates the low-level hardware structure (circuit of gates and flipflops). This is analogous to a compiler creating low-level machine code from software written in a high-level programming language. For the `Q` signal discussed here, Verilog uses a syntax of the form `Q[2:0]` mentioned above, whereas VHDL uses the forms `Q(2 downto 0)` for a multi-bit signal and, for example, `Q(2)` for individual bits.

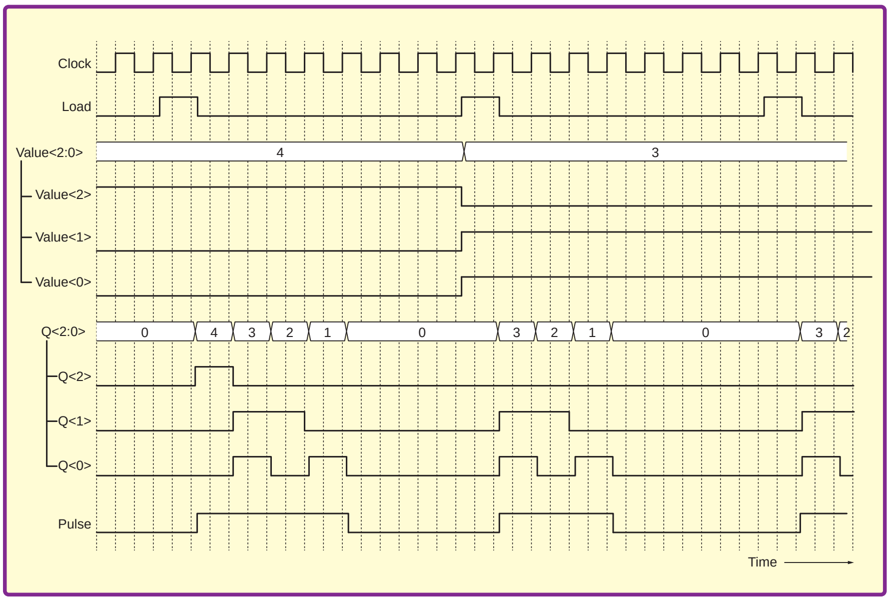

Fig.2. Timing diagram of pulse generator circuit referred to in Richard Phillips' question (from EPE May 2017). This version of the diagram is expanded to show the individual signals (bits) on the `Value<2:0>` and `Q<2:0>` buses, as well as the value of the bus as a whole.

Data on buses

A key idea here is that it is common for digital signals to be in the form of buses where multiple parallel logic signals are used to carry all the bits needed for a data item, such as the value from a counter circuit. In such cases it is common for the individual signals to be given the same base name followed by a number (the index of that signal). If the data is numerical then an index of 0 for the least-significant bit makes sense because 2 to the power 0 is 1; ie, the 'units' of a binary number. The next bit is 1; 2 to the power 1 is 2; ie, the 'twos'. That is why the index numbers in `Q` and `Value` are ordered `<2:0>`, not `<0:2>`. It reflects the fact that we write numbers with the more significant digits on the left. In the timing diagram (Fig.2) `Q` can be seen taking binary values 100, 011, 010, 001 and 000 (4, 3, 2, 1, 0 in decimal) as the counter counts down from the preset value of 4.

On the timing diagram in Fig.2 it is easier to appreciate the behaviour of the circuit by looking at the waveforms depicting the bus as a single numerical value, rather than the expanded form showing each bit independently (as in Fig.2 from the original article). If these signals had many more bits then the advantage of displaying them as a single entity would be greater still. However, sometimes it is useful to be able to see all the details, and tools such as simulators will typically provide the facility to expand the display of a bus in a similar way to that shown in Fig.2.

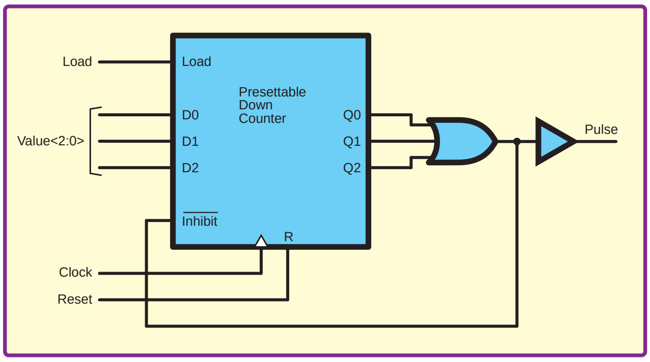

Fig.1. Schematic of the pulse generator circuit referred to in Richard Phillips' question (from EPE *May 2017)*

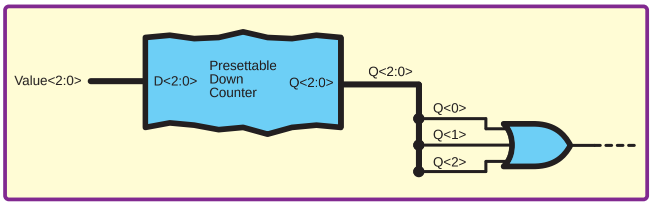

Fig.4. A redrawn version of Fig.3 with the presettable counter ports defined as buses rather than individual bits.

Ambiguity

Strictly speaking, there in an ambiguity in Fig.1 in that it does not actually specify how the 3-bit signal `Value<2:0>` connects to the three individual input ports `D2`, `D1` and `D0` of the presettable counter. The 'obvious' interpretation is `Value<2>` to `D2`, `Value<1>` to `D1`, and `Value<0>` to `D0`, but really the schematic as drawn does not define this.

A second issue with Fig.1 is that the wires connected to the `Q2`, `Q1` and `Q0` individual output ports of the presettable counter are connected to wires that do not have defined names. Again we have an 'obvious' situation, which is that the wire names are the same as the names of the output port of the counter to which they are connected. Furthermore the 'Q' wires are, like the Q output ports, only shown individually; the schematic does not categorically define the existence of a bus `Q<2:0>`, although we can infer one from the individual wires. This may seem like pedantry – in terms of the original article it is probably reasonable to assume the obvious interpretations just mentioned, but in the context of entering the schematic in design tools there is no room for ambiguity and we would have to be more careful.

Fig.3 shows a more formally correct drawing of the Value, D, and Q signals and ports from Fig.1. The input to the pulse generator is defined as a 3-bit bus `Value<2:0>` with individual bits connecting to the `D2`, `D1` and `D0` ports of the counter. The bus is drawn with a thick line to show that it is a multi-bit signal and the individual bits taken off of the bus (sometimes called bus ripping) are identified by their index values – for example, <2>, <1>. The individual Q outputs of the counter are shown connected to a three-bit bus labelled `Q<2:0>` in a similar manner. The individual Q bits are also ripped from the bus to connect to the OR gate. This drawing removes all the ambiguities discussed above, but it is more complex.

A better approach, shown in Fig.4, is to define the D and Q I/O ports of the presettable counter as buses, which then connect more naturally to the external bus signals. There is no ambiguity in Fig.2 – for example, the bits of both the Value and D signals are, in left to right order, <2>, <1>, <0>, so `Value<2>` connects to `D<2>` and so on. If we relabelled the Value bus as `Value<0:2>` then Value<0> would connect to `D<2>`.

Temperature sensors

In a letter to *EPE*, published in the August 2017 issue, Ewan Cameron suggested a number of topics of interest in the context of PIC microcontrollers, including temperature sensing. Building a microcontroller unit (MCU) system which measures temperature (possibly among many other tasks) requires the use of some form of temperature sensor device and associated circuitry. Starting in this article, and continuing next month, we will look at some sensor and circuit aspects of temperature sensing. We will not look in detail at the MCU software (coding is well covered elsewhere in *EPE*), however, to put things in context, it is worth first describing, in very general terms, how temperature sensing is performed by a MCU. We will then look at the range of sensor types available and later cover more details of the associated circuitry.

Typically a (contact) temperature sensor produces an analogue signal (voltage or current), which varies in a well-defined way with the temperature of the sensor. This is converted to a digital representation by an analogue-to-digital converter (ADC), which may be built into the MCU, be part of a temperature-sensing IC, which communicates with the MCU digitally; or it may be a separate converter chip. The MCU reads the ADC (directly or indirectly) to obtain a binary number related to the temperature of the sensor. Usually, this number must be processed in some way to obtain the temperature value on a standard scale, such as degrees Celsius. Often, the processing will be simple (eg, multiply and add) but in some cases, particularly where high accuracy is required the software may perform more complex calculations, or table look-ups, to correct for known inaccuracies in the sensor response.

As already indicated, the MCU temperature measurement code must typically deliver the temperature measurement result on a particular scale and, as there is more than one scale in use, it may need to provide the user with the option to select the scale. There are three common scales in use today: Celsius, Fahrenheit and kelvin. The first two of these are in everyday use, whereas the kelvin scale is widely used in science and engineering.

The Celsius scale is named after its inventor, Swedish physicist and astronomer Anders Celsius, who originally called the scale centigrade or 'one-hundred steps' scale because the scale was calibrated at two points – the freezing and boiling points of water – with 100 steps or degrees between them. The Fahrenheit scale is named after its creator the Polish/Dutch physicist and scientific instrument maker Daniel Fahrenheit. It was the most commonly used scale for everyday temperature description and measurement throughout the world until the 1960s to 1970s, when legislation to adopt metric systems started to require use of Celsius in specific contexts. The US is a notable exception, which still uses the Fahrenheit scale and of course Fahrenheit has remained popular elsewhere in informal situations.

The kelvin scale is named after the British scientist Lord Kelvin who worked on determining the value of absolute zero. Specifically, zero kelvins (0K) is known as 'absolute zero' and is equivalent to –273.15°C or –459.67°F. It is commonly referred to as coldest possible temperature, whereby the particle constituents of

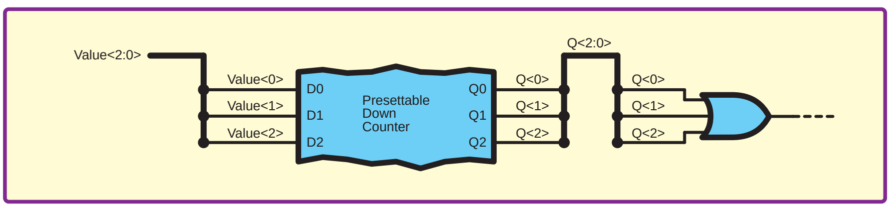

Fig.3. A more strictly correct drawing of the Value and Q wiring from Fig.2, depicting multi-bit bus signals (drawn with thick lines) and individual bit signals (drawn with thin lines).

matter have minimal motion, although the detailed thermodynamic and quantum-mechanical descriptions of matter in these low energy states is more complex. Note that temperatures in kelvins, being an absolute scale, are not stated as 'degrees kelvin', just 'kelvin'. The unit name is written without a capital letter – 'kelvin' – but the unit abbreviation is a capital letter – 'K'. Many temperature measurement applications will not require conversion to kelvins, however it may be needed in scientific instruments or situations where the temperature is used in a formula to calculate something else.

It is useful to be able to convert between temperature scales, either manually or in the code of an MCU system which measures temperature. The conversion processes are summarised below.

Celsius to kelvin: Add 273.15 to the temperature in Celsius. 0°C is 273.15K and 100°C is 373.15 K. A difference of 1K is equivalent to a difference of 1°C

Kelvin to Celsius: Subtract 273.15 from the temperature in Kelvin.

Celsius to Fahrenheit: Multiply the temperature in Celsius by 1.8 and add 32. 0°C is 32°F and 100°C is 212°F.

Fahrenheit to Celsius: Subtract 32 from the temperature in Fahrenheit and then divide by 1.8.

Categories of temperature sensor

Before designing a temperature measurement system a decision has to be made on what type of sensor to use – there are several to choose from. A broad category is contact and non-contact sensors. The most common approach to non-contact temperature sensing measures infrared radiation and includes pyrometers and thermal imaging cameras, both of which measure the temperature of the surface of the object they are 'looking at'. However, in this discussion we will only concentrate on contact temperature sensors, which are in physical (and thermal) contact with the object or substance being measured. Not all temperature measurement is electronic – the mercury bulb thermometer being an obvious example, however, this discussion will focus on sensors, which provide an electrical signal.

Bimetallic strips

The most primitive, but still widely used electrical temperature sensor is the bimetallic strip. Crude but reliable, they contain a sandwich of two different metals which expand at different rates when the temperature changes. This causes the strip to bend, making or breaking an electrical contact. Electrically, they only provide an on/off switch at fixed

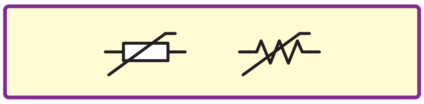

Fig.5. Thermistor schematic symbol

temperature, so are not very relevant to our discussion. They can be used to produce a thermometer by using the mechanical displacement to directly move a needle over a scale.

Thermistors

A thermistor is a temperature-sensitive resistor made of semiconducting material usually oxides of chromium, manganese, iron, cobalt or nickel. The schematic symbol is shown in Fig.5. If a thermistor's resistance decreases with temperature, ie, it has a negative temperature coefficient it is referred to as an 'NTC thermistor'. Other types of thermistor have positive temperature coefficients – PTC. The NTC types tend to be used more frequently in temperature measurement, while the PTC types are often employed in applications such as over-current protection. Thermistors come in many forms, including standard SMD packages (as used for resistors) as well as radial-leaded rod or disc-shaped devices.

Thermistors have the advantage of being sensitive – that is the resistance changes strongly with temperature, but this change is nonlinear, complicating accurate measurement. Another advantage is their fast response. They can be made very small, so they change temperature quickly and do not cause thermal loading – their presence can have a minimal effect on the object being measured. A third advantage is their low cost – the cheapest are only a few pence, although at the other end of the scale specialist thermistors for medical applications, or use in harsh environments, may cost tens of pound each. One drawback is that thermistors suffer from self-heating due to their relatively high resistance – in order to make a measurement, a current has to pass through the thermistor, dissipating power, possibly changing the temperature of the device, thus leading to measurement errors.

Thermocouples

A thermocouple consists of two different metals joined together, which generates a potential across the junction; this is an example of a generator transducer – it outputs a voltage directly rather than requiring a current to be passed through it, as a thermistor or RTD does. However, the voltage produced by a thermocouple is small and does not change much with varying temperature

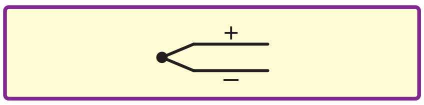

Fig.6. Thermocouple schematic symbol

– it must be amplified significantly without introducing errors. Its symbol is given in Fig.6.

Thermocouples have the advantages of being physically robust and able to operate over a wider temperature range than thermistors, so they are useful in industrial processing equipment, furnaces, ovens and so on. In addition to their small output voltage and low sensitivity they have poor linearity, although this can be corrected by appropriate circuit design, coupled with processing in software.

Resistance temperature detectors (RTDs)

RTDs are similar in basic principle to thermistors – they are temperature dependent resistors – but they are built from different materials, with platinum being the preferred choice in most cases because it provides a stable, linear, resistance-temperature relationship over a very wide range of temperatures. Unlike thermistors, platinum RTDs are available with standardised resistance/temperature characteristics, designated as Pt100 and Pt1000 for devices with resistances of 100Ω and 1000Ω at 0°C respectively. The schematic symbol is typically just a resistor or variable resistor, as shown in Fig.7.

Fig.7. Example RTD schematic symbol

In comparison with thermocouples, RTDs are relatively fragile. The lowest cost thermocouples and RTDs are similar, at a few pounds – more expensive than thermistors, but not prohibitively so. Like thermistors, RTDs may suffer from self-heating errors. The key advantage of RTDs is their accuracy and linearity. With appropriate circuit design they can be used to resolve very small temperature differences.

IC temperature sensors

An ordinary diode (pn junction) can be used as a temperature sensor, since its forward voltage changes by approximately $-2mV°C^{-1}$. Improved accuracy can be obtained by using two diodes (or transistor base-emitter junctions) – the voltage difference between two pn junctions, operated at different current densities, varies linearly with absolute temperature. This temperature sensitivity has been exploited for many temperature sensor integrated circuits, ranging from simple linear voltage outputs to highly sophisticated devices with digital interfaces. The advantage of these ICs is in functionality and/or simplicity of use, but they cover a narrower range of temperatures than 'raw' sensors such as thermocouples and cannot achieve the accuracy of the best RTD circuits.

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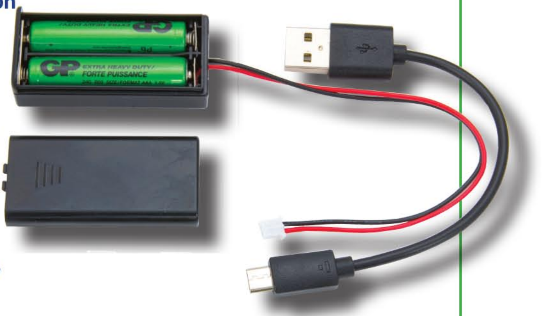

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AUDIO OUT

By Jake Rothman

Peak ESR70 review

Every electronic engineer knows that electrolytic capacitors have a short life compared to other electronic components, both in service and on the shelf. Some capacitors can dry up in just over a year, a few could go on for 50 years. Their usually (relatively) short, but nonetheless erratic shelf life makes it essential to be able to check the condition of these devices when troubleshooting circuits. Unfortunately, a simple capacitance meter is not able to sort out the duds from the functioning parts. What you need is a dedicated ESR meter – but what are they, and are they worth it?

Equivalent series resistance ESR

The problem lies chiefly in the need to construct large capacitance, reasonably compact and affordable capacitors. Making such components inevitably leads to engineering trade-offs, and real-life devices have parasitic elements, such as resistance, inductance and even diode effects. The biggest source of trouble is the 'added' resistance, which is effectively in series with the capacitor. This is what causes losses and limits the effectiveness of the capacitor for decoupling power rails. An ordinary capacitance meter will only measure the capacitance and will ignore the effective series resistance (ESR).

In the case of wet electrolytic capacitors, most of them eventually fail by going open circuit. This failure mode exhibits a slowly accelerating increase in ESR as the capacitor ages. For small capacitors, say 10µF 10V, an ESR of up to 20Ω is acceptable; for a 100µF device, this value falls to 2Ω; and for big electrolytic capacitors, as used in power supplies, ESR should be fractions of an ohm.

To quantify series resistance, ESR meters measure at 100kHz to eliminate the reactance due to the capacitance and to give an indication of a capacitor's suitability for switch-mode power supply use. This test value is an industry standard and it is what the ESR70 uses. Note that the meter's applied voltage is very low and will not turn on any semiconductors in a circuit, so there is no need to remove the component from the board – however, you must be aware of other passive components in parallel with the test component.

Audible alerts

It's not often I get a piece of test gear with character, but the ESR70 (see Fig.1) has a cartoon-like persona. It goes 'ding-ding' in a happy way when the ESR reading is very low, gives a single ding when ESR is 'okay' and goes 'uh-oh' when it's too high. This distinctive audio feedback is actually very useful for quickly testing a board's capacitors.

Fig.1. The purple Peak ESR70, not just another black box

Reforming checks

Occasionally, a wet electrolytic that has not been used for years may leak and possibly explode when charged up quickly. This problem is caused by leakage current, resulting in decomposition of the oxide layer over time. However, with care, this layer can be reformed with gradual charging, and the ESR70 will indicate if a capacitor is leaky. I do reforming by ramping up a bench power supply slowly, while keeping an eye on the current drawn with the current limit set to around 30mA. One sign of reforming being required is a value of capacitance that is suspiciously high, as detected by the ESR70 in Fig.2.

Tantalum and solid aluminium capacitors

Tantalum and solid aluminium capacitors don't have a drying out problem, but they can sometimes have a high ESR and exhibit considerable variation between individual samples. However, their long-term stability can be excellent.

Solid polymer

Unlike traditional tantalum MnO_2 capacitors, solid polymer capacitors do have a defined lifetime according to their data sheets. The conductive grains in the device gradually shrink with time, resulting in an increase in ESR. This process speeds up with temperature in the normal way. Fig.3 shows why polymer capacitors make excellent decouplers; they have the lowest ESR of all electrolytic devices apart from military-spec wet tantalums. Note that solid polymer capacitors are only suitable for decoupling – for other applications their leakage can be four-times worse than normal wet-types capacitors.

A variant of the polymer type is the hybrid polymer, which is a wet electrolytic where the paper spacer has been impregnated with polymer particles. This gives the low ESR of the solid polymer without the limited maximum voltage rating and high leakage.

Other capacitors

The ESR70 can also test big motor-start capacitors and little multilayer ceramic capacitors (MLCCs). For decoupling applications (not audio coupling) I have now started replacing a lot of small

Fig.2. This old electrolytic may be in need of reforming – it's nominal value is 220µF, but the meter reads 376µF

electrolytic capacitors with MLCCs since it's easy to get values up to 10µF and their ESR and inductance values are incredibly low.

Repair – LED lamps and valve amps

This is where the ESR70 excels, never before has a little plastic box prevented so much toxic electronic stuff prematurely going to landfill! I use it to detect capacitor failures and resurrect equipment that would either be junked or expensive to fix.

For example, one grump of mine is the use of 2000 hr 85°C-rated electrolytic smoothing capacitors in LED lamps, especially when the manufacturer claims the lamp will last 30,000 hrs. The usual warning symptom is flicker. The only real problem is finding the right capacitors that are small enough to go in the base. I use 5.6µF 400V Nichicon types from Mouser.

Another capacitor repair favourite of mine is valve amplifiers. These use relatively few electrolytic capacitors, which is just as well considering how hot they can get. Their big smoothing capacitors seem to go on forever, especially those made by Plessey. The main problem in these circuits is drying out of the small cathode bypass capacitors. This does not cause the amp to fail, but reduces the output power to about one quarter. A lot of 'faith-driven' Hi-Fi enthusiasts and rip-off companies do an amplifier 'total recap', where all the capacitors are replaced, even though only the four

Fig.3. Solid polymer electrolytics give the lowest ESR; the best for power-rail decoupling

Fig.4. The ESR70 can be used to measure low-value resistors such as this 0.2Ω component.

cathode bypasses have died. But then those people only believe in numbers starting with '£' not ending in 'Ω'.

ESR60

The ESR70 is not my first ESR meter from Peak. I bought one of the original ESR60s many years ago and it's still going strong. Its readings were within 3% of my new ESR70, despite its recalibration having been due in 2005. However, it is a lot slower because it charges the capacitor before displaying the ESR. The ESR70 gives you the ESR reading very quickly, and then the capacitance reading comes later after charging, and this may still take some time. This change results in a significant time saving for servicing and sorting through old stock, which is very handy because usually it is only the ESR that needs to be checked. A loss of capacitance is usually accompanied by an increase in ESR anyway.

Charged capacitors

Before the relay initiates a reading, a small relay discharges the capacitor through a resistor to prevent damage. The unit displays a voltage reading for a charged capacitor while it is discharging it. Obviously there has to be a limit to the voltage it can discharge, so don't expect a refund if you test something charged up to a dangerous voltage.

Calibration

The ESR70 is designed to measure low resistance values down to 0.01Ω, so it can be used to check low-value resistors. Using a precision resistor, such as that shown in Fig.4, it is possible to check the calibration of the unit. There is also a probe resistance calibration procedure in the unit. You just short the probes and hold the on button down until it enters the mode. The gold-plated crocodile clips are also detachable, which is a good idea since this is the only bit likely to wear out with use. This flexibility also allows the easy fitting of other probe types, such as surface-mount tweezers.

Construction

As can be seen from Fig.5, the ESR70's construction quality is excellent and up to date, while remaining repairable. My only gripe is the 12V battery, which is a bit unusual. I prefer to avoid them where possible because they can fail prematurely due to internal corrosion between the cells. At least there's no silly battery flap to be lost. Artistry as well as engineering is evident. A purple PCB with compound curves is a rarity and you only have to undo three standard screws to have a look – no Apple complexity here.

Competition

An ESR meter is still a fairly recent addition to the electronics engineer's armoury. The idea was originally patented by Gale Vettes, but went off patent in 1998. It's now possible to buy kits and amateurish microcontroller stuff on eBay shipped from China for around £22.00, but the poor leads always let these 'bargains' down. There are also professional devices from around £200.00, such as the German Peaktec 2170. The UK-made ESR70 from Peak sits in the middle at £81.00 (incl VAT) plus P+P at £3.00. A real bonus is that it has full UK landline support and is supplied with a decent paper manual.

The final test

The real test of any bit of service equipment is does it pay for itself in a day? The ESR70 passed. I had an old Revox B77 analogue tape machine in for repair from the studio. It had been in the 'I Give Up' rack for three years. It appeared to have a strange logic board problem – it wouldn't stay in record mode, with the tape lifter randomly triggering. I went round all the tantalum bead decoupling capacitors on the logic board and found one that had an ESR of 35Ω – problem solved. Parts 40p, labour £120.00, mainly for the previous four hours I had previously spent going nowhere.

All in all, this is an excellent, well-made, fairly priced piece of equipment, and for the right user I wholeheartedly recommend it.

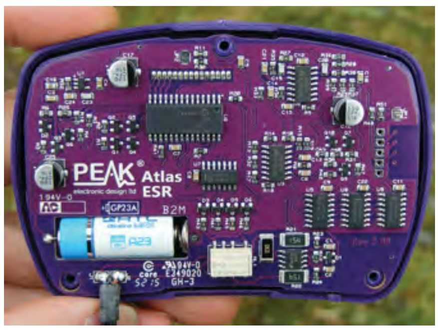

Fig.5. What a beautiful PCB!

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Max's Cool Beans

By Max The Magnificent

Duck! Incoming!

The Industrial Revolution, which took place from about 1760 to sometime between 1820 and 1840, involved the transition to new manufacturing processes. It marked a major turning point in history, with almost every aspect of daily life being influenced in some way. Do you think that prior to the Industrial Revolution people had any idea what was coming their way or how their world was going to change? I bet they didn't have a clue.

The reason I'm waffling on about this is that I think we are poised on the brink of a new turning point in history. And, like our forebears, I don't think we have any idea what's about to leap out from behind the corner and shout 'Boo!' What I'm talking about goes by many names. Some of the terms commonly bandied around are 'artificial intelligence' (AI), 'artificial neural networks' (ANNs), and 'deep-learning'. These technologies are going to power the cognitive (thinking, reasoning) systems of the future. And, when I say 'future,' I'm not talking about the dim-and-distant future – this stuff is racing towards us faster than you think.

'How fast?' you ask. Gartner, one of the world's leading research and advisory companies, defined something they call the 'Hype Cycle for Emerging Technologies,' which they use to evaluate the maturity of different technologies. As illustrated in Fig.1, this comprises five main periods: (1) Innovation trigger, (2) Peak of inflated expectations, (3) Trough of disillusionment, (4) Slope of enlightenment, and (5) Plateau of productivity.

In the 2014 Hype Cycle (**http://gtnr.it/1swZR7r**), machine learning wasn't even a blip on the radar. Just one year later, in the 2015 Hype Cycle (**http://gtnr.it/1E1OjjV**), machine learning had already sailed past the peak of inflated expectations.

The new grey matter

In reality, AI and ANNs have been around for decades. Until recently, however, they were primarily of academic interest only. This was due to a number of factors, including size, cost, speed, lack of sophistication, and – to be honest – lack of knowledge on our part. In the past few years, new tools and technologies have started to spring up all over the place. In turn, this has led to AI and ANNs being deployed in an ever-increasing number of applications.

There are many different types of ANNs, but a high-level view is as follows. We start by defining the architecture of our neural network using a tool like Google's TensorFlow (**http://bit.ly/1MWEhkH**). These days, such a network may contain hundreds of layers, each comprising thousands of neurons.

At this stage, the network, which resides on a host workstation, will be implemented using 32-bit floating-point values for its weights (coefficients). The next step is to train the network. Let's assume we have a network that is intended for vision applications, say to recognise different objects. In this case, we will show it hundreds of thousands (perhaps millions) of images with textual tags saying what each one is.

Once the network has been trained, it will be converted into a 16-bit or even 8-bit fixed-point version for deployment on a silicon chip in the form of a System-on-Chip (SoC) or a field-programmable gate array (FPGA). In the case of our hypothetical vision application, we could now use a web cam to feed images into the network, which will respond by identifying the objects it sees.

Think this is far-fetched? Well, when I attended the Embedded Vision Summit in 2016 (**http://bit.ly/2nsoinI**), one of best lines I heard was, 'You can't swing a cat in here without a load of systems saying: "Hey, someone is swinging a cat!"' In fact, the IP company CEVA loaned me such a system, which I used as part of a presentation at the Embedded Systems Conference (ESC) earlier this year. Check out this article and video to see both the system and me in action (**http://ubm.io/2pHwx3M**).

But what's the use?

Apart from identifying cat swingers, what's the use of all this? Should we be excited, or should we be afraid? How about we consider just a couple of the AI/ANN-related items that have crossed my desk recently. Take handwriting recognition, for example. I have a free ANN-based app called MyScript Nebo running on my iPad Pro (**http://bit.ly/2vbTRZy**). Using this app with my Apple Pencil is as close to writing with an ink pen on paper as you can imagine, and the handwriting-recognition capability is nothing short of phenomenal (it can even decode some of my scribbles that leave me scratching my head).

Do you think you can recognise your friends by their voices when they call you on the phone? Think again. A Canadian AI startup company called Lyrebird have a tool that can analyse a few seconds of someone talking and use this to generate a unique signature, which can subsequently be used to generate any speech, mimicking its corresponding voice, augmented with any desired emotion (**http://ubm.io/2tHiHw3**).

Speaking of speech recognition (no pun intended), things are moving really fast in this area. It's not-so-long ago that you could impress someone by asking your Amazon Echo a question or instructing it to play some music. But this doesn't work too well when multiple people are talking at the same time. Well, the UK company XMOS

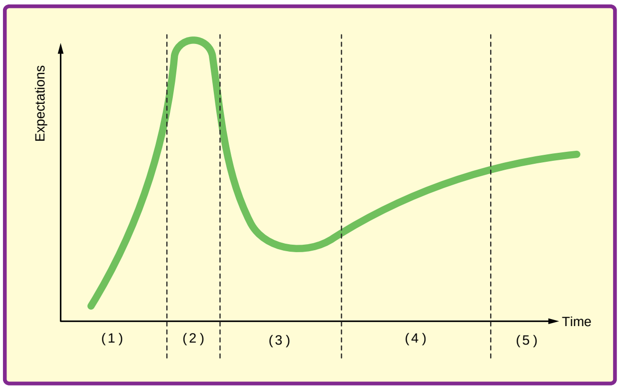

Fig.1. Gartner Hype Cycle.

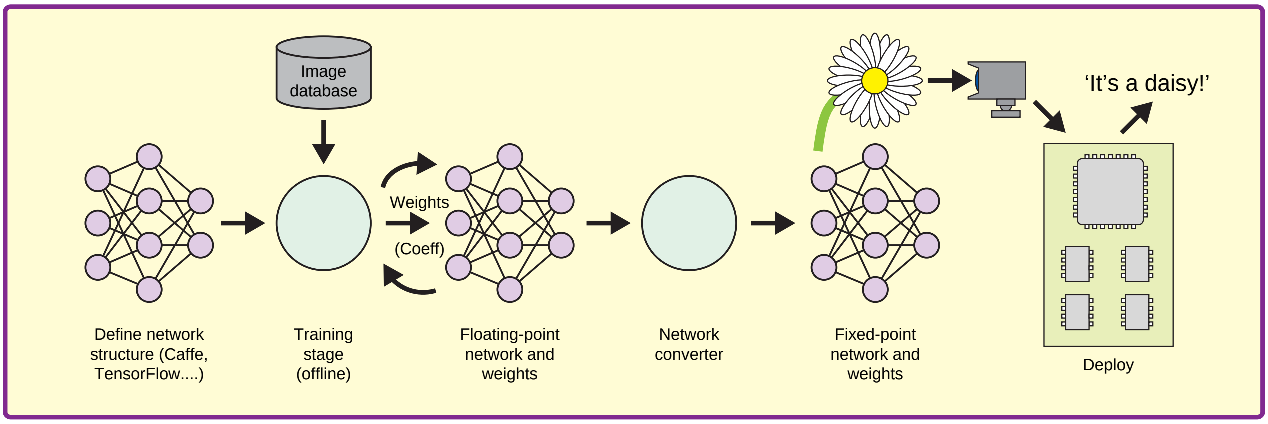

Fig.2. The process of creating an artificial neural network.

now has the ability to completely disassemble a sound space comprising multiple sources in real time – isolating individual speakers and tracking them as they move around the room while also identifying noise sources like fans, radios, and televisions. Note that this system doesn't just do this for the loudest voice – it does it for *all* of the sound sources *all* of the time (**http://ubm.io/2uqVJMk**).

There are so many possibilities for great applications here. Take the Italian company called Eyra and its Horus Technology, for example (**http://ubm.io/2fcw0kf**). This combines deep learning, machine vision, and wearable technology to enhance the lives of the blind and visually impaired. And who among us wouldn't like a robot to do household tasks like ironing our shirts (**http://ubm.io/2vPLQqk**)? But then we have to consider some of the possible downsides. Take the 2014 film *Ex Machina*, for example (**http://imdb.to/1xIhMa5**). Is this really only in the realm of science fiction? Have you seen the machines that are coming out of Boston Dynamics these days (**http://bit.ly/2h8CbrN**)? Now imagine one of these little scamps equipped with AI and armed with a machine gun chasing you down the road!

Do you want to see something really scary? Take a look at the video of BabyX v3.0 (**http://bit.ly/2uItKXb**). This is the work of researchers at the University of Auckland in the Laboratory for Animate Technologies (machine learning). I don't know about you, but this scares the bejeebers out of me! Until next time (assuming our robot overlords permit a next time), have a good one!

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

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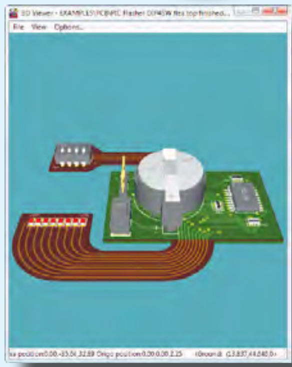

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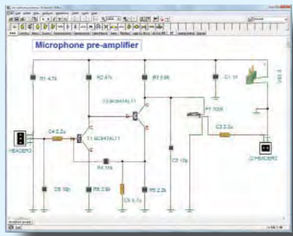

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ELECTRONICS TEACH-IN 2

ELECTRONICS TEACH-IN 2 CD-ROM
USING PIC MICROCONTROLLERS A PRACTICAL INTRODUCTION

This *Teach-In* series of articles was originally published in *EPE* in 2008 and, following demand from readers, has now been collected together in the *Electronics Teach-In 2* CD-ROM.

The series is aimed at those using PIC microcontrollers for the first time. Each part of the series includes breadboard layouts to aid understanding and a simple programmer project is provided.

Also included are 29 *PIC N' Mix* articles, also republished from *EPE*. These provide a host of practical programming and interfacing information, mainly for those that have already got to grips with using PIC microcontrollers. An extra four part beginners guide to using the C programing language for PIC microcontrollers is also included.

The CD-ROM also contains all of the software for the *Teach-In 2* series and *PIC N' Mix* articles, plus a range of items from Microchip – the manufacturers of the PIC microcontrollers. The material has been compiled by Wimborne Publishing Ltd. with the assistance of Microchip Technology Inc.

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The three sections of this CD-ROM cover a very wide range of subjects that will interest everyone involved in electronics, from hobbyists and students to professionals. The first 80-odd pages of Teach-In 3 are dedicated to *Circuit Surgery*, the regular *EPE* clinic dealing with readers' queries on circuit design problems – from voltage regulation to using SPICE circuit simulation software.

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The CD-ROM also contains the complete *Electronics Teach-In 1* book, which provides a broad-based introduction to electronics in PDF form, plus interactive quizzes to test your knowledge, TINA circuit simulation software (a limited version – plus a specially written TINA Tutorial).

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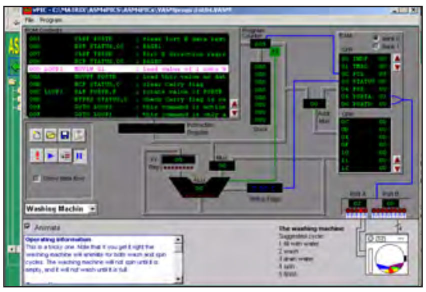
ASSEMBLY FOR PICmicro V6

(Formerly PICtutor)

Assembly for PICmicro microcontrollers V3.0 (previously known as PICtutor) by John Becker contains a complete course in programming the PIC16F84, 16F88 and 16F877a PICmicro microcontroller from Arizona Microchip. It starts with fundamental concepts and extends up to complex programs including watchdog timers, interrupts and sleep modes.

The CD makes use of the latest simulation techniques which provide a superb tool for learning: the Virtual PICmicro microcontroller, this is a simulation tool that allows users to write and execute MPASM assembler code for the PIC16F84 microcontroller on-screen. Using this you can actually see what happens inside the PICmicro MCU as each instruction is executed, which enhances understanding.

● Comprehensive instruction through 45 tutorial sections ● Includes Vlab, a Virtual PICmicro microcontroller: a fully functioning simulator ● Tests, exercises and projects covering a wide range of PICmicro MCU applications ● Includes MPLAB assembler ● Visual representation of a PICmicro showing architecture and functions ● Expert system for code entry helps first time users ● Shows data flow and fetch execute cycle and has challenges (washing machine, lift, crossroads etc.) ● Imports MPASM files.



'C' FOR 16 Series PICmicro Version 5

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.

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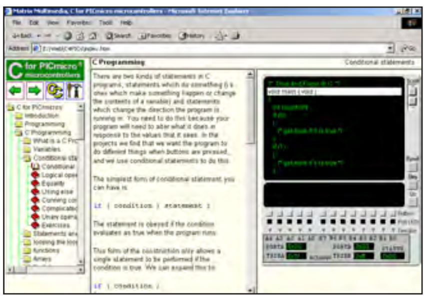

This software will run on Windows XP or later operating systems

FLOWCODE FOR PICmicro V7

Flowcode is a very high level language programming system based on flowcharts. Flowcode allows you to design and simulate complex systems in a matter of minutes. A powerful language that uses macros to facilitate the control of devices like 7-segment displays, motor controllers and LCDs. The use of macros allows you to control these devices without getting bogged down in understanding the programming. When used in conjunction with the development board this provides a seamless solution that allows you to program chips in minutes.

- Requires no programming experience
- Allows complex PICmicro applications to be designed quickly
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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
- Produces code for a wide range of devices
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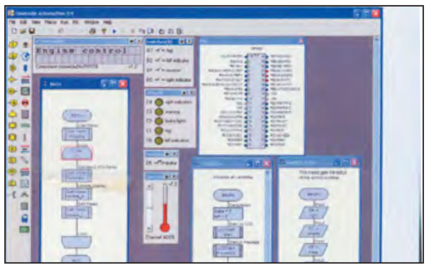
- I2C.

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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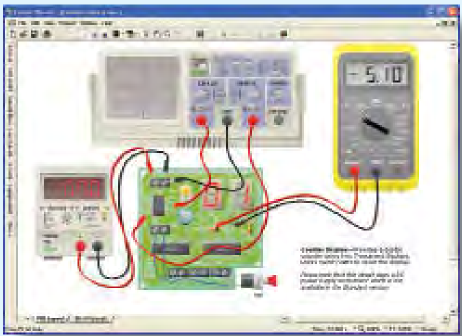

This software can be used with the *Jump Start* and *Teach-In 2011* series (and the *Teach-In 4* book).

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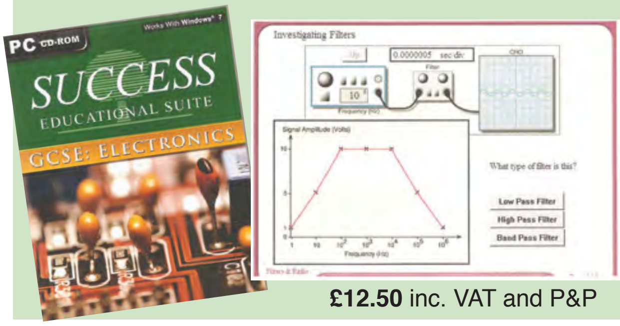

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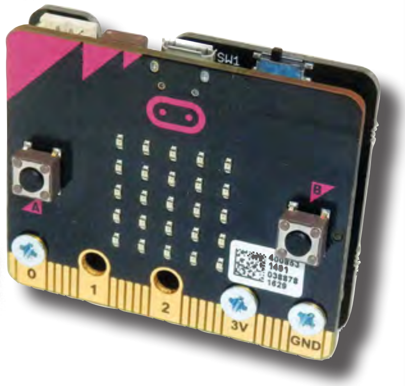

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Mike Tooley

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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**

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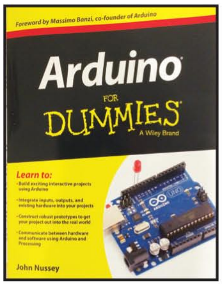
Teach-In 2016
Exploring the Arduino



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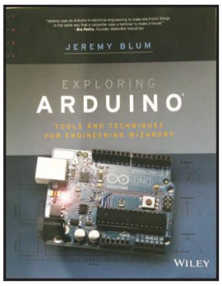

EXPLORING ARDUINO
Jeremy Blum

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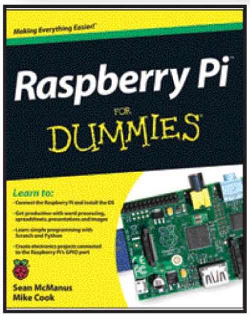

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Write games, compose and play music, even explore electronics – it's easy as Pi! The Raspberry Pi offers a plateful of opportunities, and this great resource guides you step-by-step, from downloading, copying, and installing the software to learning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

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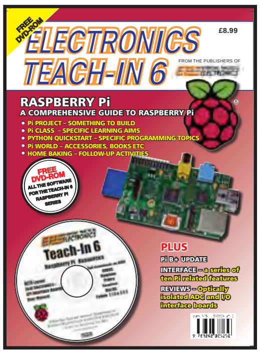

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The FUZE system: coding can be simple!

Mike Tooley reviews the latest product offerings from FUZE

The introduction of coding into the National Curriculum at Key Stages (KS) 1 to 3 has been a welcome change for many, but it has also posed problems for hard-pressed IT specialists searching for ways of delivering the curriculum within a limited budget and with minimal existing resources. The most important question centres around which language to use and what hardware to run it on? There's a wide range of potential solutions, but the choice can be confusing. This is where FUZE comes in. It offers a complete solution to the problem, with both hardware and software bundled into a workstation that will not only assist the development of coding skills, but also introduce learners to electronics.

Fig.1. A Special Edition FUZE Workstation – in appearance (and purpose) more than a passing nod to the venerable BBC computer from the 1980s

Choice of language

Nowadays, youngsters often begin their KS1 studies using Scratch, while older students (at, and beyond KS3) are likely to be using Python. Unfortunately, text-based languages, like C++, Java and Python, are challenging for beginners. Early programming languages, like GW-BASIC, BBC BASIC and QBASIC, were, by contrast much easier to learn and, in the early to mid-1980s it was these languages that made it possible for newcomers to get into computer programming. Many would-be programmers moved on to the delights of Visual Basic, C and C++, and ended up coding the powerful applications that we know and love today. Nowadays, running on modern hardware, BASIC can be fast, powerful, and efficient and the progression to more advanced languages is straightforward. Microsoft has recognised this fact with the introduction of its Small Basic.

Enter FUZE BASIC

Like Microsoft's Small Basic, FUZE BASIC very effectively bridges the gap between introductory graphical languages on the one hand and heavyweight text-based languages on the other. Unlike Small Basic, FUZE BASIC is available for use on multiple platforms, currently including Raspberry Pi, Asus Tinker Board, micro:bit, Arduino, Windows and Linux.

FUZE BASIC is based on a language written a few years ago by Gordon Henderson. He called this language 'Return to Basic' or 'RTB' for short. Henderson's aim was to demonstrate that BASIC could still be a useful introductory programming language. RTB runs on the Raspberry Pi under Raspbian but FUZE BASIC takes this a big step further by actively developing it for a wide variety of platforms. As a measure of its success, FUZE BASIC is currently being taught in over 400 UK schools. Apart from the usual range of BASIC keywords, the language includes commands for reading and writing analogue and digital data using the 40-pin GPIO, serial communication, and control of a robot arm. I/O coding couldn't be much simpler!

The FUZE BASIC editor works well and can be configured with various skins. Several of these are designed to have a 'retro' look, but I rejected most of them in favour of one that offers syntax highlighting.

Documentation

FUZE supplies manuals and worksheets to support its products. The downloadable 253-page *FUZE BASIC Programmers Reference Guide* provides a thorough introduction to the language and contains numerous code examples. A neat feature is that the digital manual will be directly displayed when learners hit the F1 key from the FUZE BASIC editor. Teachers will find the downloadable worksheets invaluable. Projects are arranged in ascending difficulty with extension activities so that teachers can differentiate students' work.

Hardware

The FUZE hardware is built into a robust metal enclosure and features a decent keyboard, yet it is still reasonably compact. Build quality is good. The keyboard uses a conventional layout

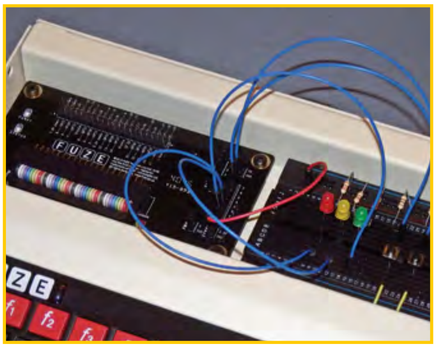

Fig.2. The FUZE IO board and solder-less breadboard are safely tucked away in a recess at the rear of the FUZE Workstation

and the aluminium enclosure is robust. Unlike several inferior products, they should easily withstand the rigours of a classroom environment.

The FUZE I/O board greatly simplifies access to the Tinker Board's GPIO connector. The most commonly used I/O lines are grouped together and they are clearly labelled. In addition, there are four analogue input ports and one output port. The I/O connections are available in the tray towards the back of the keyboard, to the right of which can be fitted with a large breadboard. Unlike most other arrangements where boards, wiring and cabling can become strewn across a classroom desk, this not only protects work in progress, but can also be a real boon when setting up and clearing away.

In conclusion

For teachers, this is a resource that will work straight 'out of the box'; all you need is a screen. FUZE BASIC provides an effective means of introducing students to text-based programming. Then, when students have developed familiarity and proficiency with text-based coding, more complex languages such as C++ and Python can follow. The FUZE I/O board allows students to safely and easily connect to the real world, making it possible to introduce electronics into the curriculum alongside coding skills.

Booting directly into the BASIC environment removes the complexity and distraction associated with starting in a desktop environment. Learners can start coding straight away without having to navigate the operating system. The desktop is still there if you need it, but it remains blissfully hidden from users. A web-browser can be started from the task bar and pages can be displayed from a network server or from the Internet using a Wi-Fi connection. Web integration with FUZE is seamless and this provides direct access to support materials and downloadable resources. In conclusion, FUZE is well-conceived, well-supported and can be highly recommended.

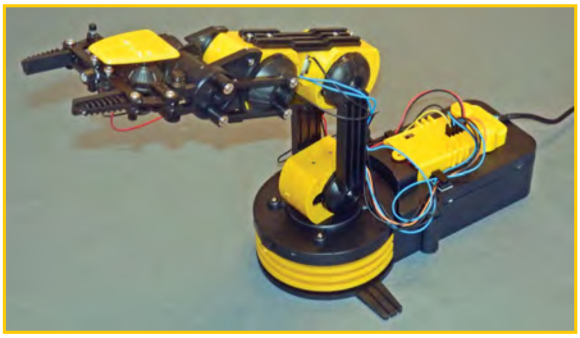

Fig.3. The basic robot arm (supplied as a kit with some FUZE Workstation options) provides an excellent resource for introducing students to robotics and control

How to get FUZE

FUZE products range in price from around £70 for a case to just under £250 for the most powerful version based on the powerful ASUS Tinker Board (this price includes a basic robot arm, supplied in kit form). The popular FUZE T2SE-D Special Edition pays tribute to the home computers of the 1980s. Priced at £119.99, it comes fitted with a Raspberry Pi V3, metal enclosure, keyboard, FUZE IO board (with access to GPIO digital and analogue I/O), USB hub and power supply, 8GB MicroSD card pre-loaded with OS and FUZE BASIC and a large solder-less breadboard. For full details of the FUZE product range, visit **www.fuze.co.uk**

PCB SERVICE

CHECK US OUT ON THE WEB

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

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

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

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

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A large number of older boards are listed on, and can be ordered from, our website.

Boards can only be supplied on a payment with order basis.

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

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

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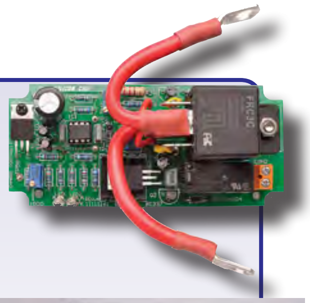

50A Battery Charger Controller

If you one of the many thousands travelling in an RV, caravan or campervan then you'll know the problems with trying to charge up your 'house'. This heavy-duty charger controller lets you charge those batteries much more quickly using a portable generator and a low-cost 40/50A charger.

Phono Input Converter

This passive converter circuit lets you use the phono inputs on an amplifier or mixer, normally used for a turntable, as a pair of line-level inputs. This lets you plug in another CD player, DVD player or other line-level program source.

Micromite Plus Advanced Programming – Part 1

The Micromite Plus is not only faster than the Micromite, but also boasts more RAM and storage space. It also has several new and important programming features such as SD card support and a graphical user interface (GUI) application library. We'll show you how to make the most of these additional features.

Micropower LED Flasher

The very popular LM3909 flashing LED IC is no longer available. What to do? Here we present a new module with a low-cost microcontroller that drives an LED in a similar way to the venerable National Semiconductor device.

Teach-In 2018

Get testing! – electronic test equipment and measurement techniques: Part 2

Next month, we'll look at oscilloscopes. Our practical project will feature a handy calibrator that will provide you with a useful signal source allowing you to check your scope's performance.

PLUS!

All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *PIC n' Mix*, *Cool Beans* and *Net Work*.

Content may be subject to change

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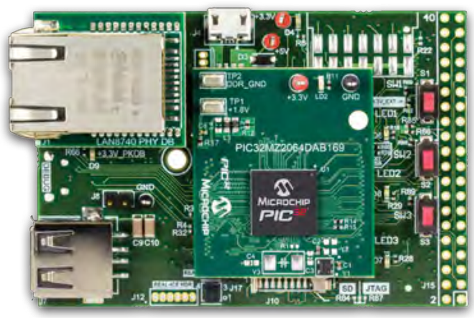
Development Tool of the Month!

PIC32MZ Embedded Graphics with Stacked DRAM (DA) Starter Kit



Part Number
DM320010

Overview:

The PIC32MZ Embedded Graphics with Stacked DRAM (DA) Starter Kit provides the easiest and lowest cost method to experience the high performance and advanced graphics integrated in the PIC32MZ DA MCUs. Microchip's PIC32MZ DA microcontroller family is the industry's first MCU with an integrated 2D Graphics Processing Unit (GPU) and up to 32 MB of integrated DDR2 memory. This combination gives designers the ability to increase their application's colour resolution and display size, up to 12 inches with easy-to-use microcontroller (MCU) based resources and tools. This kit provides an excellent board for development and testing of USB and Ethernet based applications with Graphical User Interfaces.

Key Features:

- 200 MHz/330 DMIPS, MIPS32 microAptiv core Dual Panel Flash for live update support
- 12-bit, 18 MSPS, 45-channel ADC module
- Memory Management Unit for optimum embedded OS execution
- microMIPS mode for up to 35% code compression
- CAN, UART, I^2C, PMP, EBI, SQI & Analog Comparators
- SPI/I2S interfaces for audio processing and playback
- Hi-Speed USB Device/Host/OTG

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