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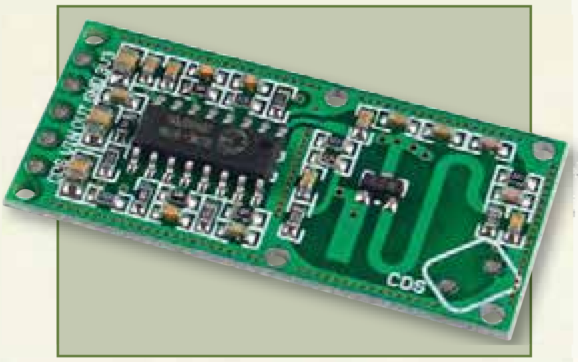

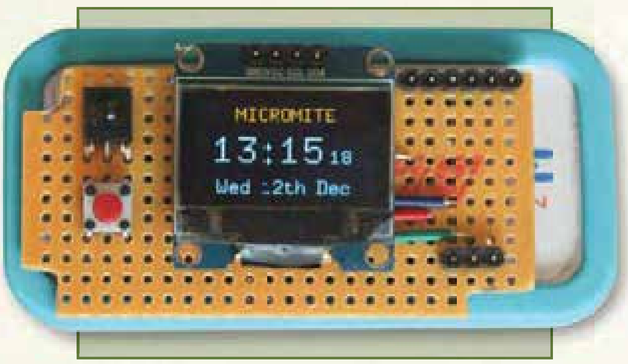

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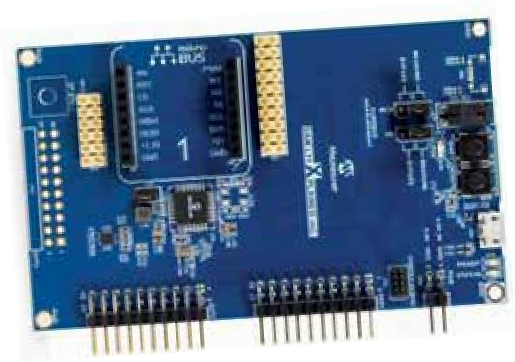
Development Tool of the Month!

SAML11 Xplained Pro Evaluation Kit



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EPE EVERYDAY PRACTICAL ELECTRONICS

Welcome to 2019

If all goes well at our printers and distributors – and I have every faith that it will – then this issue should reach you right at the start of January 2019. So, from everyone here at Electron Publishing, I hope the New Year is good for you and you enjoy the many exciting features and projects we have planned.

Make it with Micromite

New year, new column! I am delighted to welcome a new regular columnist to *EPE*. In this issue, Phil Boyce starts a new series of articles based around a fine example of Australian engineering ingenuity – the Micromite. Phil will be writing practical, hands-on articles explaining how to use this fantastically versatile, inexpensive and easy-to-use microcontroller. Micromite is a family of single-chip systems that runs on the BASIC language, making it a breeze to use. It really is the answer to a lot of control problems, and I am sure you will enjoy reading about – and using – this elegant microcontroller system.

Phil is the ideal author for this series – he works closely with Geoff Graham, the creator of Micromite, and runs his own Micromite-based business at: **micromite.org**. Do visit his website for all your Micromite-related needs.

MIDI Ultimate Synthesiser

Another new author to *EPE* is Paul Cooper. This month, he starts an impressive six-part project explaining how to build a Soundtronics *MIDI Ultimate Synthesiser*. This is a well-appointed design that neatly follows on from Jake Rothman's recent introduction to analogue synthesis.

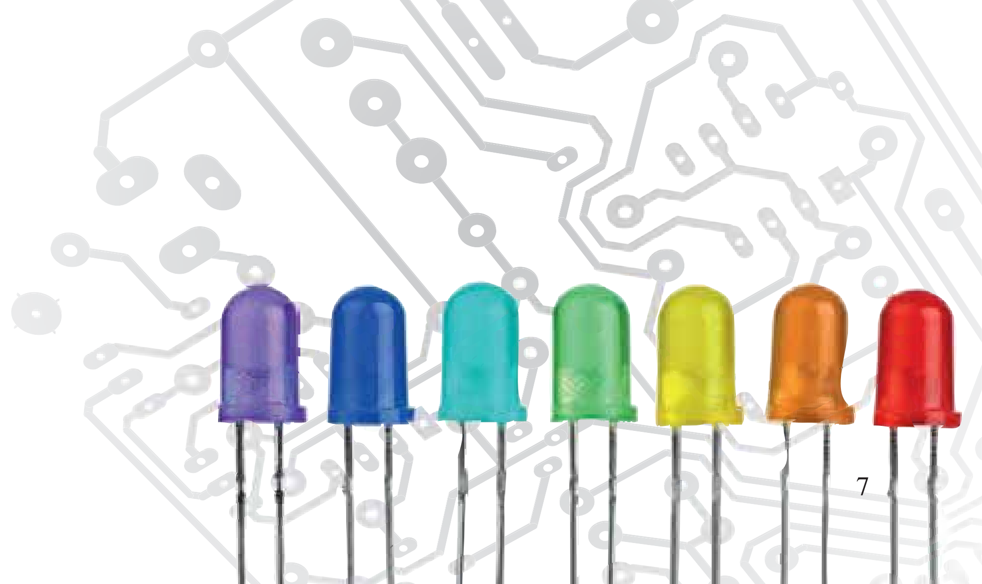
Stylophone competition

Last autumn, we ran a competition to win a Dubreq *Stylophone GEN X-1 Synthesizer*. I'm delighted to announce that the winner is Mr George Watts, who tells us that, 'he enjoys reading all of *EPE*, but especially *Audio Out* by Jake Rothman'. He will doubtless be pleased to know that the talented designer of the Gen X-1 was none other than Jake!

We are changing!

Last, but not least, let me repeat one of my messages from last month. As the opposite page explains, from the April issue we are reverting to our original title of *Practical Electronics*, together with a redesign to refresh the magazine. For those of you who subscribe, the magazine will of course be delivered in the usual way, but if you like to pick up your copy from a local newsagent then please don't forget to look out for the new title and style.

Matt Pulzer
Publisher



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NEWS

A roundup of the latest news from the world of electronics and technology

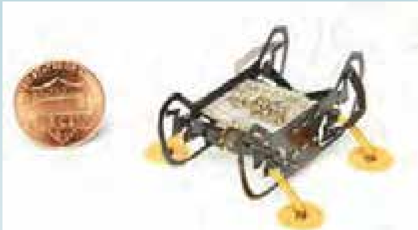
Micro-robots with 'sticky' feet

Jet engines can have up to 25,000 individual parts, making regular maintenance a tedious task that can take over a month per engine. Many components are located deep inside the engine and cannot be inspected without taking the machine apart, adding time and costs to maintenance.

To make this upkeep easier, faster, and cheaper, researchers at Harvard have created a micro-robot whose electroadhesive foot pads, origami ankle joints, and specially engineered walking gait allow it to climb on vertical and upside-down conductive surfaces, such as the inside walls of a commercial jet engine.

Called 'HAMR-E' (http://bit.ly/epe-hamre), the micro-robot is based on an earlier design, HAMR (http://bit.ly/epe-hamr), whose four legs enable it to walk on flat surfaces and swim through water. While the basic design of HAMR-E is similar to HAMR, the scientists had to solve a series of challenges to get HAMR-E to successfully stick to and traverse the vertical, inverted, and curved surfaces that it would encounter in a jet engine.

First, they needed to create adhesive foot pads that would keep the robot attached to the surface, even when upside-down, but release to allow the robot to 'walk' by lifting and placing its feet. The pads consist of a polyimide-insulated copper electrode, which enables the generation of electrostatic forces between the pads and the underlying conductive surface. The foot pads can be released and re-engaged easily by switching on and off the electric field, which operates at a voltage similar to that required to move the robot's legs, thus requiring very little additional power.



The HAMR-E micro-robot developed by Harvard researchers has 'sticky' (electroadhesive) feet. This enables it to walk and climb inside hard-to-reach spaces.

The electroadhesive foot pads can generate forces four times larger than that needed to overcome the weight of the 1.48g robot, preventing it from sliding down or falling off its climbing surface. In addition to providing high adhesive forces, the pads were designed to flex, thus allowing the robot to climb on curved or uneven surfaces.

The scientists also created new ankle joints for HAMR-E that can rotate in three dimensions to compensate for rotations of its legs as it walks, allowing it to maintain its orientation on its climbing surface. The joints were made of layered fiberglass and polyimide and folded into an origami-like structure that lets all the legs rotate freely, and passively align with the terrain as HAMR-E climbs.

Redefining the amp

Last November, representatives from 60 countries voted to redefine the International System of Units (SI), changing the world's definition of the kilogram, the kelvin the mole – and particularly relevant to *EPE* readers – the ampere, for ever.

The decision, made at the General Conference on Weights and Measures means all SI units will now be defined in terms of constants that describe the natural world. This will open the way for new methods, including quantum technologies, to implement the definitions.

The changes, which will come into force on 20 May 2019, will bring an end to the use of physical objects to define measurement units. For example, the definition of the kilogram for more than 130 years, the 'International Prototype of the Kilogram', a cylinder made of a platinum alloy will now be retired. The Planck constant – the fundamental constant of quantum physics – will replace it.

The new definitions impact four of the seven base units of the SI: the kilogram, ampere, kelvin and mole; and all units derived from them, such as the volt, ohm and joule. The ampere will from now on be defined by the elementary electrical charge (*e*).

The size of these units will not change (an amp will still be an amp), the four redefined units will join the second, the metre and the candela to ensure that the full set of SI base units will continue to be both stable and useful.

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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.

The second section – *Practically Speaking* – covers the practical aspects of electronics construction. Again, a whole range of subjects, from soldering to avoiding problems with static electricity and indentifying components, are covered. Finally, our collection of *Ingenuity Unlimited* circuits provides over 40 circuit designs submitted by the readers of *EPE*.

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).

The Teach-In 1 series covers everything from Electric Current through to Microprocessors and Microcontrollers and each part includes demonstration circuits to build on breadboards or to simulate on your PC.

ELECTRONICS TEACH-IN 5 CDROM
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15 design and build circuit projects dedicated to newcomers or those following courses in school and colleges. The projects are: Moisture Detector, Quiz Machine, Battery Voltage Checker, Solar-Powered Charger, Versatile Theft Alarm, Spooky Circuits, Frost Alarm, Mini Christmas Lights, iPod Speaker, Logic Probe, DC Motor Controller, Egg Timer, Signal Injector Probe, Simple Radio Receiver, Temperature Alarm.

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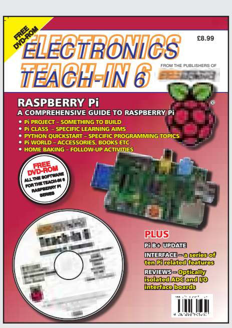
Mike & Richard Tooley

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

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

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

The CD-ROM also contains all the necessary software for the series so that readers can get started quickly and easily with the projects and ideas covered.



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This book also includes *PIC n' Mix*: PICs and the PICkit 3 - A Beginners guide by Mike O'Keefe and *Circuit Surgery* by Ian Bell - State Machines part 1 and 2.

The CDROM includes files for Teach-In 8 plus Microchip MPLAB, IDE, XC8 8-bit Compiler and PICkit 3 User Guide. Also included is Lab-Nation Smartscope software.

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'It really is appalling'

Techno Talk

Mark Nelson

That's what Prince Charles says constantly (according to *Private Eye* magazine) and I can certainly empathise with him, being of the same vintage. However, his desperation differs from mine, which is the growing annoyance of junk phone calls. What's more, if you resent these as much as I do, this article will only increase your exasperation.

In the beginning, cold callers played by a set of rules, directing their unwelcome interruptions to your landline telephone, but now they pollute mobile networks as well. Until recently, most of these calls were flagged 'number unavailable' or 'number withheld', enabling you to choose to refuse by not answering. These days, however, they lure you into responding by displaying a 'proper' phone number. And before you tell me that there are devices you can fit to your line to block numbers once you have discovered they are cold callers, allow me to point out that the gadgets do nothing to block *new* nuisance callers. Call blocking services offered by BT and TalkTalk that allow subscribers to filter calls are not a total solution either.

Resist the temptation

Some people get satisfaction by telling these callers to go forth and multiply (in pithy three and four-letter words), while others ask the caller to hang on while you consult your better half (and put the handset aside until the caller twigs what's going on and hangs up). I confess that, if given the opportunity, I used to press 1 for a call back and then lambast the luckless sales agent for insulting my intelligence. Satisfying though cursing them may be, it's actually not a good idea to respond by pressing any button. Doing that tells nuisance callers that they have reached a valid number, not a spare line, that you are a human (not a fax machine, burglar alarm or whatever), that you understand English, and that you obey instructions. All of this is useful validation data! Even if you've explained you're not interested in their solar energy, they may well call again about something else. Your number will probably also be added to a suckers list that will be sold on to others.

Fake figures

Particularly pernicious at the moment are the automated voices that announce they are calling on behalf of Microsoft or 'your Internet service provider' (it's funny how they don't know its actual name). Often, you are told that unauthorised activity has been detected and you should press 1 to speak to a technician. Of course, this 'technician' has no desire to offer assistance; he simply wants to perform a remote test 'to clear the problem in your computer or broadband router', which will involve your cooperation to let him take control of your PC for a couple of minutes. In fact, this 'help' only adds your PC to their growing botnet of infected computers. The latest variant is an advisory call 'from BT' that your Internet service will cease tomorrow unless you let them update your router.

What distinguishes these calls is the way in which they always contrive a real telephone number to appear in the Caller Display screen on your phone. And if you miss this and dial 1471, the nice lady says: 'You were called by 01936 336951' or 'You were called by 00 1 159 315082'. These are actual numbers that have called me, but they are not valid numbers; the 01936 dialling code was abolished years ago. The US number ending in 315082 has only six digits instead of seven and there are no American area codes beginning with the figure 1. Even more devious, some of these calls do now quote valid area codes (01227 and 01955 are favourites) but they use numbering ranges not yet allocated.

Total cop-out

You might think that BT and the other phone companies could – and should – do something to validate these caller ID numbers and block calls from non-diallable numbers. Equally, you might assume that OFCOM would take enforcement action, but sadly not. A friend who challenged his (minor-league but cheap-as-chips) phone company to fulfil its obligations received an email reply drawing his attention to the wording used in the company's general conditions, stating that it was obliged to act only 'where technically feasible and reasonable'.

This in turn refers to OFCOM regulations that state: 'C6.6 Where technically feasible, Regulated Providers must: (a) Take all reasonable steps to identify calls in relation to which invalid or non-diallable CLI Data is provided and; (b) Prevent those calls from being connected to the called party, where such calls are identified.'

The company's director continued, 'In reality, with the current systems most operators have (including BT) and the industry processes we employ, it would be impossible to guarantee that all invalid calls or non-diallable numbers are prevented from reaching consumers. Whilst this may seem at odds with the OFCOM General Condition, even they would recognise that there are technical limitations and they could not enforce action against individual operators. This is a problem the whole industry needs to work on. In respect of the GC C6.6 conditions, it is a BT matter that they are unable to prevent such calls. All we can do is raise this as a general issue with them – it's not a fault, so is not covered by our contractual terms with BT Openreach.'

The bottom line

A reasonable person might consider this reply to be a load of tosh. It is indeed technically feasible to block calls when the 'presentation number' (the number shown on your caller display screen) differs from the actual number making the call. Thanks to the SS7 digital signalling system (**http://bit.ly/EPE-System7**) used by telephone companies worldwide, calls are always tagged with the real number of the caller, even if the latter chooses to withhold or disguise it. So why is it 'not reasonable' to expect phone companies to block these self-evidently deceitful calls?

Answers on a postcard, not to me but to OFCOM, which our taxes pay to regulate telephone companies. It's their responsibility and problem, not yours or mine.... and before I forget, a happy, cold-caller-free New Year!

Net Work

Alan Winstanley

Alan Winstanley looks at the fast-changing world of online commerce and trade, and the rise – and potential fall – of China's 'daigou' personal shoppers. Plus, fixing printer ink headaches.

With last November's Black Friday and Cyber Monday now thankfully behind us, there's a real risk that both bricks-and-mortar sellers and Internet traders have done Black Friday to death. Hesitant consumers were warned about bogus offers, they fretted that their Black Friday price might drop further still and agonised whether a bargain could actually be a lemon. It's interesting to watch these matters play out in the consumer media, and one might also ask, who is being greedier? The seller for charging a higher price, or a consumer for wanting it even cheaper?

As predicted in *Net Work* December 2018, Amazon sold off earlier versions of its Echo Dot smartspeaker for a reasonable £19.99, but at the time of writing was listing its 3rd-generation version at half price, just £24.99, in the run-up to Christmas. Apple's HomePod costs over ten times more, and Google Home Mini is another option – though you won't find it on Amazon.

Not far from our shores is the Chinese phenomenon known as 'Singles Day'. Ostensibly a celebration (excuse) for single people to spoil themselves with gifts, in terms of turnover it completely dwarfs Black Friday and Cyber Monday. Online marketplace Alibaba sold CH¥ 213.5bn (£24bn, US$30bn) worth of goods on Singles Day *alone*, according to reports, and there are murmurs that the 'festival' might take off in Britain, too. However, as it's held on 11 November (11/11 – 'single numbers'), the day solemnly observed in Britain as Armistice Day, which retailer would break cover first and bravely suggest another day for Singles Day instead?

It has become second nature for *EPE's* technically minded readership to buy and import products from Asia, with global sites such as AliExpress doing a rip-roaring trade in gadgets, gizmos and much more. This trade has been helped by a deal struck with Britain's Royal Mail to support Alibaba's army of Chinese vendors, whose merchandise can now be airmailed directly to Britain rather than being stuck in international snail-mail for several weeks. Hence the stream of barcoded little grey polybags speeding to us from China that have become a familiar sight to British buyers.

International trade travels both ways though, and the worldwide web has broken down many borders and barriers to commerce. Some highly respected British brands, such as Cow & Gate baby formula milk are thriving on sales to Chinese and Hong Kong consumers via web portals.

Never a Daigou's buy...

The idea of using overseas shoppers to locate and ship anything from baby milk to luxury branded goods is popular in China, and is known as *daigou*. It has become an industry segment in its own right, with self-employed *daigou* shoppers carving out a niche as D2C – Daigou-to-Consumer – workers.

Things could be about to turn sour for personal daigou shoppers though, with efforts under way to wipe out that channel completely, reports the Chinese news site *Jing Daily*. One can well imagine what luxury brands such as Louis Vuitton, Rolex, Gucci or Chanel think of those 'grey' imports, and the market has also been muddied by *daigou* importing goods via airlines, like tourists, and avoiding Chinese customs and import limits altogether. Personal shoppers now face heavy fines for importing such goods into China and avoiding taxes, and stories circulate of plane-loads of luggage being seized and opened up at Chinese airports ready for spot checks by the authorities.

Royal Mail has also cashed in on China's hunger for British brands and history. Britain's mail service operates a storefront on Alibaba's TMall Global site, which sells the best of 'Britain and Northern Ireland' to Chinese and Hong Kong buyers. The marketing unashamedly draws on the Royal Mail's heritage, trumpeting its history, 'since 1516' in banner graphics. The site is powered by the logistics specialist 51Parcel, said the *China Daily*, which reports that, 'The success of Royal Mail's TMall Global store has been impressive, especially when you consider that British [bricks and mortar] retailers, including Marks & Spencer and Tesco have failed to crack the Chinese market and have ultimately decided to exit the country in recent years,' adding that '51Parcel .... [also] invests significant time and effort in helping Chinese customers to learn about the history of each brand's product.' If goods carry the Royal Warrant (for example, 'By Appointment to HM the Queen'), so much the better, in Chinese buyers' minds.

The *daigou* segment is open to all, with enterprising sites like DaigouSales.com offering foreign brands the promise of building up their brand's recognition in China and reaching out to millions of consumers via an own-label 'flagship estore'. DaigouSales also promises to handle their warehousing and fulfilment.

Clamping down on fakes

The Chinese government is also working overtime to regulate its e-commerce sector and shed its notorious image

Daigou personal shopping explained on Youtube.

Royal Mail cashes in on selling British brands through TMall Hong Kong.

of fakery, lack of trust and copyright infringement. On 1 January 2019, China's new Electronic Commerce Law will be introduced to better protect consumers and stamp out infringing or illegal goods. The law covers both shopping platforms and the merchants who sell through them, as well as vendors trading through their own websites or other channels such as WeChat, which unbelievably claims a billion users alone. Under the new law, both the sales platform itself (if it either knew, or should have known, that goods were infringing), and the merchants themselves, become jointly liable. Fake product reviews posted by fraudsters or by agents hired to do the job – comical ones are sometimes seen on Amazon – will also be outlawed. Of course, whether this impacts foreign trade to any extent remains to be seen, but at least it's a wake-up call to Chinese traders.

Going postal over paperfree

In case you missed it, last 6 November was World Paper-Free Day (WPFD), a campaign by the non-profit Association for Information and Image Management (AIIM) to switch us away from generating and wasting paper and 'do it digitally' instead. To a fresh pair of eyes the AIIM website (**www.aiim.org**) proved baffling. It cited their quest for 'Intelligent Information Management' as the precursor to securing one's 'digital transformation'. Web content designers for Britain's HMRC (Her Majesty's Revenue & Customs), a body that can't force taxpayers online fast enough, blogged on WPFD that digitising just one simple tax form might save 36 trees a year – see **http://bit.ly/EPE-HMRC**. With thousands of forms still to go, several thousand acres of trees could be saved from the chop by going digital.

As evidence of the assumption that everyone is now 'wired', we are constantly being urged by HMRC, banks and other institutions to cut waste and 'go paperless' by opting for web-based billing and statements instead of receiving printed ones in the mail. Downloading PDFs of complex utility bills or brochures makes obvious sense and some organisations offer better deals and cheaper tariffs to those who can download correspondence this way. Customer service is increasingly provided by soul-less web forms or robotic email: laudable in some ways, but it discriminates against those for whom Internet access or comprehension is beyond their reach.

Going paperless is more secure given the risk of private or confidential paperwork going astray in the mail or being delivered to the wrong address, creating opportunities for fraud or identity theft. There comes a point where postal deliveries can no longer be relied on for critical shipments, and so 'going paperless' has become the norm, especially for today's Internet generation. Many consumers, though, still rely on the timely arrival of, say, a credit card statement or bill as a trigger to check accounts and arrange payments. Paperless transactions also push the cost of printing onto those customers who, distrustful of IT systems, want a hard copy printed on dead trees for their records. Apart from the benefits of having less paper to shred or archive, as someone used to thumbing through heaps of invoices and statements I find electronic paper-free transactions both a blessing and a curse. For many wary and traditional users, the trend towards 'paperless' goes against the grain as it demands a new level of trust and a whole new way of working. Inevitably, paperwork will gradually be sidelined in favour of sub-directories full of PDFs hosted on some remote server or other. Noting that, at the time of writing, Microsoft's OneDrive cloud-based storage is temporarily down for users in the EU, there's life in my lever-arch file yet!

Reset the printer

Still on the subject of printing, in last month's *Net Work* I mentioned some ways of saving expensive inkjet printer ink, which in the case of my Epson All-In-One I calculated costs about £2,000 ($2,600) per litre for a full set of five colour cartridges. Annoyingly, many inkjet printers have built-in obsolescence and they guesstimate their operating life by counting how many dots of ink have been deposited; some risk-averse machines will shut down without blinking, once a limit has been reached. Manufacturers cite as a reason the risk of producing unreliable print results due to printer wear and tear. A printer's waste ink 'spittoon' (if fitted) can also be monitored by the firmware's digital counter and some Epson models, for example, stop working once it thinks the waste tank is full, something worsened by frequent head-cleaning operations. Many users may write off the printer at that point, but an online search revealed that rescue may be possible by resetting the counters using software such as WICReset, along with a paid-for reset key ($9.99), from: **www.wic.support/download**

It read the waste tank and platen pad counters, plus ink cartridge levels of my Epson without a problem. Instead of scrapping a deceased printer you could try salvaging it by resetting it manually, and YouTube often contains handy amateur videos showing how to swap waste tanks yourself: spares are often sold on eBay where I picked up two Epson tanks for a song, so I'm prepared for the day when my printer opts to go on strike!

If your printer is causing a headache, the chances are that others have had the same problem and some intensive googling for part numbers or hints and tips may yield a solution. It's worth a try. Be warned that swapping a waste tank can be an extremely messy job, and the horrifying cost of wasted ink 'paste' that has piled up in the machine during its lifetime does not bear thinking about. The author's spare Epson 'porous pad' tanks can probably absorb up to 100ml of wasted ink – or £200 ($266) worth, if not more.

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This is an improved and updated version of the original *Silicon Chip Induction Motor Speed Controller*. It incorporates a number of improvements which have been made since they published the original design, including PCB design improvements, up-rated parts and revised software.

1.5kW Induction Motor Speed Controller

Part 2

by ANDREW LEVIDO

Last month, we described the features of the *1.5kW Induction Motor Speed Controller* and explained in detail how it works. This month, we describe its construction and testing, and give some guidelines for use.

BEFORE GOING any further, we must again remind readers that this project is intended only for experienced constructors. **Most of the circuit operates at 230VAC mains potential and has portions operating at 325-350V DC. Furthermore, the circuit can remain potentially lethal even after the 230VAC mains has been removed.**

Construction begins with assembly of the PCB, which is available from the *EPE PCB Service*. **Be sure to use the revised PCB, which is coded 10105122. Note that several component values were changed after this board was designed, so the screened overlay on early versions of this revised board may show the old values. The parts layout of Fig.8 is correct – USE IT!**

Be sure also to use a PIC micro that's programmed with the latest version of the software; ie, 1010512B.hex.

Note that some components are mounted on the underside of the board and there are five surface-mount components to contend with. These surface-mount components are all passive (four 10µF capacitors in 2012/0805 packages and one 0.015Ω 2W resistor in a 6432/2512 package). They're easy to install using a conventional soldering iron with a small tip.

Start by loading these SMT components, then move on to the rest of the components in reverse height order. Don't install any of the parts that mount underneath the board at this stage.

Note that the 4N35 opto-coupler is mounted the opposite way to the two HCPL2531s. The 4.7kΩ 5W resistors must be mounted 2-3mm proud of the PCB to ensure free airflow on all sides.

The input surge-limiting NTC thermistor TH1 should be mounted with about 15mm of bare lead exposed above the surface of the board. This serves two purposes: first, it prevents the solder joints from overheating, since this component runs quite hot at full load. Second, it allows the thermistor to be bent down parallel with the PCB so that it will fit inside the IP65 case and not foul the lid. This can be seen in the photograph on page 20.

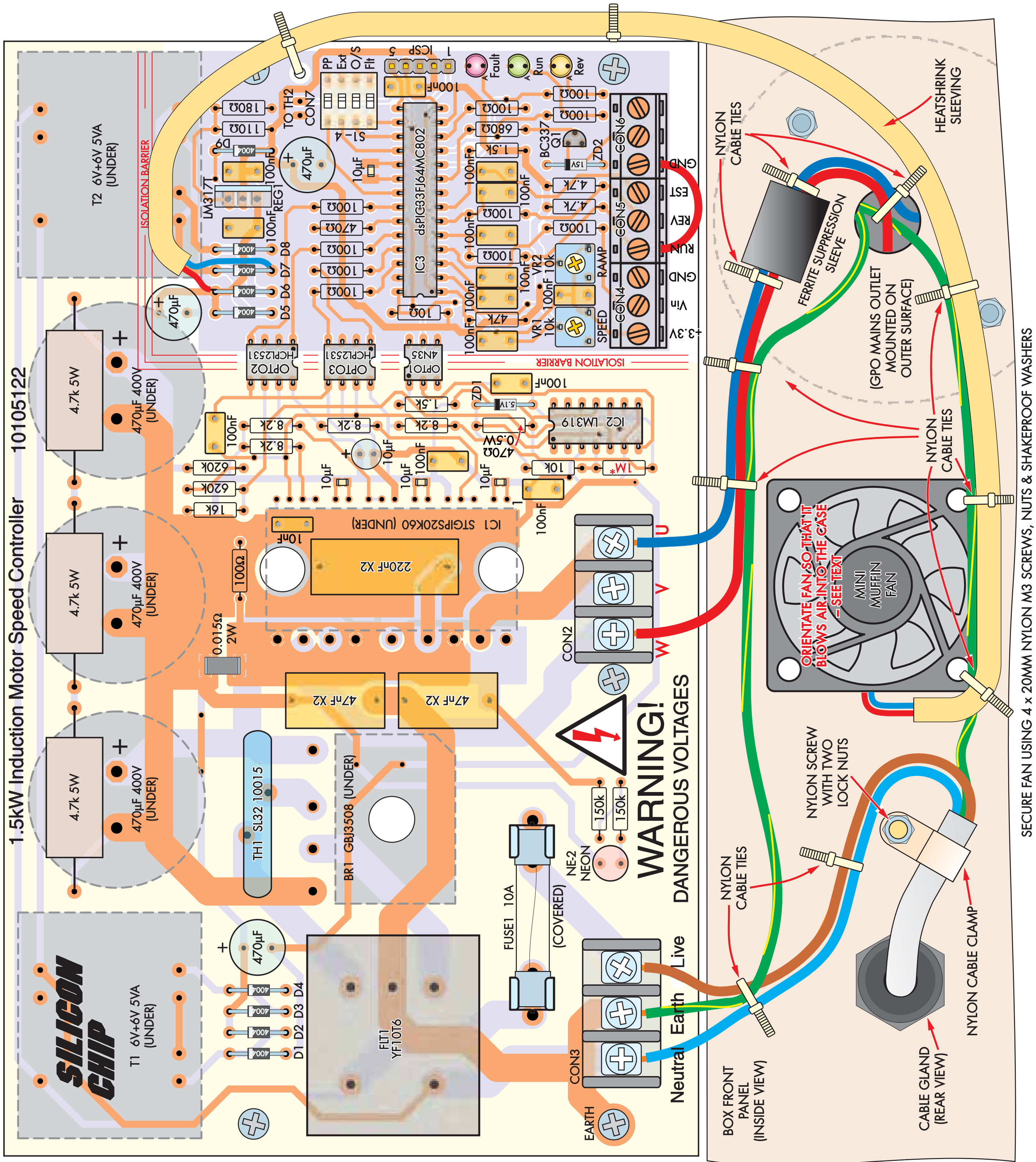
However, don't bend the thermistor down at this stage because you need access to the screw hole for the bridge rectifier, BR1. The bridge rectifier must be secured to the heatsink and soldered to the PCB before the thermistor is bent over.

Next, you can begin mounting the parts on the bottom of the board. Leave the IGBT driver and bridge rectifier off for now. **The polarity of the large electrolytic capacitors must be correct – a mistake here would be disastrous (not to mention messy and dangerous).**

Heatsink assembly

Drill and tap nine M3 holes in the machined surface of the heatsink as shown in Fig.9. Make sure the holes are carefully de-burred so that the heatsink surface is completely smooth.

Next, use the PCB as a template to bend the leads of the bridge rectifier upwards so that the leads fit and the



WARNING: ALL PARTS IN YELLOW AREA ON PCB OPERATE AT LETHAL VOLTAGE & LETHAL VOLTAGES REMAIN FOR SOME TIME AFTER POWER IS REMOVED – SEE TEXT

Fig.8: follow this diagram to build the unit. Note that transformers T1 and T2, the three 470µF 400V electrolytic capacitors, bridge rectifier BR1 and IC1 (the IGBT module) are mounted on the underside of the board.

mounting hole is directly under the corresponding hole in the PCB.

The next step is to mount thermistor TH2 on the heatsink with its leads twisted and poking upwards so that they can be later soldered directly to CON7's pads. Before fitting the heatsink thermistor, smear a small amount of heatsink compound on the mounting lug and then attach it to the heatsink with an M3 x 6mm screw and lockwasher. Orient the lug so that the thermistor wires run to the right – see Fig.10.

Now apply a thin smear of heatsink compound on the mounting surfaces of the IGBT driver (IC1) and bridge rectifier (BR1). Insert them in their appropriate places in the circuit board (from the bottom) but don't solder them yet. You can stop them from falling out when you turn the board upright by making a small bend in a couple of the leads.

Next, mount the PCB assembly on the prepared heatsink using M3 x 16mm screws, star lockwashers and 9mm spacers, as shown in Fig.10. Once the board is firmly screwed into place you can screw down the IGBT and diode bridges using M3 x 10mm screws. These screws are inserted through the holes in the PCB but the flat washers have to be carefully manipulated into position under the board using tweezers.

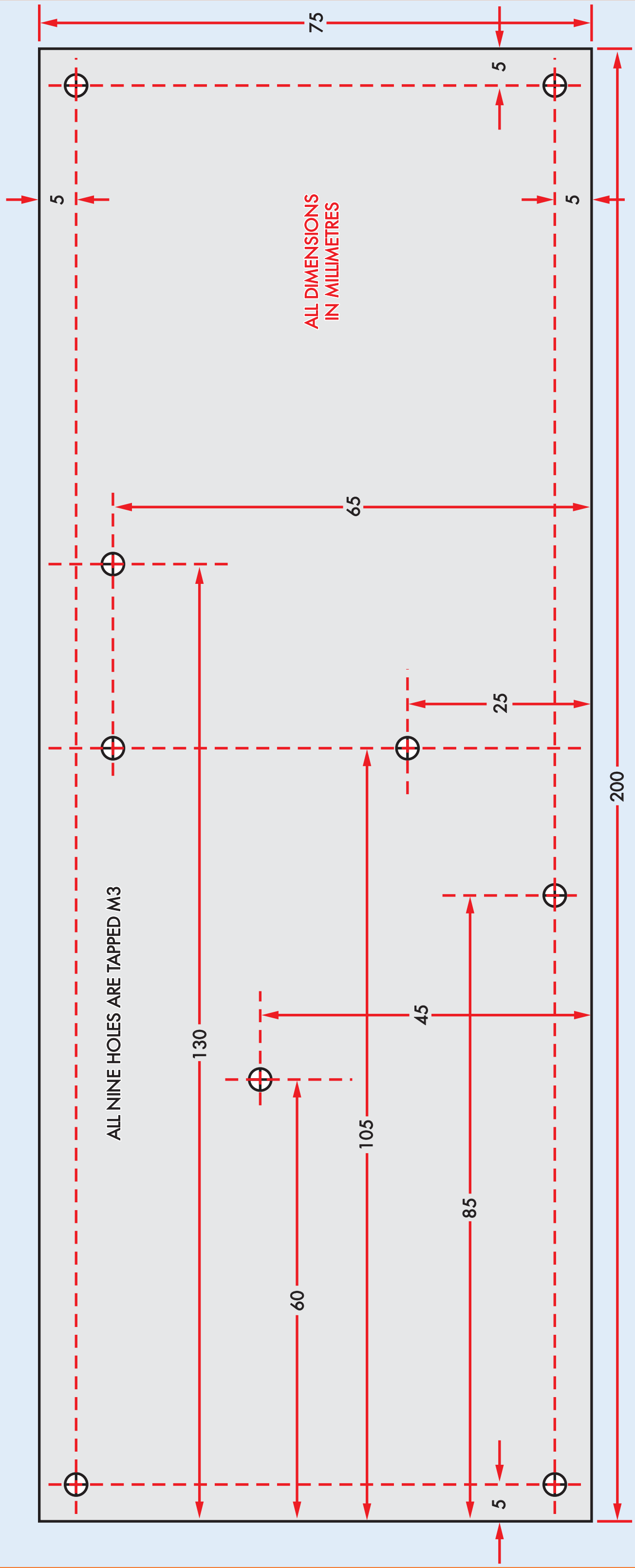


Fig.9: this full-size diagram shows the drilling details for the heatsink. It should be copied, attached to the heatsink with sticky tape and used as a drilling template. Use a small pilot drill (eg, 1mm) to start the holes, then drill each one to a depth of about 8mm using a 2.5mm drill. The holes are then tapped to 3mm. Use plenty of light machine oil to lubricate both the drills and the tap during this procedure and withdraw these parts frequently from the hole being worked on to clear any metal swarf. If this is not done, the aluminium swarf will bind to the tool and spoil both the tool and the job. Note: the drilling diagram is also available in PDF format from the *EPE* website.

Alternatively, you could glue them in place on the devices with a drop of superglue before assembly. Tighten the screws carefully, making sure both devices are flat against the heatsink.

Once everything is in place, solder the pins from the top, clipping off any excess very carefully. Finally, twist and feed the heatsink thermistor (TH2) wires up through the CON7 pads with a pair of tweezers and solder them on the top of the PCB. (Note that it doesn't matter which lead goes to which pad.) **Keep these leads short, so that they cannot possibly short against high-voltage circuitry if they come adrift.**

That completes the assembly of the controller module.

Case and wiring

Since much of the printed circuit board is at lethal potential, it is essential that the speed controller be mounted in a fully enclosed case. Whatever case you choose, you must take care that the mains wiring is fully compliant with the relevant standards. If the case is metal, it must be securely earthed.

The *Speed Controller* dissipates around 28W at idle and over 50W at full power. So we recommend that you either use a vented case or drill a series of holes on one side and fit a fan on the other side. We'll show how to do this with the specified case. Obviously, with vents, the IP65 case is not waterproof or dustproof but the unit will run much cooler (and therefore more reliably) with airflow.

Note also that if a plastic case is used, there must be no metal screws protruding through to the outside since that would present a safety hazard.

We assembled our controller into a plastic case measuring 200mm x 250mm x 95mm (Altronics H0363). As shown in the photos, the PCB/heatsink assembly is installed inside the case using a pair of brackets cut from aluminium angle. These brackets are screwed to the heatsink using M3 x 10mm screws, nuts and shakeproof washers and secured to the short pillars in the base of the enclosure using No.4 x 9mm self-tapping screws.

Mounting the fan

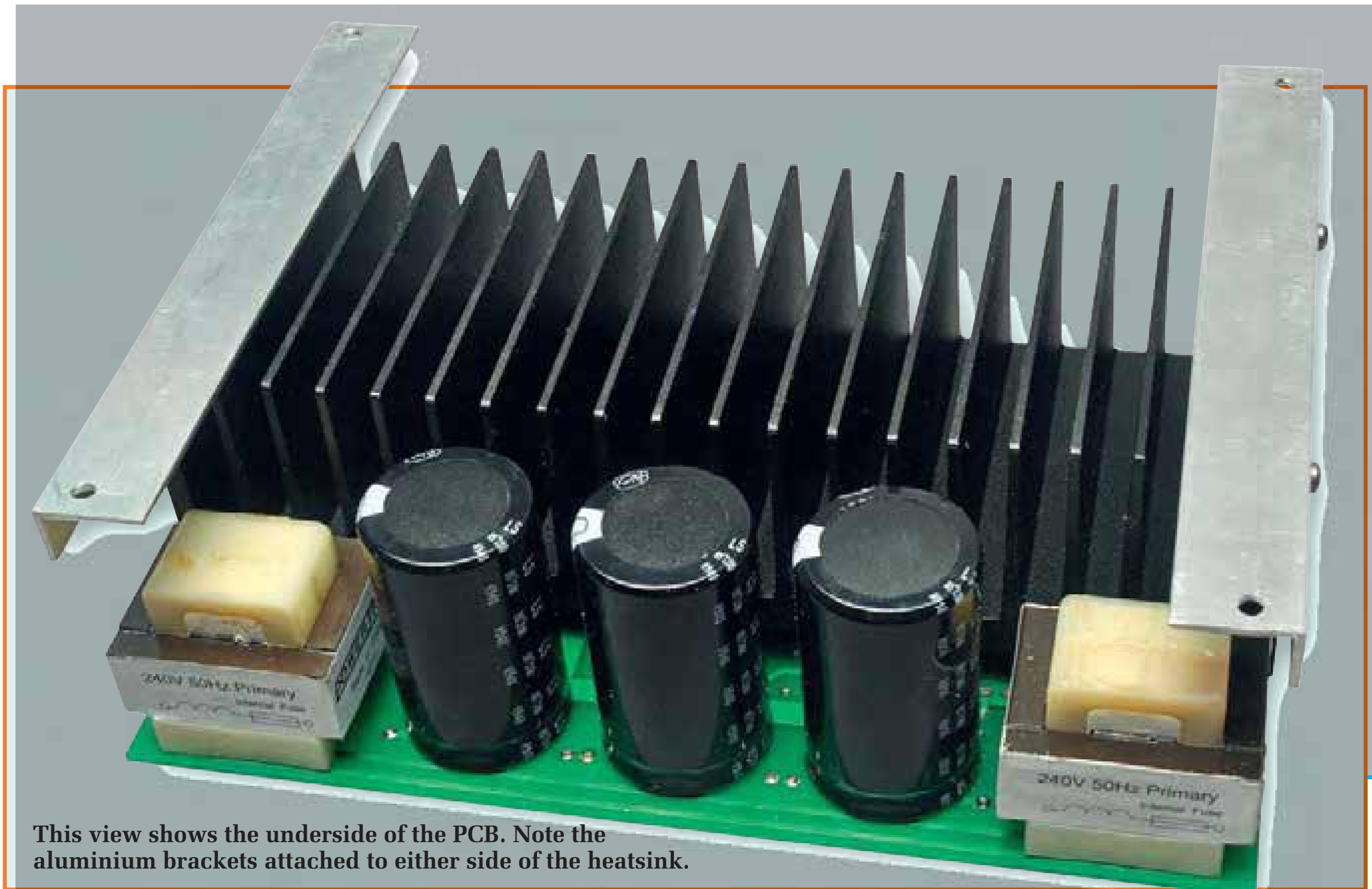
Before installing the PCB, drill four mounting holes in the front side panel of the case for the fan and grille. **The fan goes right in the middle of the panel and must be oriented so that it blows air into the case.** The airflow direction is indicated with arrows moulded into the plastic housing.

When drilling the holes, make sure that the fan (when mounted internally) will sit all the way down against the bottom of the case (so that the lid will still fit). You can use the grille as a template to locate the four 3mm holes, one in each corner. You will also have to make a 50mm-diameter cutout in front of the blades, so that the fan can draw air into the case.

While you're making holes in the box, drill a row of 6mm holes along the bottom half of the case side panel opposite the fan (see photo), to allow fresh air to be blown out of the box when the fan is running. The more holes you drill, the better the airflow will be (up to a point) but a row of 15 should be adequate.

If you are using a larger case than that specified, you may want to consider using a 230VAC 120mm fan instead, which will move substantially more air and thus provide extra cooling.

Secure the fan and the matching grille (with filter) in place using four nylon M3 x 20mm screws, nuts and shakeproof washers.



This view shows the underside of the PCB. Note the aluminium brackets attached to either side of the heatsink.

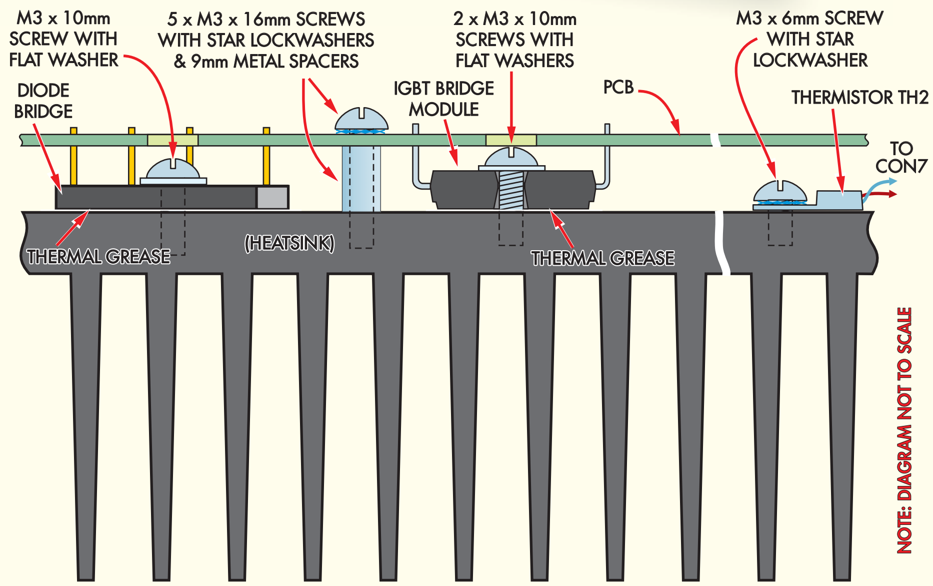


Fig.10: diode bridge BR1, the IGBT module (IC1) and the 10kΩ thermistor TH2 are mounted on the heatsink as shown here. The PCB is attached to the heatsink at five points on 9mm untapped spacers. The leads from the heatsink thermistor are fed up through the PCB's CON7 pads and soldered.

Mains socket

If fitting a standard mains socket for a single-phase motor, mark out the hole positions to the right of the fan. (The mains ('GPO') socket shown in the photos is for Australian constructors – **UK builders will need an appropriate equivalent.**) The central hole needs to be large enough to comfortably fit four mains-rated wires through (about 12mm diameter) and should be smooth, ie, no jagged edges. Mount it using M4 x 20mm machine screws with shakeproof washers under each head and nut.

The mains input cable enters via a gland to the left of the fan and is secured to the inside of the case with a nylon P-clamp. Use a nylon screw and nut to secure it (not metal) and **fit a second nylon nut to lock the first one into place, so that the P-clamp assembly cannot possibly come loose.**

Complete the mains wiring according to Fig.8, taking care that everything is properly secured with cable ties. **Note that, for a plastic case, the earth lead from the mains cable goes direct to the earth terminal on the mains socket. A separate earth lead is then run from the GPO to the earth terminal on the PCB. Use green/yellow mains-rated cable for this connection.**

The 'W' and 'U' outputs from CON2 go to the live and neutral terminals of the GPO socket. Use red and blue mains-rated cable for these connections. Don't forget the ferrite RF suppressor on these output leads. This helps reduce the RFI radiated from the motor cable.

With the mains wiring in place, you can then wire up the fan. It runs off the unregulated input to REG1 (about 6-7V) and so will run quite slowly (and hence, quietly). DO NOT wire it across the 15V HOT rail as the insulation of the fan may not be adequate.

Because they run adjacent to high-voltage circuity, sleeve the fan leads with a continuous length of 5mm diameter heatshrink tubing. Route the fan power cable around the right-hand side of the board and solder the leads to the cathode of D6 (red) and anode of D7 (blue or black) – see Fig.8.

Use the hole immediately to the right of CON7 and the lower-right corner mounting post as cable tie points to clamp the fan cable (enlarge the hole next to CON7 if necessary). This is most important, as otherwise the solder joints could break and the wire could easily float around inside the case and cause havoc.

That done, attach additional cable ties to ensure that all the wiring is properly tied down so that even if one of the wires breaks or becomes disconnected from the PCB, it can't make contact with something that it

Parts List: Induction Motor Speed Controller

1 double-sided PCB, code 10105122, 200.5 x 125mm
1 front panel label (147 x 102mm)
1 diecast heatsink, 200 x 75 x 48mm (Jaycar HH8546, Altronics H0536)
1 IP65 ABS case, 250 x 200 x 130mm (Altronics H0364A)
1 IP68 cable gland to suit 4-8mm cable (Jaycar HP0724, Altronics H4313)
1 surface-mounting single mains (3-pin) socket
1 10A mains lead
1 ferrite suppression bead, 28mm long, 15mm OD, 7mm ID (Jaycar LF1260, Altronics L4802A)
1 60mm 12V DC fan (Jaycar YX2505)
1 60mm fan grille (Jaycar YX2550)
2 6+6V 5VA PCB-mount transformers (Altronics M7052A)
2 10kΩ mini horizontal trimpots (VR1, VR2)
2 PCB-mount 3AG fuse clips (F1)
1 10A 3AG fast-blow fuse (F1)
1 fuse cover for F1
1 SL32 10015 NTC thermistor (TH1) (Element14 1653459)
1 10kΩ NTC thermistor with mounting lug (TH2) (Altronics R4112)
1 YF10T6 mains filter (FLT1) (Jaycar MS4000)
1 NE-2 neon lamp (Jaycar SL2690, Altronics S4010)
2 3-way PCB-mount terminal barriers, 8.25mm pitch (CON2, CON3) (Altronics P2102)
3 3-way terminal blocks, 5/5.08mm pitch (CON4-CON6)
1 4-way DIP switch (LK1-LK4)
1 5-way pin header, 2.54mm pitch (ICSP)
1 2-way pin header, 2.54mm pitch (CON7)
1 nylon* P-clamp to suit 5mm cable
12 small cable ties
1 nylon* M4 x 15mm machine screw (to secure P-clamp)
3 nylon* M4 nuts
2 M4 x 20mm machine screws / nuts
4 M4 shakeproof washers
4 M3 x 20mm machine screws
4 Nylon* M3 x 20mm screws (to secure fan)
4 Nylon* M3 nuts
5 M3 x 16mm machine screws
6 M3 x 10mm machine screws
5 M3 x 9mm untapped metal spacers
14 M3 star washers
3 M3 flat washers
8 M3 nuts
4 No.4 x 9mm self-tapping screws
1 250mm length mains-rated heavy-duty green/yellow striped wire, 10A+
1 200mm length mains-rated extra-heavy-duty red or brown wire
1 200mm length mains-rated extra-heavy-duty dark-blue wire
1 200mm length mains-rated extra-heavy-duty white or blue wire
1 300mm length 6-8mm diameter heatshrink tubing
1 300mm length aluminium L-shaped extrusion, 20 x 10mm

**** Use genuine nylon (polyamide) parts rather than clear plastic***

Semiconductors
1 STGIPS30C60 3-phase IGBT bridge (IC1) (Mouser 511-STGIPS30C60, Digi-Key 497-13647-ND)
1 LM319 dual high-speed comparator (IC2)
1 dsPIC33FJ64MC802 16-bit microcontroller (Element14 1576842) programmed with 1010512B.HEX (IC3)
1 4N35 optocoupler (OPTO1) (Altronics Z1647)
2 HCPL2531 high-speed dual optocouplers (OPTO2, OPTO3) (Element14 1021247)
1 LM317T adjustable linear regulator (REG1)
1 3mm green LED (LED1)
1 3mm yellow LED (LED2)
1 3mm red LED (LED3)
1 BC337 NPN transistor (Q1)
1 5.1V 0.4W/1W zener diode (ZD1)
1 15V 1W zener diode (ZD2)
1 GBJ3508 35A SIL bridge rectifier (BR1) (Mouser 833-GBJ3508-BP, Digi-Key GBJ3508-BPMS-ND)
9 1N4004 1A diodes (D1-D9)

Capacitors
3 470µF 400V snap-in electrolytic (Altronics R5448)
3 470µF 25V electrolytic
1 10µF 25V electrolytic
4 10µF 25V SMD ceramic [2012/0805] (Element14 1867958)
1 220nF X2 250VAC (22.5mm pitch) (Jaycar RG5238, Altronics R3127)
14 100nF monolithic ceramic
2 47nF X2 250VAC (15mm pitch) (Jaycar RG5234, Altronics R3117)
1 10nF MKT or ceramic

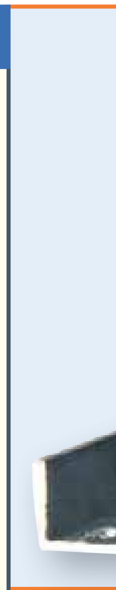
Resistors (0.25W, 1%)

1 1MΩ	2 4.7kΩ
2 620kΩ	2 1.5kΩ
2 150kΩ	1 680Ω
1 47kΩ	2 470Ω 0.5W
1 16kΩ	1 180Ω
1 10kΩ	1 110Ω
4 8.2kΩ	11 100Ω
3 4.7kΩ 5W 5%	1 10Ω

1 0.015Ω 2W SMD resistor [6432/2512] (Element14 1100059, Digi-Key MCS3264R015FERCT-ND)

Note: additional components are required for external motor run/speed/direction control – see text and Fig.11.

Altronics have a kit for this project: Cat K6032. This kit still uses the 20A IGBT bridge specified in the original version of the IMSC, rather than the 30A version. While that is theoretically adequate, it's safer to use the 30A version. You could buy the kit and the 30A IGBT bridge and subsitute it, but be careful to get the right part (there's one with a different pin-out and a slightly different code).

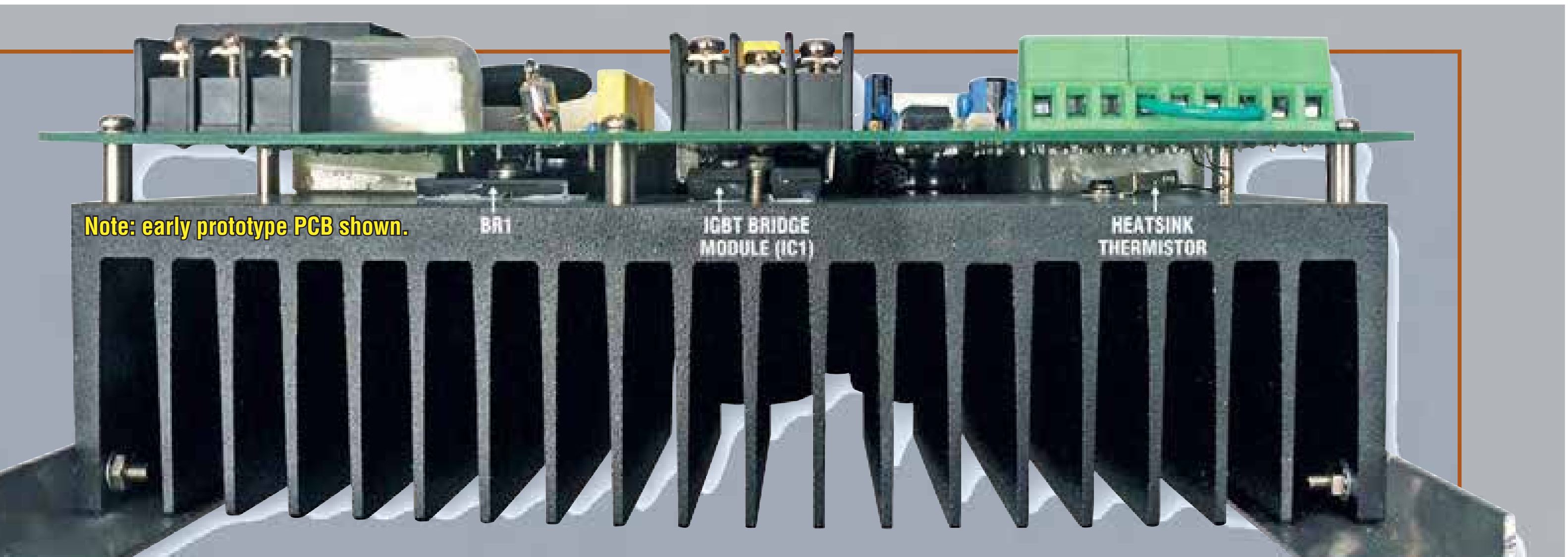


WARNING: DANGEROUS VOLTAGES

This circuit is directly connected to the 230VAC mains. Therefore, most of the parts and wiring operate at mains potential and there are also sections running at 325-350V DC. Contact with any part of these non-isolated circuit sections could prove FATAL. *Note also that the circuit can remain potentially lethal even after the 230VAC mains supply has been disconnected!*

To ensure safety, this circuit MUST NOT be operated unless it is fully enclosed in a plastic case. Do not connect this device to the mains with the lid of the case removed. DO NOT TOUCH any part of the circuit unless the power cord is unplugged from the mains socket, the on-board neon indicator has extinguished and at least three minutes have elapsed since power was removed (and the voltage across the 470µF 400V capacitors has been checked with a multimeter – see text in *Part 1*).

This is not a project for the inexperienced. Do not attempt to build it unless you understand what you are doing and are experienced working with high-voltage circuits.



This view shows how the PCB assembly is mounted on the heatsink. Be sure to mount the PCB in place and tighten BR1 and the IGBT module (IC1) down on the heatsink before soldering their leads.

shouldn't – see Fig.8 and the photos. **In particular, note how the sleeved fan leads and the mains earth wire to the GPO are tied to the mounting holes at the top rear of the fan.**

Finally, double check your work, especially the mains wiring.

Testing

To test the control electronics, take a short piece of hook-up wire and connect it between the RUN terminal and one of the GND terminals. Ensure that all the DIP switches are off (sliders to the left), and set both trimpots to about 50%. Do not connect a load at this stage.

With the unit on the bench, apply power and observe the neon and LEDs **(it's a good idea to wear goggles in case there are any nasty surprises when power is first applied)**. The neon should come on almost immediately and the green LED should begin flashing as the microcontroller ramps up the output frequency. After about 15 seconds, the flashing should stop and the green LED should remain lit.

If this is the case, the micro is working fine. **If there is a problem, switch off, unplug the unit from the mains socket and wait until the neon has fully extinguished. You should then wait a further three minutes and check the voltage across the 470µF 400V electrolytics to make sure the circuit is safe.** You can then carefully inspect your work for errors.

Avoid making any measurements or troubleshooting this circuit while it is live. Only the portion of the circuit in the bottom right-hand corner of the board inside the marked isolation barrier is isolated. The rest is at 230VAC mains potential and is lethal.

If you want to check the control circuitry more thoroughly, first check that the unit is disconnected from the mains and that the 400µF 400V electrolytics have discharged, then feed 3.3V from an external regulated power supply into terminals 1 and 3 of the control terminal block (ie, at CON4). You could also simultaneously feed 15V from a second supply into the +15VHOT line (cathodes of D2 and D3) to check the control circuitry on the high-voltage side (the negative side of this supply can be connected to the anodes of D1 and D4).

In fact, we debugged this circuit in this manner, even adding a third supply at 60V DC feeding the DC bus and some 10W load resistors. This way you can check pretty much all of the circuitry in a safe manner.

Using it

Once you've made some basic checks, you are ready to put the controller to use. We will examine three likely use scenarios: pool pump power saving, driving a single-phase motor with external controls and driving a 3-phase motor.

The first step is to ensure that your motor is suitable for use with a speed controller of this type – see last month's article for full details. In summary, any induction motor with a centrifugal switch is NOT suitable. Check the name-plate to ensure the motor is rated for 230V or 240V and 1.5kW (2HP) or less. 3-phase motors should be rated for 230/400V or 240/415V operation and 1.5kW or less.

Pool pump operation

In this mode, the controller operates in stand-alone mode (ie, without external controls) and is connected to the output of the pool pump timer switch.

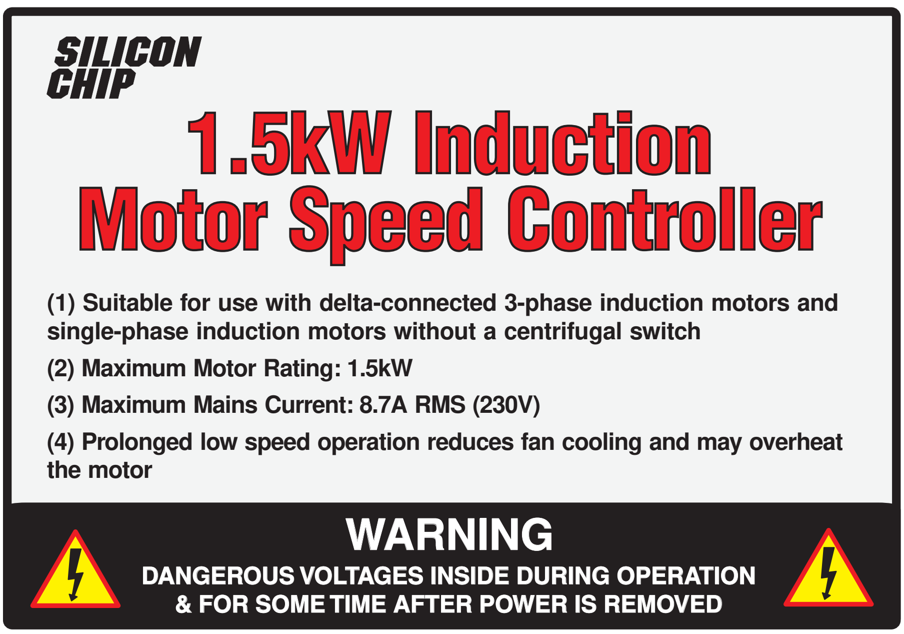
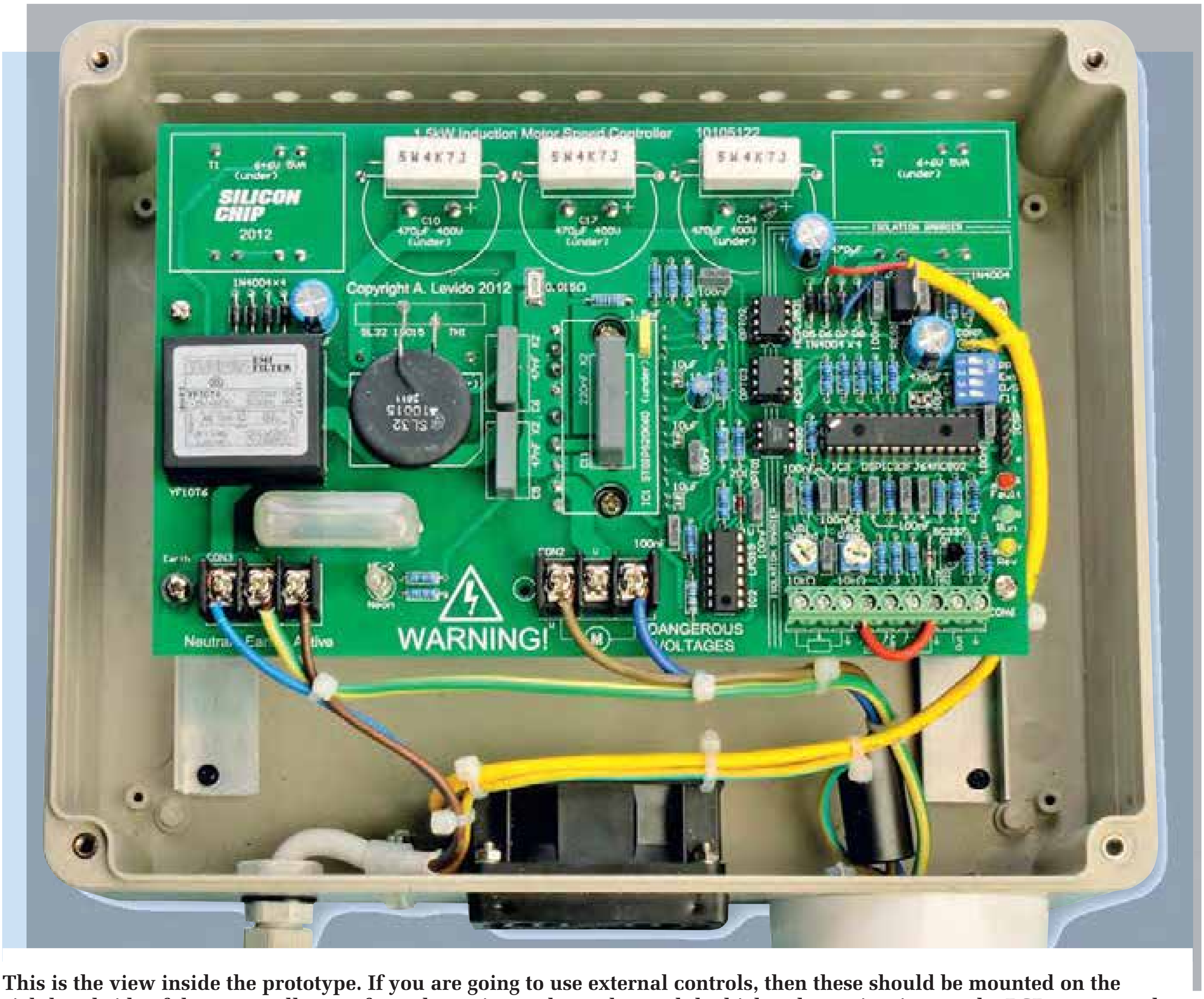


Fig.11 this front panel label (shown here 80% full size) should be placed behind a perspex window which is then affixed to the case lid using silicone adhesive. It can be downloaded in PDF format from the *EPE* website.



This is the view inside the prototype. If you are going to use external controls, then these should be mounted on the righthand side of the case well away from the mains outlet socket and the high-voltage circuitry on the PCB – see panel overleaf. Note the row of ventilation holes towards the bottom of the rear panel. Use cable ties to secure the high-voltage leads, the fan wiring and the ferrite cylinder, as shown.

When the pump is switched on, it ramps up to full speed, then runs the pump at full speed for 30 seconds, before ramping the pump down to a lower speed for the rest of the filtration period. When the timer switch disconnects the mains, the pump coasts to a stop, ready for the next cycle. This was explained in more detail in the previous article.

To achieve this, the controller is configured as shown in Fig.11(A). The RUN terminal is hardwired to GND, so that the motor will automatically start, and the DIP switch for pool pump (PP) mode is set to ON.

A row of ventilation holes must be drilled across the lower section of the rear panel (22-23mm up from the bottom) to allow the air sucked in by the fan to be blown out of the case. These holes should be about 6mm diameter.

The speed pot should be set for about 70% of full speed, which gives a good compromise between efficient filtration and power saving. You may need to experiment with this setting.

The ramp speed is not critical – about 25% of rotation seems to work quite well.

Tool spin-up mode

This is a variation on pool pump mode, where the motor spends less time at full power before dropping to the set speed (half a second rather than 30s). This feature can be useful for lathes or other equipment which start off-load and is activated with Pool Pump enabled and a shorting block across pins 3 and 4 of the ICSP header.

Single-phase motor with external control

In this example, we want to run a single-phase motor equipped with external controls. Fig.11(B) shows how this configuration is wired.

The speed is controlled using an external 10kΩ pot. The EXT DIP switch must be set to ON, to tell the micro to read the external pot instead of the on-board trimpot. In this case, we want to be able to run the motor at higher-than-rated speed, so the O/S (overspeed) DIP switch is also set to ON. Resistor R sets the minimum speed.

Now when the RUN switch is closed, the motor will ramp up to the speed setting of the external pot. When the RUN switch is opened, the motor will ramp down to zero.

The speed control pot and the RUN switch must be mounted on the side of the case near the isolated area.

3-phase motor operation

The final example (Fig.11(C)) is for a 3-phase motor with external controls. This is similar to the previous example. **The motor must be wired for 230V operation in delta configuration. Any 3-phase wiring should be run by a licensed electrician.**

One of the big advantages of 3-phase motors is that they can be reversed electrically. In this example, a reverse switch is connected between the REV terminal and ground. If the reverse switch is opened or closed while the motor is running, it will ramp down to zero speed, pause for a short time and then ramp back up in the opposite direction.

Extended low-speed caution

Finally, we should warn against running any induction motor, single-phase or 3-phase, at low speeds for extended periods. Where fitted, the internal fan will be ineffective at low speed and so there is no cooling.

In fact, larger motors designed for speed control often have separately powered cooling fans for this reason. However, these tend to be rated over 1.5kW and thus are not suitable for use with this speed controller.

Check list

Before switching on:

(1) Check that the electrolytic capacitors are all correctly oriented.

(2) Check that the mains wiring and the output wiring from CON2 to the GPO are correct and securely laced.

(3) Check that the heatsink is correctly earthed (ie, use a multimeter to check for continuity between the heatsink surface and the earth pin of the mains plug). Make sure that the earth screw to the left of CON3 is tight and has a shakeproof washer fitted under its head.

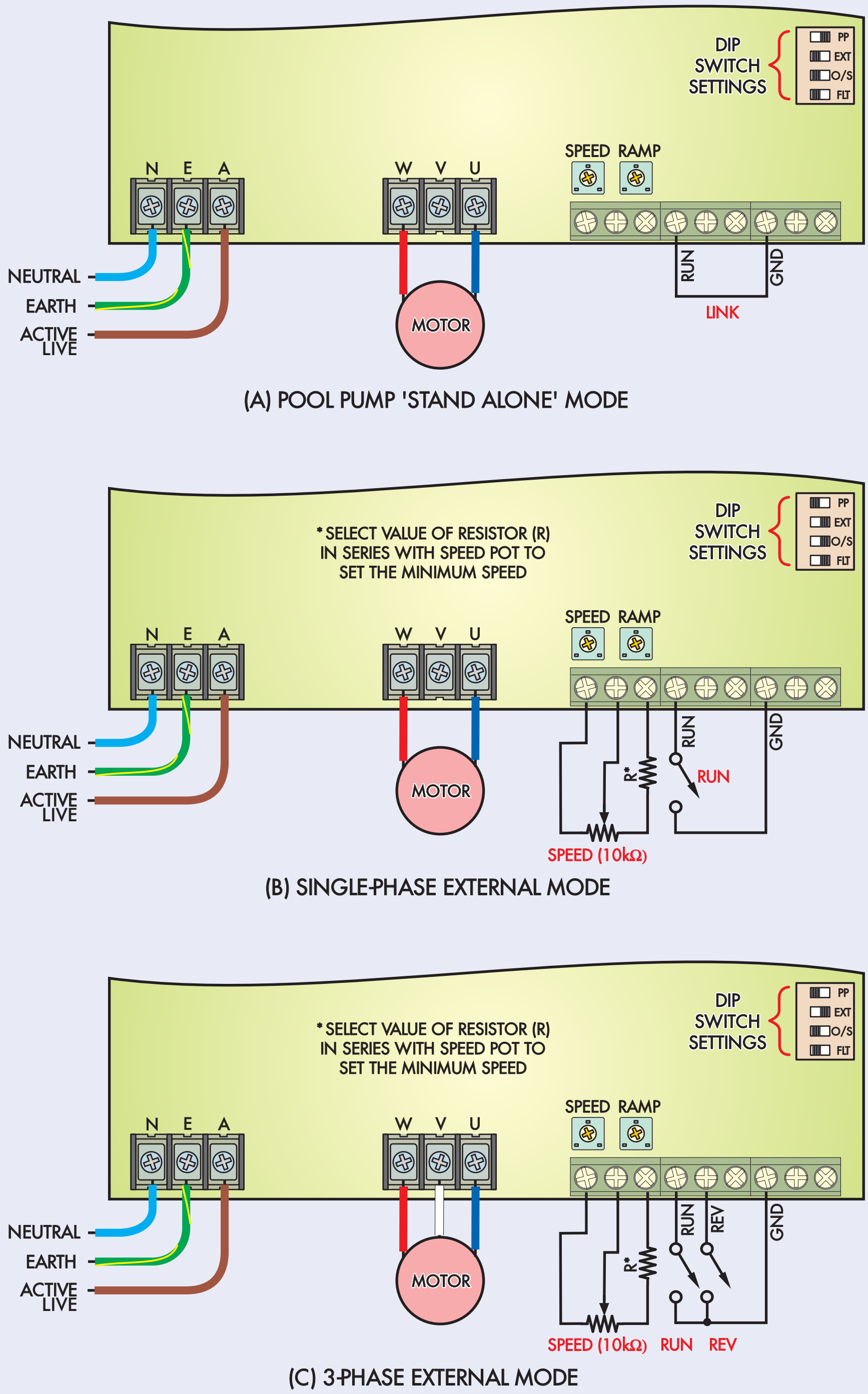


Fig.11: these diagrams show how to use the controller in Pool Pump mode (A), in single-phase mode with external controls (B) and in 3-phase mode with external controls (C).

Safely installing external control wiring

The wiring to any external front-panel controls (ie, speed pot and switches) must be run using 230VAC-rated cable. This wiring must not be longer than necessary to reach the controls and must be securely terminated at both ends and laced together and to fixed tie points using cable ties. This will ensure that the leads cannot possibly come adrift and contact the motor output terminals or any other high-voltage circuitry outside the isolation barrier. Provided you do this, the external controls are electrically isolated from the high-voltage components and are safe.

The controls themselves must be mounted on the righthand side of the case near the isolated area, well away from any high-voltage components. The controls should all be sleeved with heatshrink insulation and properly secured in place.

Win an ATmega4809 Xplained Pro (ATmega4809-XPRO)

Everyday Practical Electronics is offering its readers the chance to win an ATmega4809 Xplained Pro (ATmega4809-XPRO).

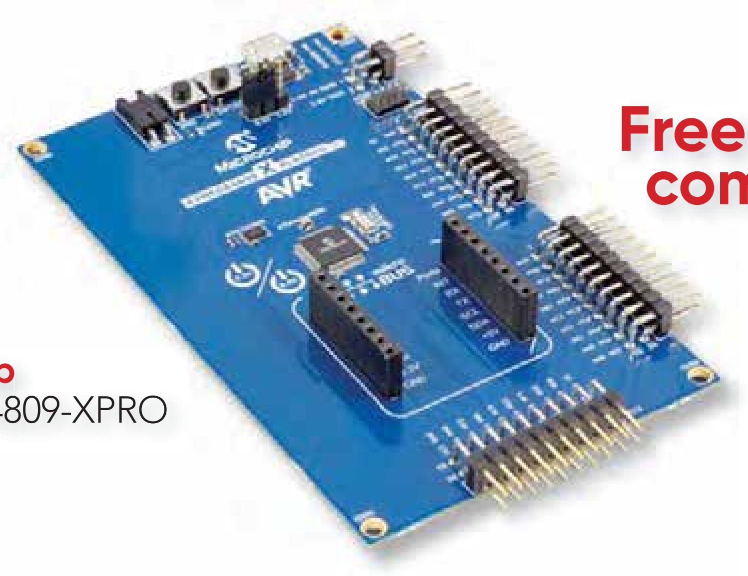
The ATmega4809 Xplained Pro evaluation kit is a hardware platform for evaluating the ATmega4809 AVR microcontroller (MCU). Supported by the integrated development platform Atmel Studio, the kit provides easy access to the features of the ATmega4809, enabling designers to fully understand how to integrate the device into their custom microcontroller designs.

Worth $75.99 (approx £59.85) each

The ATmega4809 is a microcontroller featuring the 8-bit AVR processor with hardware multiplier – running at up to 20MHz and with up to 48KB Flash, 6KB SRAM and 256 bytes of EEPROM in 48-pin packages. The series uses the latest Core Independent Peripherals with low-power features. It also features Event System, intelligent analogue and advanced peripherals.

The ATmega4809 Xplained Pro evaluation kit has a mikroBUS-compatible socket, allowing easy addition of sensors, actuators or communications interfaces from MikroElektronika's extensive library of Click boards. The Xplained Pro extension kits offer additional peripherals to extend the features of the board and ease custom design development.

The Xplained Pro MCU series evaluation kits include an on-board Embedded Debugger (EDBG), eliminating the need for external tools to program or debug the ATmega4809. The kit supports additional peripherals to extend the features of the board with Xplained Pro extension kits and also MikroElektronika mikroBUS-compatible Click boards.



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The closing date for this offer is 28 February 2019.

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ARDUINO MEGA BOX MUSIC PLAYER

By Bao Smith

Combine an Arduino MP3 player shield with the *Altronics Mega Box*, along with clever software, to make a neat little music or audio player with endless possibilities.

We introduced the *Altronics Mega Box* kit last month. It lets you give your Arduino projects a much more professional appearance and provides many convenient functions.

In that article, we mentioned that one possible use of the *Mega Box* would be to combine it with an MP3 player shield to create an Arduino music player (For example, the VS1053 shield would work well.)

Without the *Mega Box*, projects like this often end up as an unhoused collection of boards and modules wired together. That's pretty typical for your average Arduino project, but we wouldn't say that it gives a finished product that you can use every day.

Well, that changes now thanks to the facilities provided by the *Mega Box*. By using the *Mega Box*, rather than just stacking the MP3 Player shield on an Arduino Uno, we can use a universal infrared remote control rather than the 4×4 keypad.

That provides several benefits, including a larger number of keys and buttons, more intuitive user interface and the fact that you can carry the remote around with you.

We've also written software so that you can use at least two of the four illuminated pushbuttons on the front panel to control the player.

If you want to use the other two and the rotary encoder, you'll need to use an Arduino Mega instead of the Uno; the Uno just doesn't have enough free I/O pins. The software will auto-detect if you are using a Mega board and allow use of the extra front panel controls.

Using the display

Now, having mentioned how well the *Mega Box* suits this project, we should add some caveats. The *Mega Box* is supplied with a 16×2 LCD. This LCD has a slightly non-standard pinout; you can't easily attach an I^{2}C translator module (but it isn't impossible if you want to save four pins). This means we need to use the LCD in 4-bit data transfer mode, which requires the use of six of the Arduino's I/O pins (plus an additional PWM pin if you want to control the backlight).

Also, the way the MP3 player shield is designed places the headphone and microphone sockets facing into the box, rather than out through the hole provided near the rear of the shield mounting point. That means you will need to drill a couple of holes to mount chassis sockets and wire them up to plugs which go into the shield sockets. Alternatively, you can run two 3.5mm male-female extension leads from the shield to the rear of the case.

As an alternative, you can use the SparkFun version of this shield (**www.sparkfun.com/products/12660**). It has the same pin layout but has the headphone jack pointed at the rear, but you will need to solder your own microphone input socket onto the board.

That shield is a bit more expensive but it uses a proper level translator between the 5V Arduino board and the 3.3V audio player IC.

The infrared interface is now the main means of controlling the unit, and while you could probably use just about any universal remote, we've designed it with the Altronics A1012 in mind.

We're using TV code 170 (see supplied instructions for how to set that). You can use this to operate the unit from up to five metres away. The A1012 TV code 170 button codes are shown in Table 1.

Table 1: IR codes

Button	Hex code (0x)
Standby (on/off)	0C
Mute	0D
Buttons 0-9	00-09
Channel up/down	20/21
Volume up/down	10/11
Up/down	12/13
Right/left	14/15
OK	23
Teletext	3C
Page hold	29
TV/Video	3F
Pause	3D
Exit	0B
Rewind	37
Play	32
Fast forward	34
Stop	36

If you want to use a different remote control you will need to set it to produce Philips RC5 codes and then change the **#define** lines at the top of the Arduino code to the appropriate code numbers to suit your remote.

The best way to check what commands your remote sends is by running the *Mega Box* program – **ExampleCode.ino** – and reading the values off the serial console in the Arduino IDE. This code is supplied in a download bundle from the *EPE* website.

Assembly

Assembling the project is fairly simple if you've already built the *Mega Box*. If you haven't, see our January 2019 article for the details and/or follow the instructions supplied with the kit.

The main difference will be in how you want to handle audio input and output. What we did was mount two 3.5mm stereo sockets in a convenient location on the front or rear panel (eg, above S1-S4, or to the left of the rotary encoder); a 6mm drill bit should do.

After this, solder an adequate length – depending on the location of the sockets – of stereo shielded cable to their pins. (Just use one cable and cut it in two and then strip the outer sheath.)

Next, separate the individual leads and strip the ends of the red and white leads before soldering them to the connector; white to tip, red to ring and the shield wires to ground.

Be careful, some sockets are switched and will have more than three pins; you will need to plug an audio cable in and use a DMM set on continuity mode to figure out which is the tip (left), ring (right) and sleeve (ground) connections.

Wire these up to the two line plugs using the same pin assignments, so that you end up with what are essentially two extension leads that can then be plugged into the MP3 Player shield – see photo on the next page.

We also recommend that you add a 3.6V 1W zener diode between the 3.3V line (cathode) and ground (anode). The easiest place to fit this is between CON3 and CON5, which are located between the Arduino and the shield on the *Mega Box* board (these may be labelled U3 and U5 on the PCB).

This is not necessary if you're using the SparkFun MP3 Player shield. The reason it's required is that the Geeetech MP3 Player shield's lack of level shifting circuitry causes the Arduino output pins to 'pump up' the 3.3V supply when they go high and this can cause a buzzing in recorded audio.

The zener helps to prevent loss of regulation on the 3.3V rail due to this pumping action. Note that there's a small risk that the diode could overheat; we're counting on the fact that its voltage 'knee' is just above the normal voltage of the 3.3V rail and so it will only conduct a small amount of current (mA) at 3.3V. However, it's possible your diode could have a low knee voltage or your 3.3V regulator could have a slightly higher output than typical. So after fitting it, power up the Arduino and make sure it isn't getting too hot.

Wiring it up

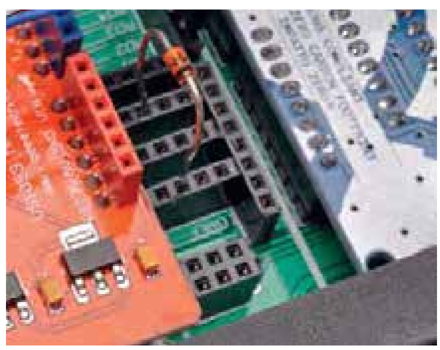
Now refer to Table 2 to see which connections you need to make using jumper leads. Some of the connections can only be used with an Arduino Mega, as indicated in the table, so if you're using the Uno you will have to leave them out and their related functions will not be available.

Since the pushbuttons are wired with pull-up resistors, the pins connected to the pushbuttons are read as high by default and low when pressed. The button's NO connection should be wired to +5V by placing jumpers on JP1.

Note that Arduino pins D2, D6, D7, D8 and D9 are exclusively being used by the MP3 Player shield and cannot be used for anything else, while D11-13 can be used with other SPI devices. This leaves D0 (receive), D1 (transmit), D3, D4 and D10 (slave select).

Generally, D0 and D1 should not be used as this would interfere with the serial console, nor D10 as that is driven by the Arduino SPI unit.

We've used a 3.5mm switched stereo audio socket (enlarged). You'll need to use a DMM on continuity mode to determine which lead is the tip (white; left), ring (red; right) and ground.



A close-up of the 3.6V zener diode inserted with cathode to the 3.3V line and anode to GND.

Table 2: Lead connections

Component	Lead	To Pin
16x2 LCD	RS	A0
	EN	A1
	D4	A2
	D5	A3
	D6	A4
	D7	A5
	Backlight	5V
Infrared remote	IR interface	D3
Pushbuttons	S1 COM#	D4
	S2 COM#	D5
	S3 COM^#	D14
	S3 COM^#	D15
Rotary encoder	Encoder interface A^	D16
	Encoder interface B^	D17

Parts list

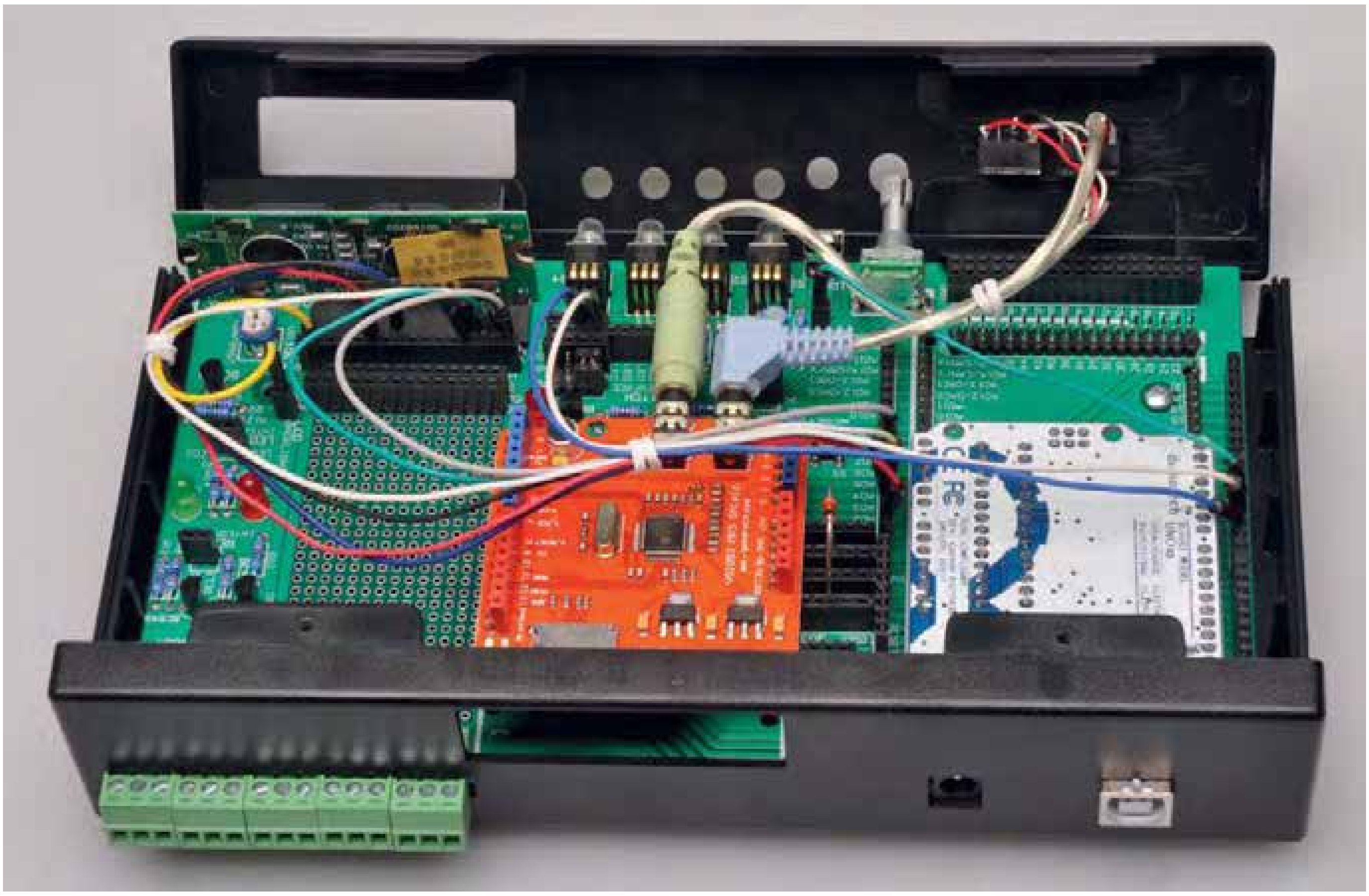
1 Inventa Mega Box kit (Altronics Cat K9670)
1 Arduino Mega (recommended) or Uno (or compatible)
1 VS1053b based MP3 Player shield (Silicon Chip Online Shop Cat SC4315 [Geeetech] or SparkFun version [see text])
1 Altronics A1012 universal remote control
4 jumper shunts (2 if using the Uno)
2 3.5mm stereo chassis-mount sockets
2 3.5mm stereo line plugs (Altronics Cat P0030)
1 1m length stereo shielded audio cable
1 USB Type A to Type B (full size) cable
1 USB charger or other USB power supply
16 150mm long male-male jumper leads (minimum 11)
1 3.6V 1W zener diode
1 Bluetooth audio transmitter (optional)
1 PCB-mount Type-A USB socket (for Bluetooth audio transmitter)

^ only available when using Arduino Mega board
 # place a jumper on JP1
With an Arduino Mega these pins MUST be connected in parallel: 11 → 51, 12 → 50, 13 → 52 for the SD card to work.

Once all connections have been made, the Arduino sketch software can be loaded. It's available for download from the *EPE* website.

You will also need to load your audio files **(and two required patch files)** onto the root directory of a properly formatted microSD card (FAT16 or FAT32) and insert this into the socket on the player module. If you don't already have the latest version of the Arduino IDE, download it from **www.arduino.cc/en/Main/Software** and install it.

The next set-up step you need to make is to install the required libraries – again, these are supplied in our download package, along with the sketch. Use the Tools → Libraries → Add .ZIP Library menu option to install each one in turn.



Shown above are the flying lead connections that need to be made to use the project with an Arduino Uno. Take note of the jumpers for S1 and S2. If you have a spare PWM pin, the backlight can be controlled using that instead of the yellow lead going to 5V. The audio sockets don't need to be placed where we have as it does interfere with the header for the Arduino Mega. Other good locations include above the four pushbuttons or on the back panel above the five relays.

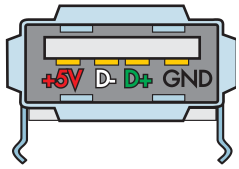


Fig.1: USB Type-A socket showing the required connections.

Then open up the sketch file, make sure the correct COM port is selected in the Tools menu, and then select the Upload option (CTRL+U in Windows). Check the bottom of the IDE window to make sure the upload was successful.

Next, adjust LCD contrast potentiometer VR1 so that you can comfortably read the text on the LCD screen. If you don't see any text, check that the SD card is properly connected and try connecting the LCD backlight interface to the +5V line to make sure the screen isn't too dim.

By default, the software uses the line in connection when recording, which means you will need an external microphone. You can alter the software to use the Geeetech on-board electret microphone by removing the line **#define USE_LINEIN 1**, but the resulting quality is quite poor.

Remote control functions

You should find the infrared remote control buttons to be fairly straightforward. The arrow keys are used to navigate the menus, and the OK button is used to select the current choice.

Alternatively, you can press a button on the numeric keypad to directly choose the respective menu option (as shown on the LCD).

When playing an audio file, the up/down arrow keys and channel up/down will go to the previous or next file respectively. The OK, play and pause can be used to pause or play the current file.

Volume up/down will alter the volume, the mute button will toggle mute, fast-forward and fast-rewind will speed up or slow down playback, rewind will restart the current song from the beginning and the back/exit/return button on the remote will end playback.

When choosing the menu option 'play track number', you use the numeric buttons on the remote control to enter a specific three-digit track number to play. The left/right arrows can then be used to select which file format to play from (MP3 and OGG are supported).

When recording, you will need to select a file number to record to and the process is the same. Or you can simply press OK to record in a sequential order, ergo, record00.ogg, 01, 02…

Using Bluetooth speakers

If you want to use Bluetooth speakers, headphones or some other Bluetooth audio receiving device, all you need to do is buy a Bluetooth audio transmitter.

They're quite cheap and compact. Here is one we've purchased and used quite successfully: **http://bit.ly/2OJcU2K**

It can actually be used as a transmitter or receiver; dedicated transmitters cost around the same price (about £15). We found the audio quality to be reasonable.

It comes with a short 3.5mm plug-to-plug cable so it can be plugged straight into the audio output on the MP3 Player module. It's also supplied with a short USB cable to power it, with a Type-A plug on the end.

You will need to solder a PCB-mount Type-A socket to the prototyping area on the *Mega Box* and wire up its +5V and GND pins to supply points on the *Mega Box* board.

Fig.1 shows the connections required for the USB socket; the D– and D+ connections do not need to be made. Be careful, because reverse polarity may destroy the Bluetooth transmitter.

You will then need to attach the transmitter inside the case somehow (eg, double-sided tape or silicone sealant) and then wire it to the socket with the supplied USB power cable.

If you're clever, you could drill a hole into the case giving you access to the button on the transmitter unit, which you need to press before you can pair it with your receiver.

However, given that pairing is something you only need to do when connecting it to a new receiver, that may not be necessary.

What can it play?

Assuming you have the correct patch file located in the root directory of the SD card, the player can play these formats/containers: Ogg Vorbis, MP1, MP2, MP3, AAC, WMA, FLAC, WAV and MIDI. This should cover most of the audio file formats that you will commonly encounter.

The VS1053b chip is able to record in the following file formats: Ogg Vorbis, PCM and ADPCM. However, the software is only programmed to record in the Ogg Vorbis compressed format.

A list of individual bitrates which are supported by the IC for each file format can be found under section 8 in the VS1053 datasheet: **www.vlsi.fi/fileadmin/datasheets/vs1053.pdf**

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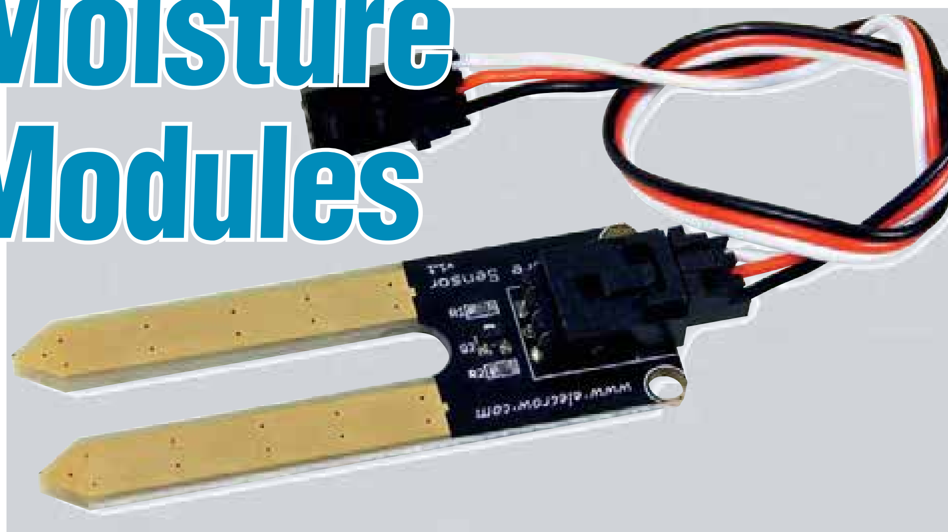
Using Cheap Asian Electronic Modules Part 13: by Jim Rowe

Motion Sensor and Soil Moisture Sensing Modules



This month we look at two low-cost modules from Elecrow. One is a motion sensor which uses microwave Doppler radar technology rather than passive IR sensing. The other module is designed to sense the soil moisture level in a garden or pot plant. Both modules can be easily interfaced with an Arduino or Micromite device.

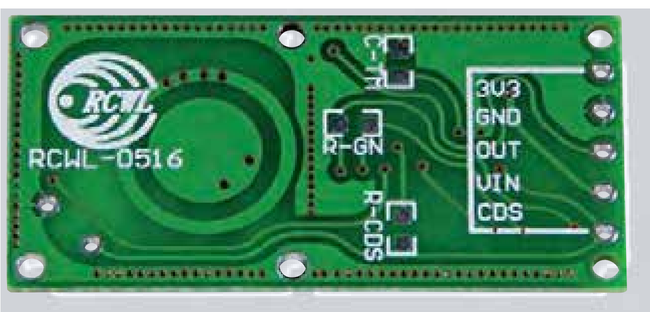
Let's start by looking at the Elecrow RCWL-0516 Microwave Radar Motion Sensor module. It measures just 36 x 17 x 4.5mm, including the on-board transmit/receive antenna. It is available from AliExpress, part number SEM25428R, for US$4.75 incl. P&P.

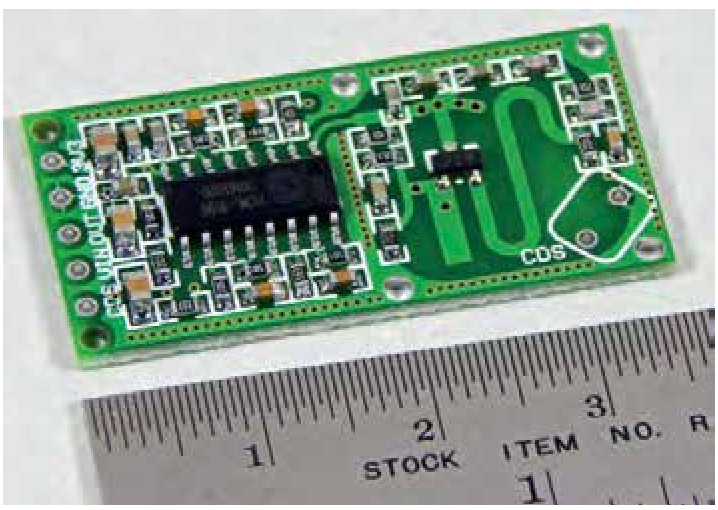
Essentially, this module is designed as a replacement for passive IR movement sensors, as used in intruder alarms, movement-actuated lighting and movement-sensing toys. It is designed to operate on any DC supply voltage between 4V and 28V, with an operating current under 3mA. The UHF oscillator/mixer transmits a signal at around 3.2GHz, with an output of between 20mW and 30mW.

This is claimed to provide movement sensing at distances of up to 7m, with close to 360° of coverage from the front of the module.

Additional features include the ability to adjust the trigger repeat time and the sensing distance, plus the option to use a CdS LDR (cadmium sulphide light-dependent resistor) to disable the sensor at night.

The trigger repeat time is nominally about two seconds, but an optional SMD capacitor labelled 'C-TM' can be added on the back of the PCB to increase this time. Similarly, a 1MΩ resistor 'R-GN' can be added on the back to reduce the sensing range from 7m to 5m.





Both photos show the microwave-based motion sensor module at just over twice normal size (36 x 17mm). The PCB has numerous vias to connect the top and bottom layer ground planes. An odd feature of this module is that nearly all the optional parts (R-GN, R-CDS and C-TM) are soldered to the bottom of the PCB instead of the top; with the exception of the LDR (marked CDS).

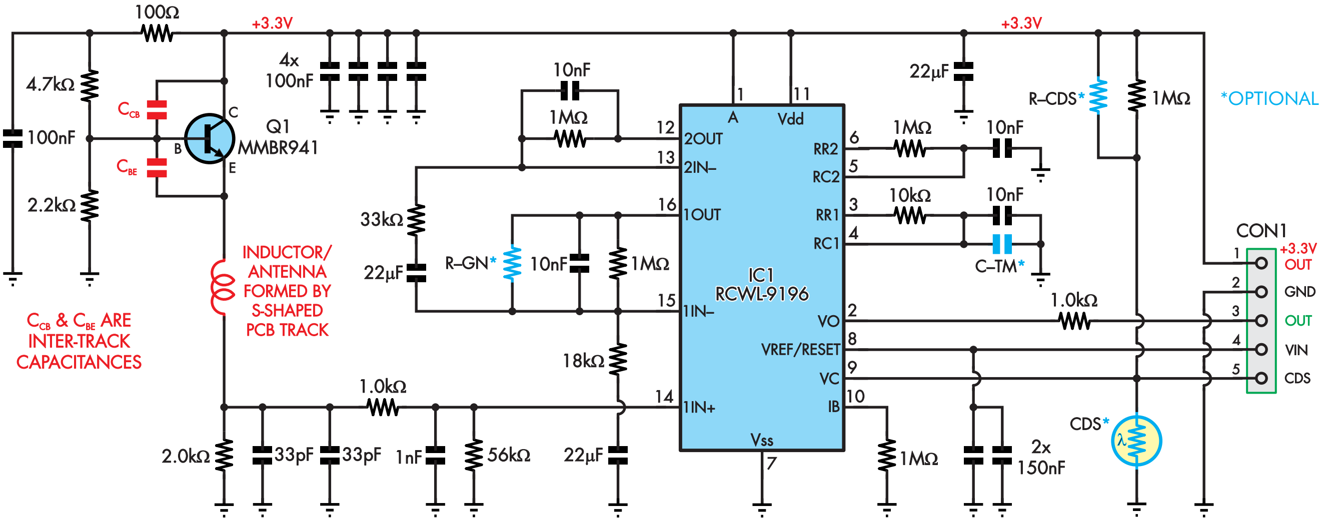


Fig.1: complete circuit diagram for the Elecrow RCWL-0516 microwave radar motion sensor module. The track inductor forms the antenna for both transmission and reception of microwave signals and has a range of approximately 7m.

The optional LDR is added to the front of the board if a user needs to disable the sensor at night. This option would probably only be used for applications like movement-sensing toys because for many other applications, the main use of the sensor would be at night.

Motion sensor circuit

The circuit for the RCWL-0516 sensor module is shown in Fig.1. The UHF oscillator/mixer is on the left, using Q1, an MMBR941 NPN transistor. The low-frequency Doppler signal output from Q1 is fed to pin 14 of IC1, which forms the triggering circuit.

IC1 is an RCWL-9196 device, for which no data seems to be available. However, it's claimed to be very similar to the BISS0001 'micropower PIR motion detector' IC used in many passive IR motion sensors.

The oscillator/mixer circuit around Q1 is interesting because of the use of PCB track components rather than discrete ones. It appears to be a Colpitts circuit, with capacitors C_{BE} and C_{CB} formed by inter-track capacitance, and the inductor/antenna comprising an S-shaped track creating a microstrip line on the top of the PCB. Notice that the microstrip inductor not only forms a key part of the oscillator circuit, but also serves as the antenna for both transmission and reception.

The circuit around Q1 is not only an oscillator and transmitter, but also serves as a mixer to combine the transmitted and received signals and deliver the resulting Doppler difference frequency.

This appears as a relatively small low-frequency signal across the 2.0kΩ resistor connecting the 'cold' end of the inductor/antenna to ground, which then passes through a low-pass RC filter before being fed to input pin 14 of IC1.

Inside IC1, the signal apparently passes through two stages of amplification and filtering and is then used to trigger one of a pair of timers. This timer provides the module's 'movement sensed' pulse at pin 2 (V_O), while the other timer sets the trigger repeat time.

Optional resistor R-GN is connected between the output (1OUT) and inverting input (1IN–) of the first gain op amp inside IC1, so clearly the sensing range is reduced by lowering the gain of this stage. On the other hand, optional capacitor C-TM is used to increase the capacitance from the RC1 pin (pin 4) to ground, to extend the trigger repeat time.

IC1 has an internal 3.3V regulator. This is used to step down the supply voltage fed to the module via the V_{IN} pin (4) of CON1 and then into IC1 itself via pin 8.

The output of the regulator not only powers IC1's internal circuitry but also is made available via pin 11 (V_{DD}), where it's used in this case to power the microwave oscillator/mixer stage around Q1. It can supply up to 100mA of current to external loads, via pin 1 of CON1.

Another point to note is that pin 9 of IC1 allows the chip's triggering to be disabled. As you can see, this pin (V_C) is pulled high to 3.3V, as well as being brought out to pin 5 (CDS) of CON1.

So triggering is normally enabled but it can be disabled quite easily, either by shorting pin 5 of CON1 to ground or by fitting the optional CdS LDR to the module.

When an LDR is fitted, its resistance drops when the ambient light level increases, pulling the voltage at pin 9 of IC1 down. Once it drops to below 0.2V, triggering is disabled.

The purpose of optional resistor R-CDS is presumably to allow fine tuning of the light level at which triggering is disabled when the LDR is fitted. This is useful since LDRs can vary quite a bit in their light/resistance characteristic.

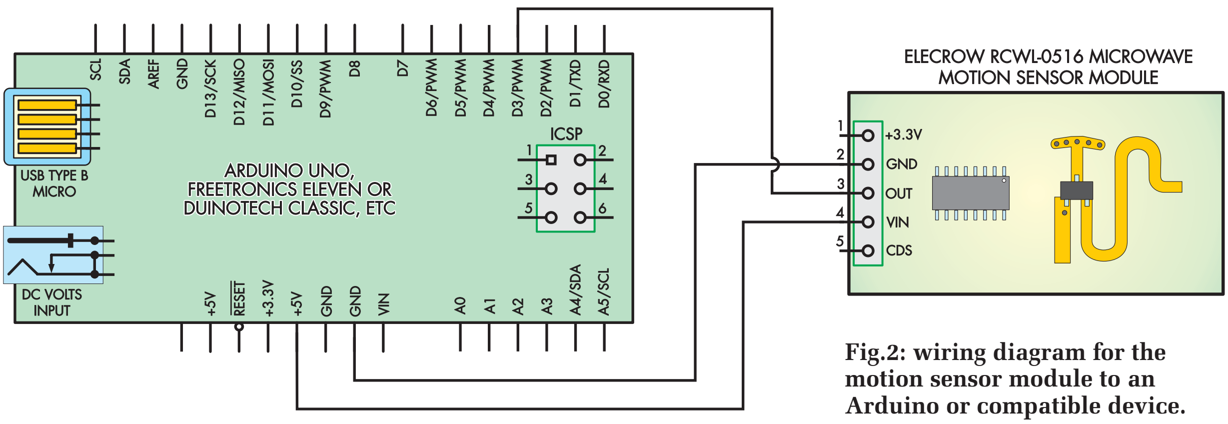


Fig.2: wiring diagram for the motion sensor module to an Arduino or compatible device.

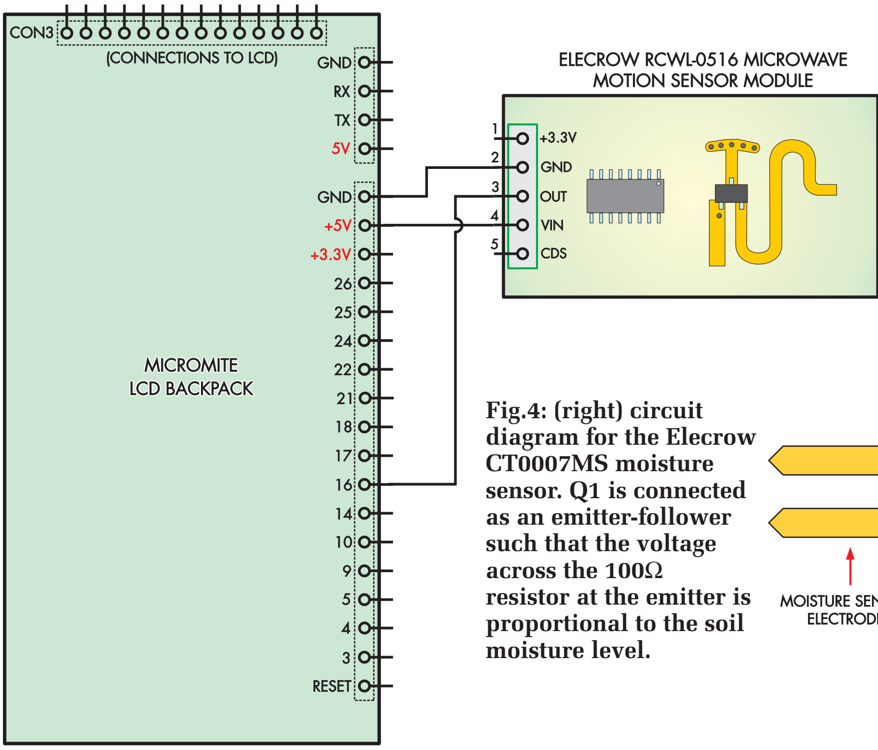


Fig.3: (left) wiring diagram for connecting the motion sensor module to a Micromite. The MMBasic program for this module also displays data on an LCD screen.

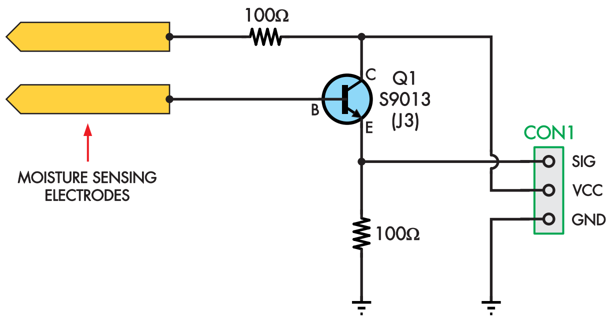


Fig.4: (right) circuit diagram for the Elecrow CT0007MS moisture sensor. Q1 is connected as an emitter-follower such that the voltage across the 100Ω resistor at the emitter is proportional to the soil moisture level.

Connecting to a micro

Fig.2 shows a very simple way of connecting the RCWL-0516 motion sensor module to an Arduino micro. The V_{IN} and GND lines connect to the +5V and GND pins of the Arduino, while the OUT pin (pin 3 of CON1) connects to pin D3. That's all there is to it.

It's just as easy to connect the module to a Micromite, as you can see from Fig.3. Here the V_{IN} and GND lines again connect to the corresponding pins on the Micromite, while the OUT pin connects to pin 16. In both cases, the actual pin of the micro to which the

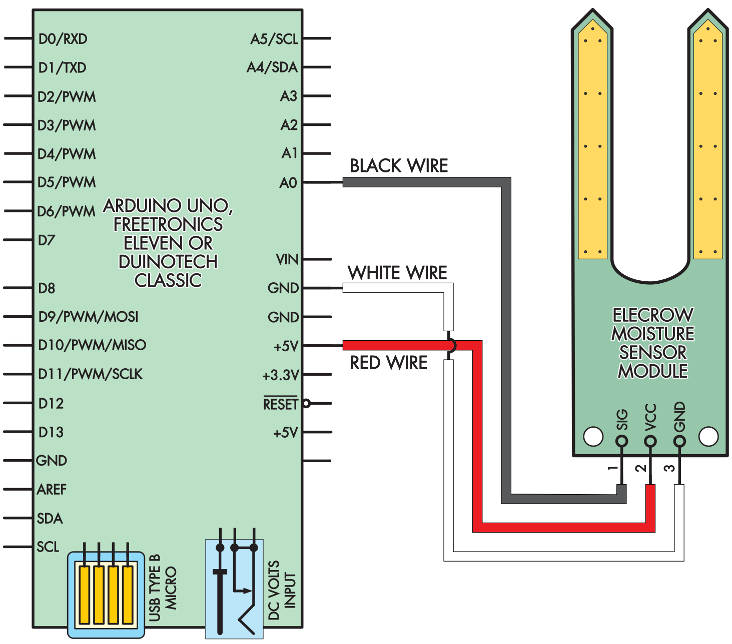


Fig.5 (above): wiring diagram for the moisture sensor module connected to an Arduino or similar. Note that its V_{CC} line can be powered from either the 5V or 3.3V rail.

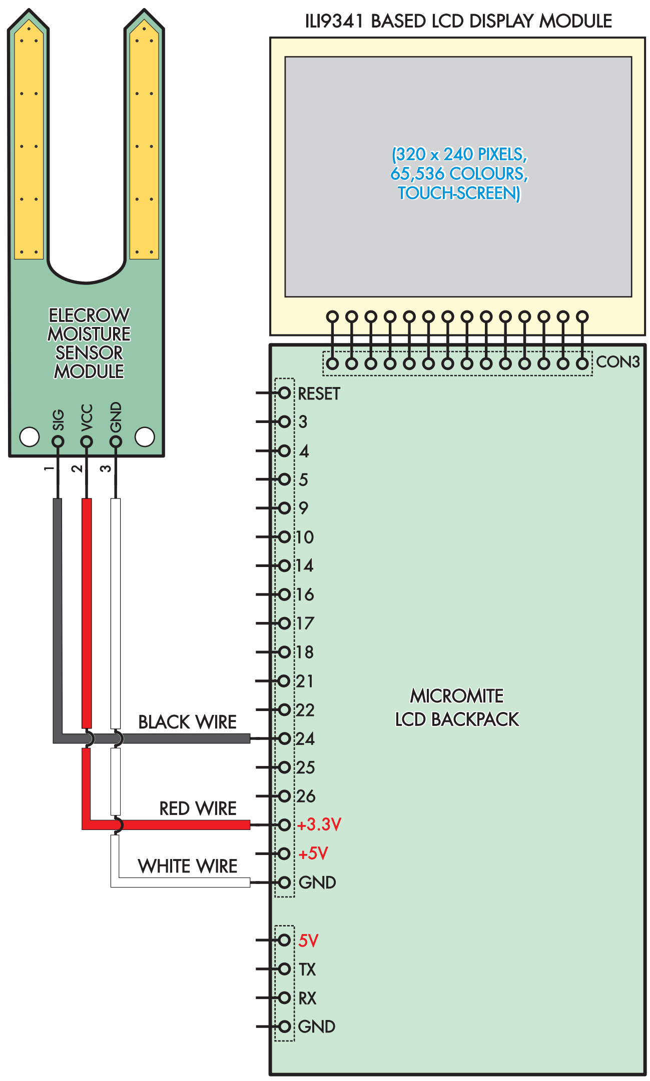


Fig.6 (right): wiring diagram for the moisture sensor with the Micromite and an optional touchscreen attached. If a screen is present there will be a bar display of the soil moisture level, as shown on page 32. As with the Arduino, the module can be powered from either the Micromite's 5V or 3.3V line.

OUT pin of the module is connected is purely to suit the program you'll be using to monitor the sensor's output. We've shown the connections in Fig.2 and Fig.3 merely because they are intended to match the simple programs we will now discuss.

Programming it

It's easy to get the RCWL-0516 module working with either an Arduino or a Micromite, as all it needs in each case is a few brief lines of code.

On the *EPE* website, you'll find two short programs which show just how easily it can be done. The file **RCWL0516_motion_sensor.ino** is suitable for an Arduino.

When you download it, verify and compile it using the Arduino IDE and then upload it to your Arduino. You should find that when you open the IDE's Serial Monitor you'll see a sequence of one-line messages from the module like this:

No movement detected: Output = LOW
No movement detected: Output = LOW
Movement detected: Output = HIGH

Messages will arrive at the rate of two per second, and you'll soon find that moving anything within the sensing area will immediately result in the 'Movement detected' message.

To use the module with a Micromite, download **RCWL0516 motion sensor check.bas** and use MMEdit to upload it to your Micromite.

You'll find that it works in much the same way as the Arduino program, but with one exception; as well as sending messages back to your PC, this one can also provide a display on a Micromite *LCD BackPack* screen.

Elecrow's soil moisture sensor

Now let us take a quick look at the Elecrow CT0007MS Soil Moisture Sensor module, which is essentially an updated version of earlier analogue soil moisture sensors.

Although this module is much simpler than the microwave movement sensor we've just looked at, it's on a somewhat larger PCB because its two sensor probes form about 70% of the PCB area. The overall size of the module is 60mm long by 20mm wide.

Each probe is formed by gold-plated tracks on both sides of the PCB, connected together with 11 vias in each case. You can see this fairly clearly from the lead photo of the module.

Also visible in the photo is the 210mm-long three-wire lead that is supplied with the module, and used to hook it up to a micro. The connecting lead is provided with a 3-way line socket at each end, one of which mates with the plug on the module itself.

Fig.4 shows the CT0007MS module circuit, which is just an emitter-follower using NPN transistor Q1.

When the two probe electrodes are pushed into the soil they form a resistance whose value is inversely proportional to the moisture present in the soil.

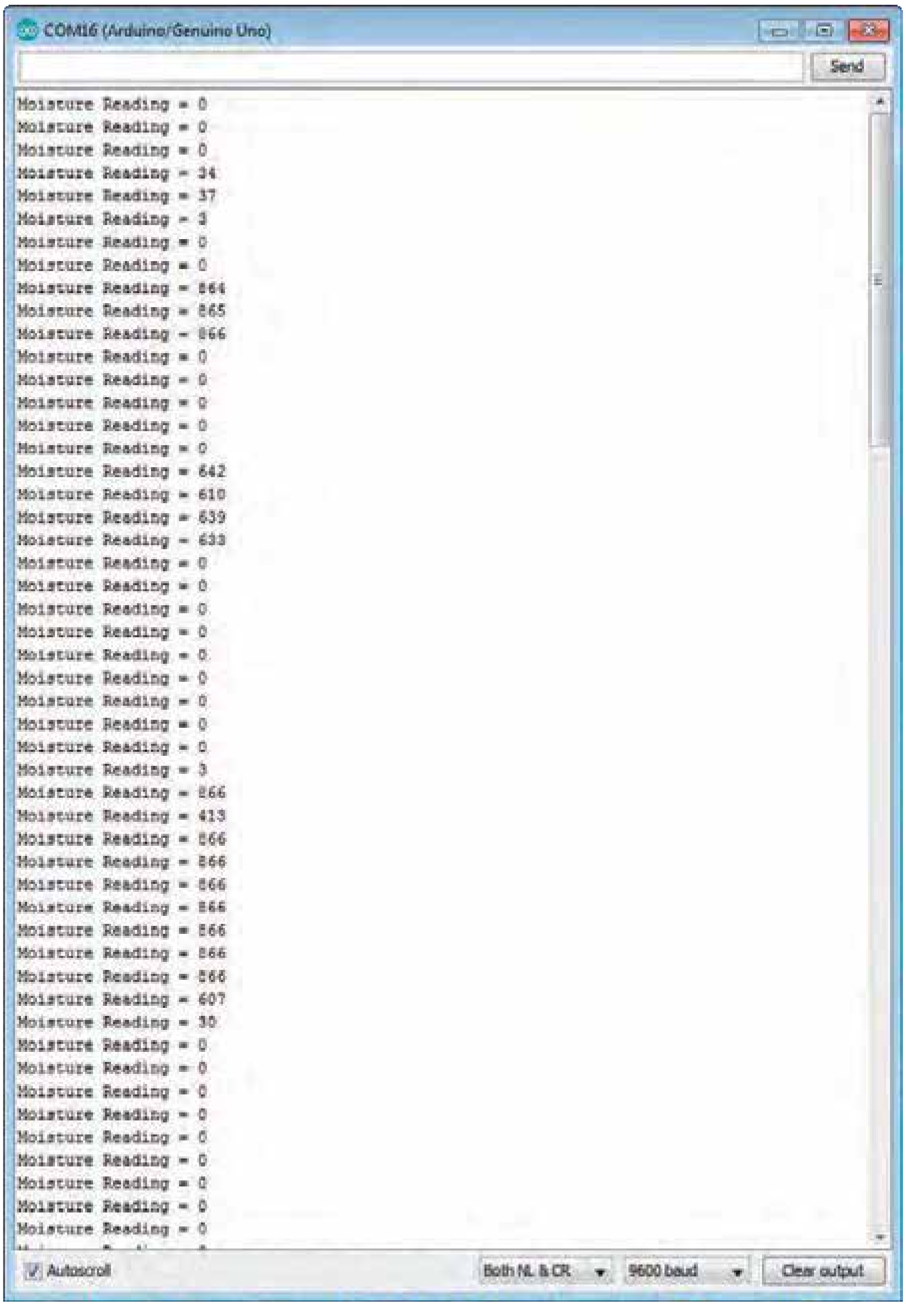
As this resistance is effectively between the DC supply rail (V_{CC}) and the base of Q1, this means that its base current will vary according to the soil moisture. Ergo, wetter soil equals a lower resistance in the base circuit and a higher base current.

Since Q1 is wired as an emitter-follower, the voltage across its 100Ω emitter resistor will also be proportional to the soil moisture level.

The wetter the soil, the higher the voltage across the resistor due to the higher base current. Since the voltage across the resistor forms the signal (SIG) output from the module, this voltage will also vary according to the soil moisture.

Thus, the CT0007MS module is essentially just an analogue transducer converting soil moisture into a DC voltage. In order to use it with a micro, all that's needed is to feed its SIG output to one of the micro's ADC inputs and to connect its V_{CC} and GND inputs to the corresponding supply lines.

Fig.5 shows the sensor connected with an Arduino, while Fig.6 shows it with a Micromite. The module's V_{CC} lead can be connected to either the +5V line or the +3.3V line. To emphasise this, we've connected it



Above: example output data from running the sample Arduino program with the CT0007MS moisture sensor.

to the Arduino's +5V line, but to the +3.3V line in the case of the Micromite.

Programming for the soil moisture sensor

Programming an Arduino to use the CT0007MS moisture sensor module is easy. All you need to do is read the module's SIG output voltage. The higher the reading, the more moisture in the soil.

To get you going with this, we have produced a simple little program called **CT0007MS_moisture_sensor.ino** which is available for download from the *EPE* website.

Use the Arduino IDE to upload it to your Arduino and you should find that it will start printing out (via the IDE's Serial Monitor) moisture readings from the sensor every two seconds, as shown in the screen grab.

During our test, the sensor probes were inserted into soil a number of times. On the last occasion the soil was quite wet, resulting in readings of around 866 (out of 1023). On the other hand, the readings were zero (0) when the probes were not inserted into any soil.

We've also written a small program to show how easy it is to use the sensor with a Micromite. It's called **CT0007MS moisture sensor.bas** and as before, it's available from the *EPE* website. This program produces the same sort of printout of moisture readings (a feature of MMEdit) as the Arduino program. But if your Micromite is connected to an LCD panel, then it will also display a bar graph on the screen, indicating the current moisture level.

You can see this in the two small screen grabs above/below, one showing the display when the soil is fairly dry and the other showing the display when it's very wet.

Hopefully, these two simple programs will give you a good introduction to what's possible using the Elecrow CT0007MS module. It is available from AliExpress, part number CT0007MS, for US$3 including P&P.

MIDI Ultimate Synthesiser

Part 1 | by Paul Cooper | soundtronics.co.uk

The MIDI Ultimate project is a fully featured analogue synthesiser with a performance comparable to many commercially available instruments. Visit the Soundtronics YouTube channel 'Soundtronics Ltd' to see and hear the synth in action. The *MIDI Ultimate* is an evolution of the **musicfromouterspace.com** (MFOS) Sound Lab Ultimate design by the late Ray Wilson, who is credited for much of the design and which has been reproduced here with kind permission of **Synthcube.com** in the US.

Jake Rothman introduced the key elements of an analogue synth in his series of *EPE* articles that ran from August to November 2018; and they are considered essential reading for those wishing to fully understand the fundamentals of analogue synthesis and we will be referring to those articles from time to time in this project series.

A large project – but you can do it!

This project will appeal to both those whose primary interest is in electronics and those whose interest is purely making music. This is quite a large build to take on, with nearly 700 components (Fig.1) and it may initially appear to be rather daunting. However, with care and with our detailed constructional articles, it is quite achievable. The two essential skills needed to undertake this construction are soldering and component identification. If soldering is new to you then numerous guides (**www.epemag.wimborne.co.uk/solderfaq.htm**) and videos can be found online. If you are a first timer or relatively inexperienced in electronics, do practise your soldering before starting on this synth. While the component count is high, the PCB is assembled systematically with each individual section tested before moving onto the next. Plus, all components are through-hole; there is no tricky surface-mount soldering. By the end of the third of these articles, the main audio path will be complete and you will be making sounds. Later parts will introduce the modulation effects.

Ideally, you should have access to the following recommended gear:

- Digital multimeter
- Oscilloscope
- Frequency meter
- 0 to 6V variable voltage source
- Soldering iron and tools.

If you don't have all of the above then it certainly doesn't mean you cannot successfully build the project; it will just take a little longer and require a keen ear to get some of the circuits running optimally.

In later issues, we will discuss low-cost solutions for setting up, including a PC-based oscilloscope. As a minimum,

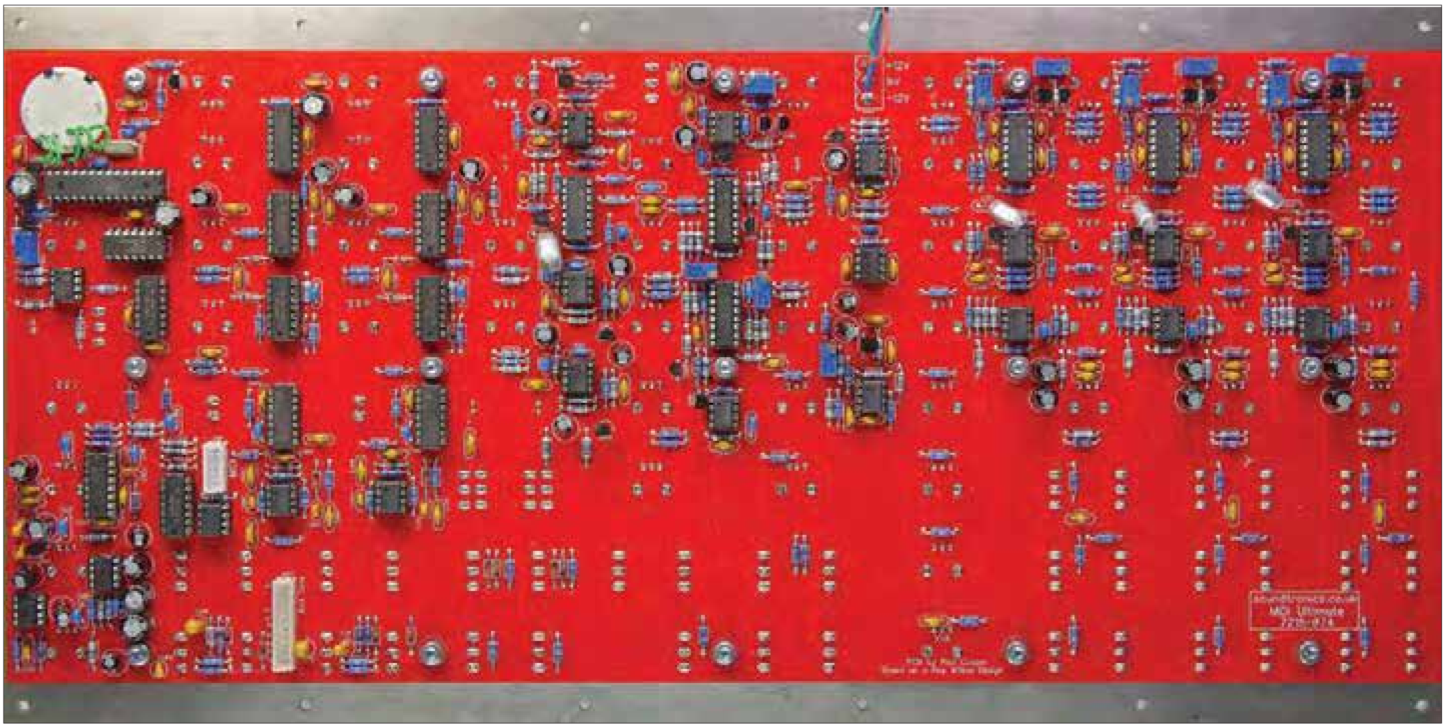


Fig.1. Approximately 700 components are needed to build the *MIDI Ultimate Synthesiser*

you will need a pocket multimeter. The variable voltage source is not essential as the MIDI interface can be used to calibrate the oscillators and voltage-controlled filter.

All parts will be available from Soundtronics, either individually or in kit form, including the front panels and hardwood case. Soundtronics is a UK-based company specialising in DIY synth building – from simple sound effects generators to complete modular synths.

Why analogue?

Analogue synths featured in popular music from the late 1960s onwards, but eventually succumbed to the digital revolution around 1979 with the ground-breaking sampling Fairlight CMI and digital synths from Casio and Yamaha, among others. Even digital synths were not immune from advancing technologies, with the 'softsynth' (PC based) becoming firmly established in music making from the latter half of the 1990s. Today, many of the famous analogue and digital synths have been sampled and recreated in softsynths.

Examples of 'old tech' making a comeback in 21st century are of course vinyl records and even cassette tapes, but why are analogue synths becoming popular again, given that what was seen as their flaws and limitations were designed out with digital and microprocessor technology? Debates on the pros and cons of analogue synths versus digital synths are plentiful in electro music forums, and rather subjective. Musicians using analogue synths suffered many temperature-related effects, including de-tuning, distortion, noise, and drifting of filter cut-off points and wave shapes, to name just a few. It would seem counter-intuitive to want to go back to those days – but, many musicians and enthusiasts are doing just that. Even mainstream synth manufacturers are once again making genuine analogue synths available; no doubt they noticed the second-hand prices for 1970s and 1980s classic analogue synths increasing.

In an attempt to answer 'why analogue?', here is a personal view. Analogue synths allow for an interaction with the instrument that was largely lost with the advent of fixed instrument presets and PC-based synths – the interface. The tactile feel to twiddling knobs and switches with instant feedback with an almost infinite number of permutations allows for greater expression and creativity. The tricky one is why analogue over digital when digital addresses the temperature-related

Table 1: Examples of different analogue synth panel formats

Manufacturer	Format	Connector	Height	Smallest width	Power supply
Soundtronics	5U	¼-inch	8.75-inch (5U)	1.75-inch (1U)	±12V
Modcan	MOTM	¼-inch	8.75-inch (5U)	1.75-inch (1U)	±15V,+5V
MOTM	MOTM	¼-inch	8.75-inch (5U)	1.75-inch (1U)	±15V
Synthesizers.com	MU*	¼-inch	8.75-inch (5U)	2.125-inch	±15V,+5V
Moog	MU*	¼-inch	8.75-inch (5U)	2.125-inch	+12V,-6V
Digisound		3.5mm	9-inch	3-inch	±15V,+5V
Aries		TiniJax/3.5mm	9-inch	3-inch	±15V,+5V
Blacet	FrackRack	3.5mm	5.25-inch (3U)	3-inch	±15V
Paia	FrackRack	3.5mm	5.25-inch (3U)	1.5-inch	±15V
Doepfer	EuroRack	3.5mm	128.5mm (~3U)	10mm (0.4-inch)	±12V,+5V
EuroRack	EuroRack	3.5mm	128.5mm (~3U)	10mm (0.4-inch)	±12V,+5V

*'MU' is 'Moog Unit', where the widths are in multiples of 2.125-inch instead of the 1U's 1.75-inch.

Fig.2. Toggle switch patching.

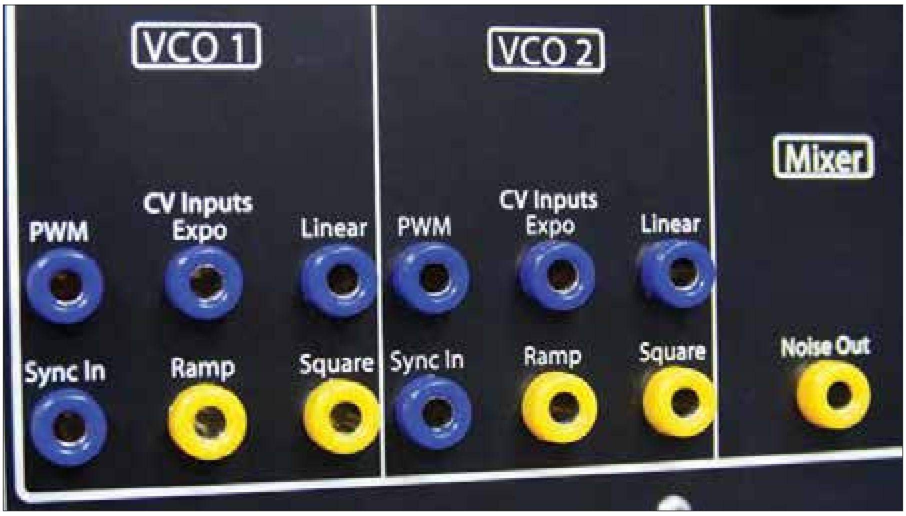


Fig.3. Banana plug lead patching.

Synth features

- Three musically accurate voltage-controlled oscillators (VCOs) with sawtooth and variable-width pulse wave forms, pulse width modulation, hard-sync, log CV (control voltage) inputs
- Voltage-controlled low-pass filter (VCF) 12db/oct (octave) doubles as a sinewave oscillator
- Voltage-controlled amplifier (VCA) with log response
- White noise generator
- Active 8-channel mixer for all VCO waveforms, noise and external input
- Two attack, decay, sustain and release envelope generators (ADSR)
- Two low-frequency oscillators (LFO) with square, ramp, triangle and sawtooth waveforms
- Repeat gate generator that can also double as another square wave LFO
- Sample and hold (S&H) with variable sample rate and glide
- Toggle switch patching with potentiometer mixing
- Echo effect sound processor
- MIDI-to-CV Interface with 1-16 channel selector switch, responds to all 128 MIDI note keys
- Headphones and line output
- Integral ±12V DC power supply regulator (needs external 12VAC 500mA plug top adaptor)
- DIY construction with through-hole components
- Single-board design with PCB-mounted pots and switches eliminates panel wiring.

de-tuning and others drifts mentioned above. It is these uncertainties that actually take away the clinical edge of digital synths. The variations, when managed, are actually what make analogue synths richer in naturally varying harmonic content. Having listened to Tangerine dream for 40+ years, the Pink and Virgin years (1969 to 1983) were heavily influenced by analogue synths. Despite further releasing over 100 albums after that period using later technologies, the early period remains a firm favourite with their fan base. Recommended Tangerine Dream listening: *Ricochet* (1975) and *Encore* (1977).

The score to the 2016 Netflix hit sci-fi mystery TV show *Stranger Things* set in 1984 was created by musicians Stein and Dixon in their studio of mostly vintage synths, accurately evoking the 80s atmosphere and is equally worth checking out.

Analogue synths are not just the preserve of the big manufacturers, synth DIY is well served by smaller niche companies and home enthusiast sharing their designs to the benefit of the DIY community worldwide, including Yves Usson of **yusynth.net**

MIDI Ultimate

The *MIDI Ultimate* uses analogue circuitry for almost all signal production, filtering and modulation sources, which we will call 'modules'. Exceptions are the echo circuit, which uses ADC and DAC elements in the creation of the echo processing effect, and the MIDI interface, which uses an ATMEGA328 chip. We will overview each of the synth modules later in this article. Routing of audio and modulation signals between modules (patching) is often achieved using jack leads (Fig.4), banana leads or patch panels. Full modular synths traditionally use ¼-inch or 3.5mm jacks, depending on the form; ie, 5U or Eurorack respectively. Where the modules are not individual assemblies, but

Fig.4. Jack socket lead patching.

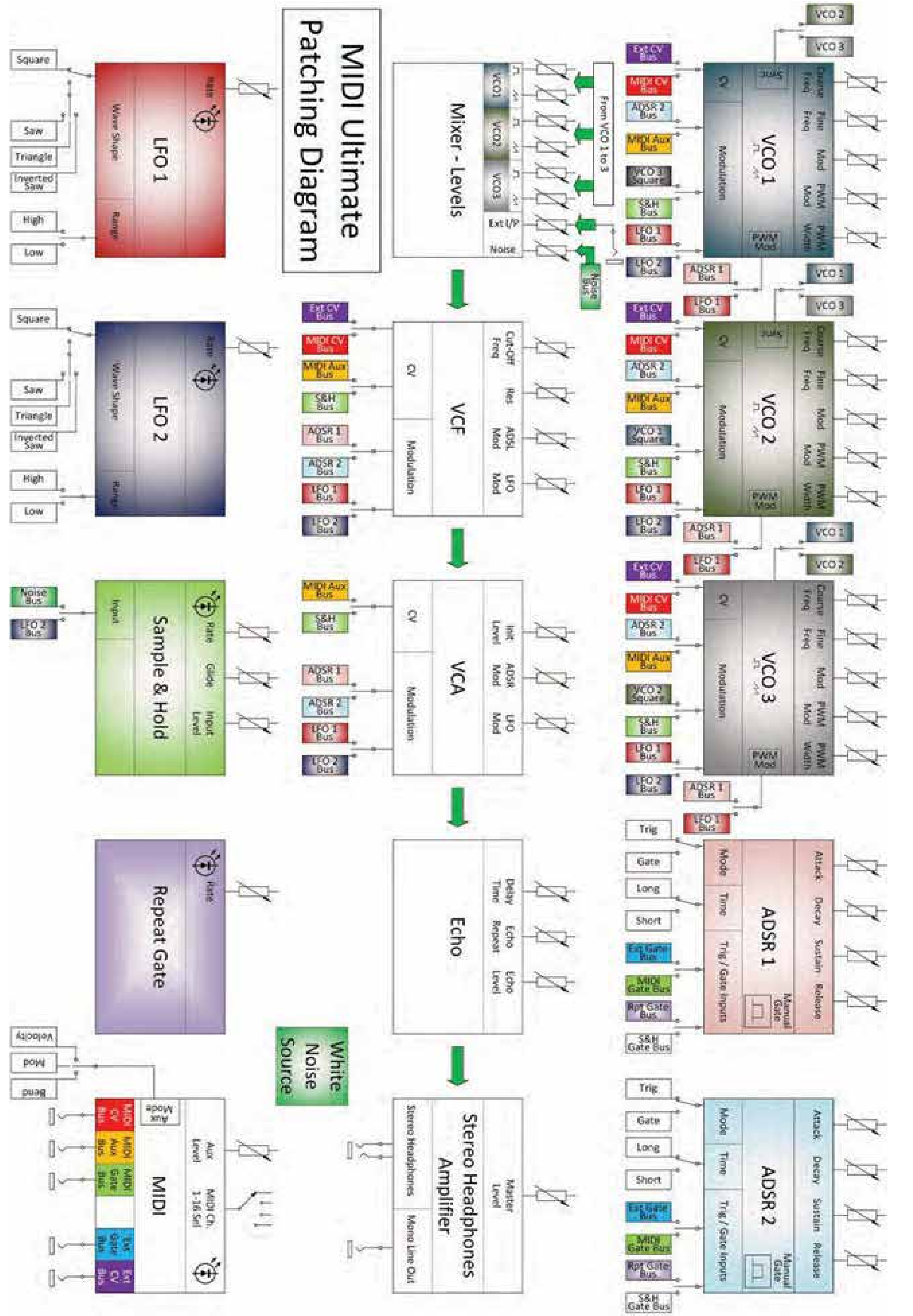


Fig.5. Block diagram of the *MIDI Ultimate* synthesiser

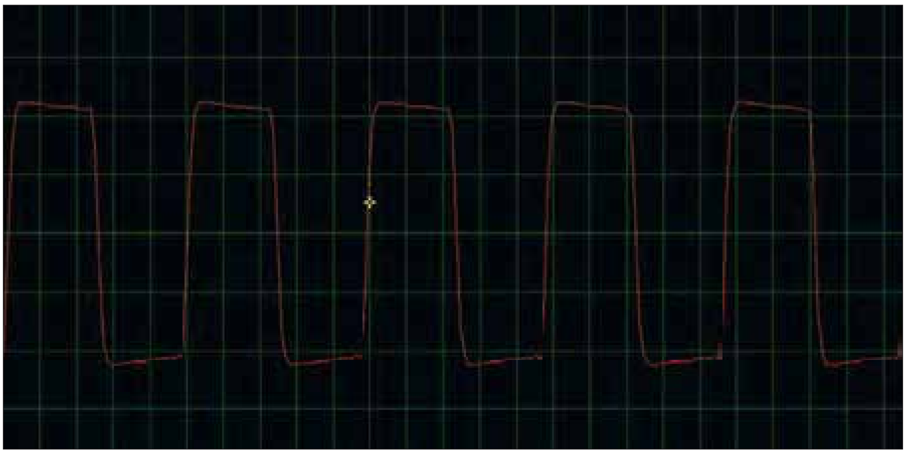


Fig.6. Square wave after the low-pass filter.

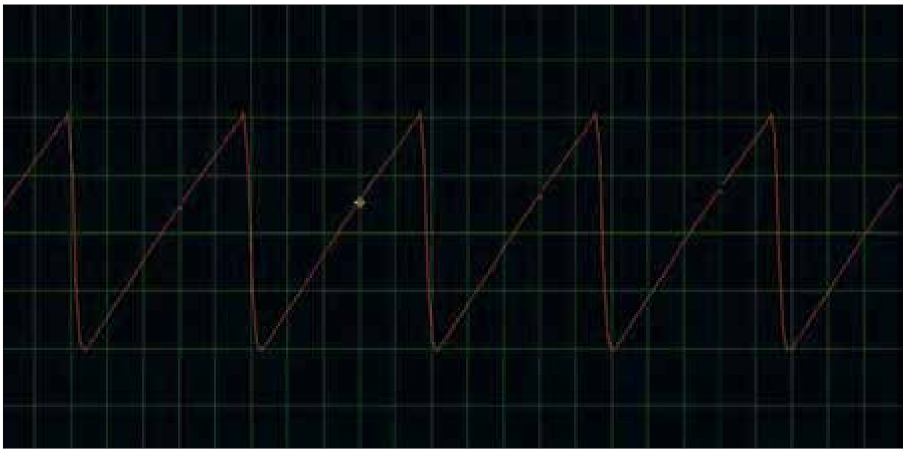


Fig.7. Sawtooth wave after the low-pass filter.

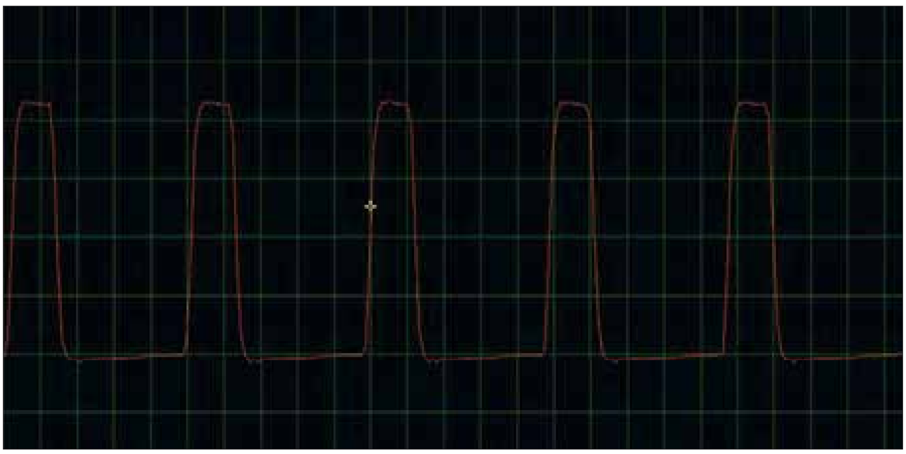


Fig.8. Pulse wave after the low-pass filter.

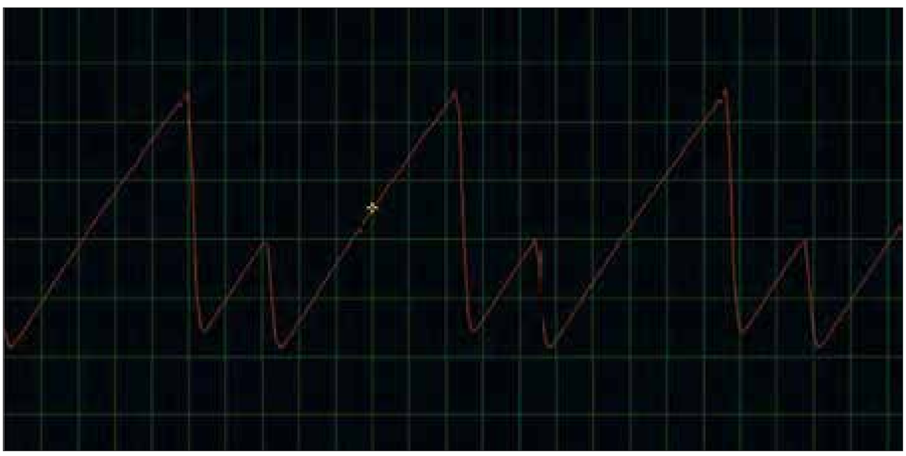


Fig.9. Sawtooth wave with sync from a second VCO.

embedded into a single board synth, like the *MIDI Ultimate*, banana lead patching is common (Fig.3) but we chose to use toggle switches (Fig.2) as that allows for quicker and tidier patching without significantly compromising flexibility.

Modular formats

There are many manufacturers own 'standard' formats for modular synths, covering items such as physical dimensions, connectors, supply voltages and power connectors, see Table 1. Common formats include MOTM, MU, Frack-Rack and EuroRack; the *MIDI Ultimate* is likely to fit MOTM and MU panels with little modification.

While the *MIDI Ultimate* is not a modular design, it can be installed in a 5U modular system and takes up 10U width + 1U wide socket panel. This provides you with a neat way to mount the whole panel assembly – either now or in the future – into your 5U-compatible modular system. You'll have a route to grow, because you can never have too many synths!

Modules block diagram

The *MIDI Ultimate* has various modules that form the basis of an analogue synth – creation of sound through pitch, timbre and loudness electronic circuits using a technique called subtractive synthesis. Pitch generators, often rich in harmonics pass through filters to alter the harmonic content (timbre) of the sound. Additive synthesis is where sinewaves of integer multiples of the fundamental frequency are combined to generate other waveforms, such as square and sawtooth.

Fig.5 shows each module within the synth with their potentiometer, switching controls and jack sockets. With 49 pots and 41 toggle switches, signal routing between modules is certainly flexible. Most toggle switches are 3-position to allow that particular function to be either turned off (centre) or to choose from two sources. For example, VCO 1 frequency modulation has three main source options: LFO 1 or LFO 2; VCO 3 Pulse Wave or S&H output; and ADSR 2 or MIDI Auxiliary signal. Each of these three main options can be used simultaneously, allowing for very complex modulation effects. The depth of modulation is controlled by the VCO's modulation depth pot, in some cases the source signal level can also be adjusted.

Feature of each module

I've mentioned a lot of circuit sub-systems and their associated acronyms; let's go a little deeper into each of these.

Voltage-controlled oscillator (VCO)

- Variable-width square wave (pulse) (Fig.6) plus sawtooth (Fig.7) waveforms
- Temperature compensated 1V/oct tracking from either the MIDI converter or an external control voltage – for each 1V increase in control voltage, the oscillator frequency doubles
- Six sources of frequency modulation, of which three can be used simultaneously
- Two sources for pulse-width modulation (PWM) (see Fig.8)
- Controls for coarse and fine frequency, initial pulse width, modulation depth and PWM depth
- Waveform sync from either of the two other VCOs.

The VCOs are the core of your synth, they provide the pitch element with harmonics. A perfect square wave contains only odd integer harmonics (Fig.10). Whereas the sawtooth (for string and brass like sounds) contains both odd and even harmonics (Fig.11).

Filters are used to change the harmonic content but there are other ways, such as changing the pulse width of the perfect square wave introduces the missing 'even' harmonics. The harmonics in the pulse waveform of Fig.8 are shown in Fig.12.

Synchronising the VCO with another VCO (see Fig.9) adds further harmonics (Fig.13).

Another technique is using two VCOs with one slightly detuned from the other so that constructive and destructive interference occurs at the beat frequency. Varying filters, pulse width against time using modulation sources allows for the harmonic content to vary. The *MIDI Ultimate* has this functionality, but more on this later.

Voltage-controlled low-pass filter (VCF)

The VCF is used to alter the timbre of the sound from the VCOs for example. While filters can be high pass, band pass or comb, the *MIDI Ultimate* has the most common type used in analogue synthesis – the low pass. The low-pass filter passes frequency below the cut-off point and attenuates those above.

- 1V/octave tracking
- Control filter cut-off frequency, resonance, LFO cut-off modulation depth and ADSR cut-off modulation depth
- Four sources for cut-off modulation, of which two can be used simultaneously
- Voltage control of the cut-off point from either the MIDI converter or external control voltage, the MIDI auxiliary converter or the sample and hold output

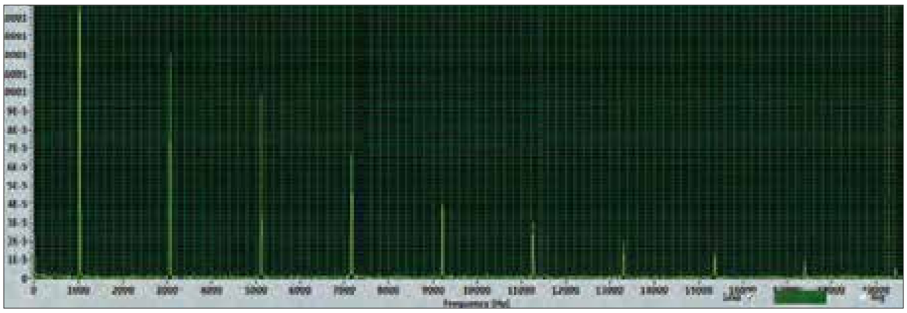


Fig.10. Square wave with its odd harmonics.

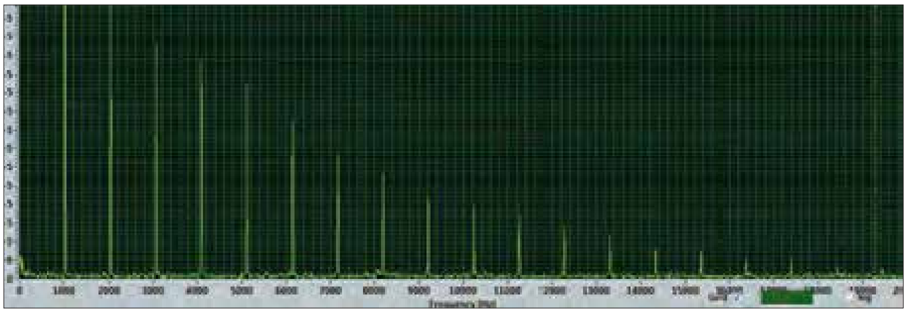


Fig.11. Sawtooth wave with its odd and even harmonics.

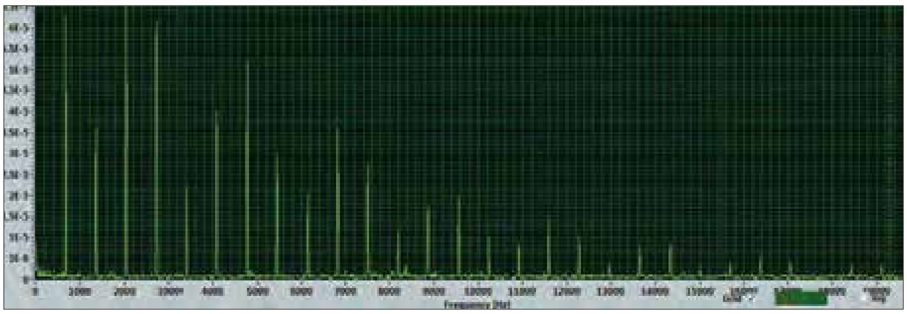


Fig.12. Pulse waveform showing both odd and even harmonics in varying levels.

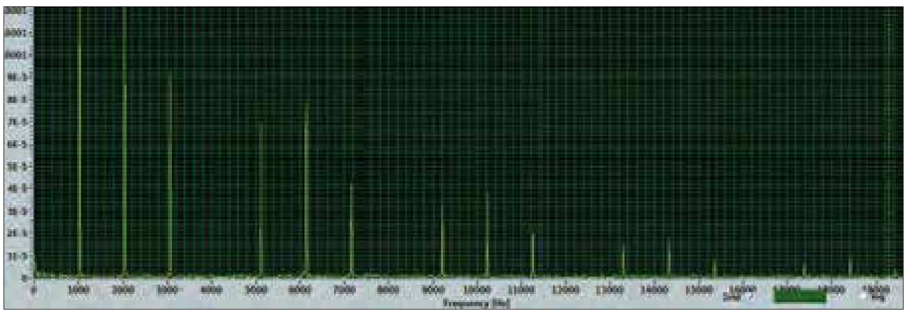


Fig.13. Harmonics from syncing two VCOs.

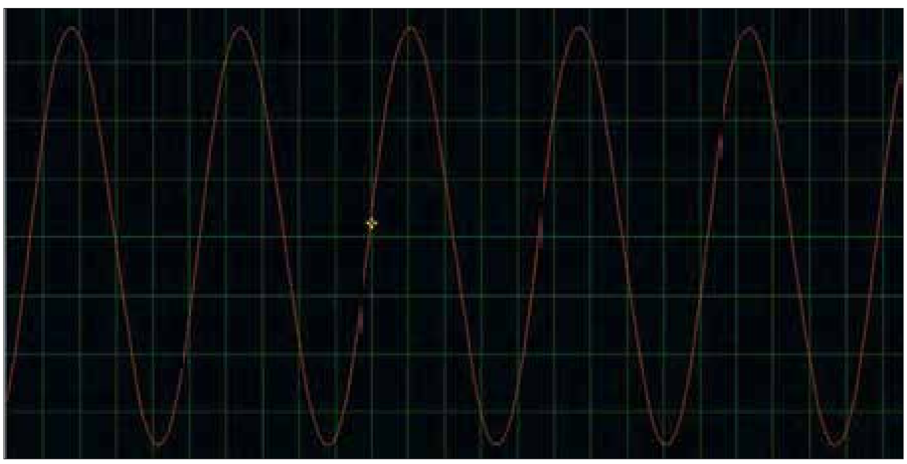


Fig.14. Turning up the low-pass filter resonance causes it to self-oscillate producing a sinewave with less than 5% distortion.

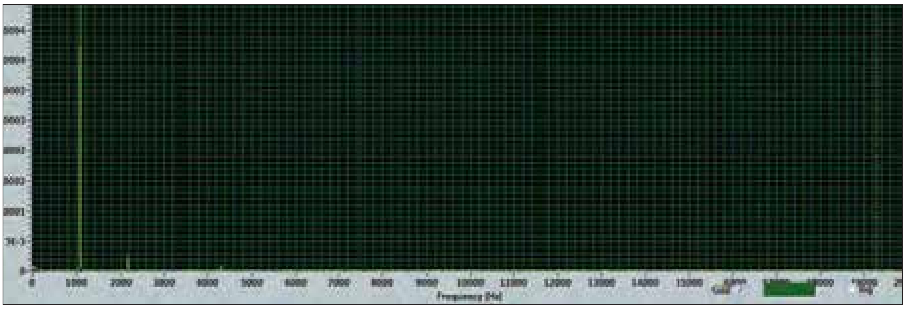


Fig.15. The low-pass filter as a 1kHz sine wave source with low levels of harmonics above the 1kHz fundamental frequency.

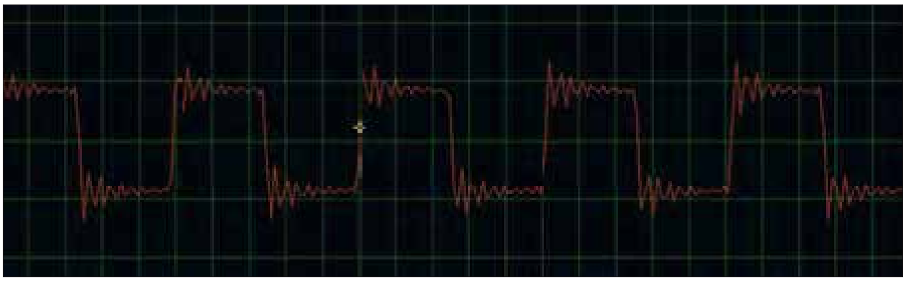


Fig.16. Square wave with low-pass filter resonance.

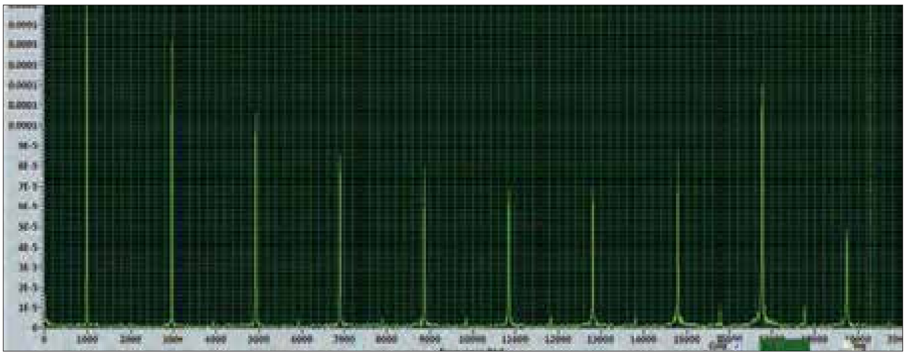


Fig.17. Harmonic spectrum of square wave with low-pass filter resonance.

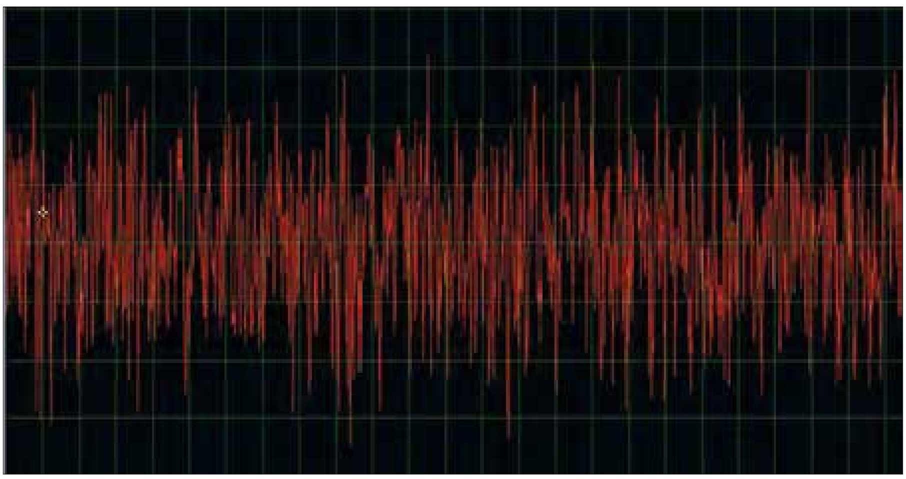


Fig.18. Noise source after the low-pass filter.

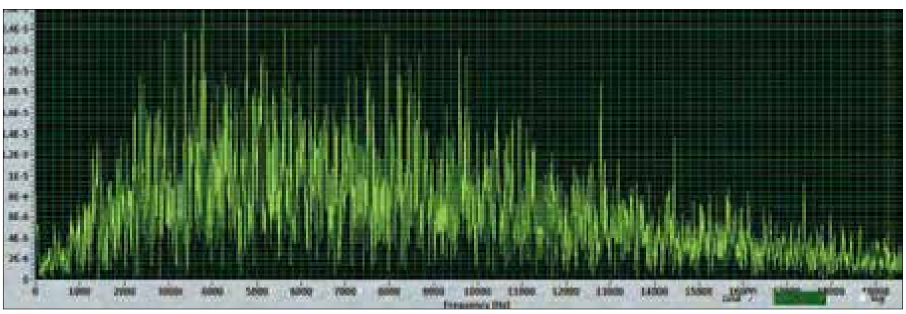


Fig.19. The low-pass filter attenuates higher frequencies of the noise spectrum.

- Self-oscillating at high resonance settings creating a pure sinewave oscillator (Fig.14 and 15)
- Resonance is where the harmonics at the cut-off frequency are boosted. Higher resonance gives a ringing type sound (Fig.16) and a boost to the higher harmonics (Fig.17).

Voltage-controlled amplifier (VCA)

The VCA is an amplifier whose gain can be controlled by a voltage level from another module, such as an ADSR. The ADSR envelope generator with the VCA can be set to represent the amplitude profile of the sound or add tremolo effects.

- Controls for setting the base gain of the amplifier, the depth of LFO and ADSR modulation
- Four sources for amplitude modulation, of which two can be used simultaneously
- Voltage control of the amplitude can be from either the MIDI auxiliary converter or the S&H output.

White noise source

White noise is used as another audio signal source, like the VCOs, but it has no controls associated with it. White noise simply consists, in theory at least, of an equal level of all frequencies across the audio spectrum (Fig.18). Its use includes emulating percussive sounds, wind instruments and as a random signal source for the S&H module.

The low-pass filter attenuates the upper frequencies in the white noise source, see Fig.19.

Mixer

The 8-channel mixer has inputs for each of the VCO waveform outputs, the white noise and the external audio input. The mixer output feeds directly into the VCF.

- Controls for setting the level of each individual audio signal source.

Envelope generator (ADSR)

Two ADSR envelope generators are provided, allowing for independent amplitude modulation through the VCA, as well as sweeping the VCF. It can also be used for modulating the PWM and frequency of the VCOs.

- Controls for setting the attack, decay, release times plus the sustain level
- Switch for selecting long or short delay times
- Mode switch for selecting either trigger or gate operation. In trigger mode, the rising edge of the trigger pulse creates an envelope consisting only of the attack and release elements (Fig.20).

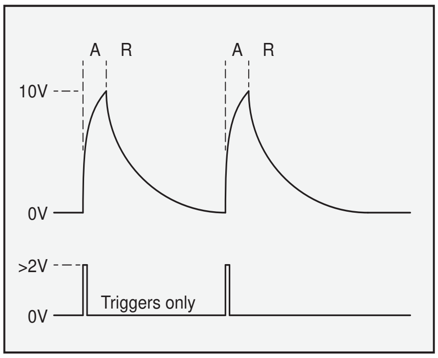


Fig.20. ADSR in trigger mode.

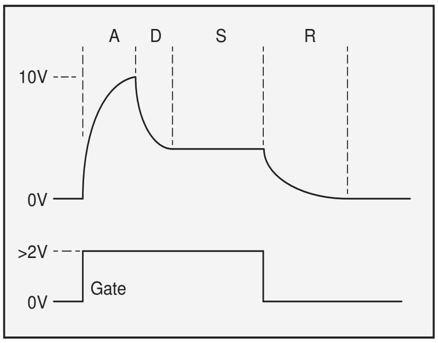


Fig.21. ADSR in gate mode with long gate pulse.

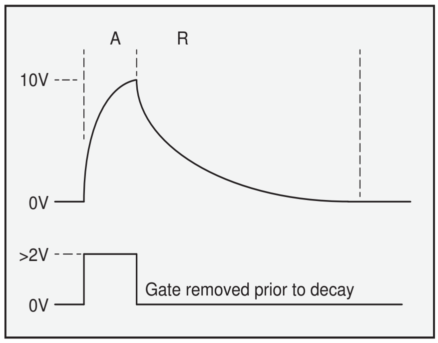


Fig.22. ADSR in gate mode but with short gate pulse width.

In gate mode, the gate signal has to be active for at least as long as the attack and decay time periods. At the end of the decay period, the output will remain at the sustain level for as long as the gate signal remains. When the gate signal is removed, the envelope will execute to the release phase (Fig.21).

If the gate is removed during the attack or decay phases then the release phase is immediately started (Fig.22).

- Push button for manual triggering of the envelope.

Low-frequency oscillator (LFO)

Two LFOs are provided as modulation sources. Each LFO has a choice of four waveforms: square, triangle, saw (ramp upwards) and inverted saw (ramp downwards).

- Control for setting the rate with a toggle switch for selecting high- or low-frequency rate.

Repeat gate generator

A square-wave low-frequency oscillator for generating trigger pulses for the ADSR envelope generators.

- Control for setting the rate.

Sample and hold (S&H)

The S&H circuit consists of a pulse generator that triggers a sample and hold of a changing voltage input signal. The stored voltage is then buffered and used as a modulation source for other modules. For example, you can use a sawtooth signal to generate a staircase modulation for the VCF for a very interesting effect.

Fig.23. Roland UM-ONE USB-to-MIDI Interface.

- Controls for setting the pulse rate, the input signal level and glide of the buffered output voltage
- Choice of LFO 2 or the white noise source as an input signal for random output voltage levels.

Echo effect post processing

Using the PT2399 delay chip to sample, store and play back a variable period of time later to create a rich layering of sounds with amazing results.

- Controls for the amount of echo, the delay time and the number of echo repeats.

MIDI-to-CV interface

The MIDI-to-CV interface enables you to connect the synth to any MIDI keyboard or your PC with a suitable USB interface (Fig.23). The MIDI-to-CV interface generates control voltages and key-pressed gate signals.

- Decodes the key note pressed, a gate signal for key pressed, and a selectable auxiliary channel for key velocity, modulation wheel or pitch bend wheel
- Controls for selecting the MIDI channel from 1 to 16, a selector switch for the auxiliary function and a pot to attenuate the auxiliary signal level.

Headphones amplifier

The line output of *MIDI Ultimate* is a mono signal. However, this mono signal also feeds a pair of amplifiers for the headphones output so you have sound out of both ear pieces.

- Control for master volume level.

Construction

This is a large project, so the build will be covered over five further issues of EPE, in the following order:

Part 2 Power supply, VCOs, VCF and mixer
Part 3 VCA, echo, noise and headphone amplifier
Part 4 LFOs, ADSRs, S&H and repeat gate
Part 5 MIDI interface
Part 6 Final assembly, rear panel, front panel, enclosure, tips and sample patches with links to YouTube.

Experienced builders may decide to construct the synth in their own unique way. Fabricating the double sided 436 x 192mm PCB at home is beyond the reach of most, and drilling close to 2,000 holes will require exceptional patience.

Fortunately, a ready-made through-hole plated, silk screen printed PCB is available from Soundtronics (Fig.1).

Since all pots and switches are mounted on the same PCB, the front panel layout is fixed. You could choose to hard wire the PCB to remotely mounted pots and switches, but over 200 panel wires would be needed!

The front panel is certainly an opportunity to do your own thing. The Soundtronics front panel is of a very classic design. Looking for a jazzy design? – why not print your own? A hardwood case for the *MIDI Ultimate* is available, but some builders may prefer to design and build their own or mount the synth in their existing 5U cabinet.

Assembling the PCB pots and toggle switches will require the back panel to ensure accurate alignment. The panel comes in two parts, the 3mm-thick aluminium back panel and the 1.5mm thick laser engraved front panel. The front panel material is not rigid enough alone so requires the aluminium back panel for stiffness. Only the 3mm back panel is needed for alignment but an alternative acrylic template can be used as a substitute if not using the Soundtronics front panel assembly. I will provide plenty of panel assembly advice and details in Part 6.

Next issue

Next month, we will dive straight into the *MIDI Ultimate Synthesiser* project, starting with the circuit's power supply, the VCOs, VCF and mixer. Lots to look forward to!

MIDI Ultimate Synthesiser parts list

Qty	Description	Value	Designator
Resistors			
2	1% 0.25W	10R	R523, R524
4	1% 0.25W	100R	R911, R913, R916, R917
3	1% 0.25W	200R	R21, R611, R622
5	1% 0.25W	220R	R420, R902, R903, R904, R908
1	1% 0.25W	360R	R905
2	1% 0.25W	470R	R407, R518
3	1% 0.25W	475R	R108, R208, R308
16	1% 0.25W	1k	R3, R30, R114, R214, R314, R419, R421, R610, R621, R717, R719, R720, R817, R819, R820, R901
2	1% 0.25W	1k8	R511, R907
3	Tempco	2k +3500ppm	R103, R203, R303
10	1% 0.25W	2k	R123, R223, R323, R402, R406, R503, R514, R528, R716, R816
10	1% 0.25W	3k	R12, R25, R31, R37, R43, R132, R232, R332, R603, R614
7	1% 0.25W	3k3	R137, R237, R337, R602, R609, R613, R620
12	1% 0.25W	4k7	R38, R102, R135, R202, R235, R302, R335, R422, R423, R501, R601, R612
1	1% 0.25W	7k5	R24
3	1% 0.25W	9k1	R138, R238, R338
36	1% 0.25W	10k	R2, R104, R113, R115, R120, R128, R204, R213, R215, R220, R228, R304, R313, R315, R320, R328, R408, R521, R522, R703, R704, R709, R712, R714, R715, R718, R803, R804, R809, R812, R814, R815, R818, R906, R914, R920
2	0.1% 0.4W	10k	R912, R919
1	1% 0.25W	13k	R909
1	1% 0.25W	15k	R531
2	0.1% 0.4W	15k	R910, R915
3	1% 0.25W	18k	R129, R229, R329
25	1% 0.25W	20k	R14, R22, R23, R35, R42, R133, R136, R140, R233, R236, R240, R333, R336, R340, R413, R520, R526, R529, R530, R701, R707, R710, R801, R807, R810
3	1% 0.25W	30k	R412, R414, R426
3	1% 0.25W	39k	R415, R416, R513
10	1% 0.25W	47k	R131, R141, R231, R241, R331, R341, R424, R425, R713, R813
3	1% 0.25W	49k9	R105, R205, R305
1	1% 0.25W	56k	R403
1	1% 0.25W	68k	R525
1	1% 0.25W	82k	R502
67	1% 0.25W	100k	R4, R15, R16, R20, R26, R28, R34, R39, R40, R101, R107, R112, R117, R118, R119, R122, R124, R125, R126, R127, R130, R201, R207, R212, R217, R218, R219, R222, R224, R225, R226, R227, R230, R301, R307, R312, R317, R318, R319, R322, R324, R325, R326, R327, R330, R401, R404, R405, R410, R411, R417, R505, R506, R508, R509, R515, R605, R608, R616, R619, R705, R706, R711, R805, R806, R811, R918
3	1% 0.25W	110k	R134, R234, R334
2	1% 0.25W	120k	R418, R527
2	1% 0.25W	130k	R606, R617
5	1% 0.25W	150k	R19, R29, R409, R512, R517
1	1% 0.25W	180k	R504
15	1% 0.25W	200k	R5, R6, R7, R8, R9, R10, R11, R27, R33, R106, R116, R206, R216, R306, R316
2	1% 0.25W	270k	R604, R615
1	1% 0.25W	300k	R32
6	1% 0.25W	470k	R1, R17, R18, R507, R510, R519
2	1% 0.25W	680k	R36, R41
21	1% 0.25W	1M	R13, R109, R110, R111, R121, R139, R209, R210, R211, R221, R239, R309, R310, R311, R321, R339, R516, R702, R708, R802, R808
2	1% 0.25W	3M	R607, R618
Potentiometers			
1	Pot RV09	10k	VR404
1	Pot RV09	20k	VR505
29	Pot RV09	100k	VR11, VR101, VR102, VR103, VR104, VR105, VR201, VR202, VR203, VR204, VR205, VR301, VR302, VR303, VR304, VR305, VR401, VR402, VR403, VR501, VR502, VR503, VR506, VR507, VR601, VR602, VR703, VR803, VR901
3	Pot RV090	1M	VR9, VR10, VR12
9	Pot RV09	100k Log	VR1, VR2, VR3, VR4, VR5, VR6, VR7, VR8, VR504
6	Pot RV09	1M Log	VR701, VR702, VR704, VR801, VR802, VR804
Preset potentiometers			
4	Preset 25T	100R	P102, P202, P302, P401
2	Preset 25T	2k	P502, P901
1	Preset 25T	20k	P1
4	Preset 25T	100k	P101, P201, P301, P501
Capacitors (M-Ceramic = multilayer ceramic)			
3	Ceramic disc	4p7	C109, C209, C309
5	M-Ceramic	10p	C115, C215, C315, C601, C607
3	M-Ceramic	22p	C16, C909, C910
1	M-Ceramic	47p	C6
14	M-Ceramic	100p	C101, C102, C110, C201, C202, C210, C301, C302, C310, C503, C703, C707, C803, C807
2	M-Ceramic	330p	C407, C408
2	Ceramic disc	560p	C522, C523
10	M-Ceramic	1n	C11, C104, C204, C304, C705, C709, C805, C809, C912, C913
3	Polystyrene	5n	C0105, C205, C305
1	Polystyrene	10n	C15
6	M-Ceramic	10n	C401, C501, C702, C710, C802, C810
3	M-Ceramic	22n	C13, C602, C608
2	M-Ceramic	47n	C508, C509
69	M-Ceramic	100n	C1, C3, C4, C5, C7, C8, C10, C12, C14, C18, C19, C20, C21, C23, C103, C106, C107, C108, C112, C114, C203, C206, C2007, C208, C212, C214, C303, C306, C307, C308, C312, C314, C403, C404, C406, C502, C505, C506, C524, C525, C527, C529, C604, C605, C610, C611, C701, C704, C706, C708, C712, C713,

Qty	Description	Value	Designator
			C714, C716, C801, C804, C806, C808, C812, C813, C814, C816, C901, C904, C905, C907, C908, C911, C914
1	M-Ceramic	220n	C504
4	M-Ceramic	1u	C516, C518, C519, C526
2	Electrolytic	1u 63V	C512, C513
4	Tantalum	1u 35V	C520, C521, C715, C815
1	Electrolytic	2.2u 50V nPol	C17
6	Electrolytic	10u 25V	C2, C9, C514, C515, C609, C612
1	Electrolytic	10u 50V nPol	C22
2	Tantalum	15u 25V	C718, C818
1	Electrolytic	47u 25V	C528
16	Electrolytic	100u 25V	C111, C113, C211, C213, C311, C313, C402, C405, C507, C517, C603, C606, C711, C717, C811, C817
5	Electrolytic	220u 25V	C510, C511, C902, C903, C906

Switches

2	DPDT	Toggle	S601, S604
7	SPDT	Toggle	S1, S602, S605, S703, S705, S803, S805
32	SPDT CO	Toggle	S101, S102, S103, S104, S105, S106, S201, S202, S203, S204, S205, S206, S301, S302, S303, S304, S305, S306, S401, S402, S403, S404, S501, S502, S503, S603, S606, S701, S702, S801, S802, S902
2	SPST	Push Button	S704, S804
1	Rotary	Hex Switch Lorlin BCK1002	S903

Connectors

2	JST XH Lead Assembly, 5-Way	J901, J904
1	JST XH Lead Assembly, 10-Way	J902
1	Power socket CTB9308/3J903	
1	Power plug	

Diodes

28	1N914	D1, D2, D5, D101, D102, D201, D202, D301, D302, D601, D603, D604, D606, D701, D702, D703, D704, D705, D706, D707, D801, D802, D803, D804, D805, D806, D807, D901

LEDs

2	Green	LED	D3, D4
2	Yellow	LED	D602, D605
1	Blue	LED	D902

Transistors

4	BJT	2N3904	Q1, Q601, Q602, Q901
3	BJT Matched Pair	2N3904	(Q101, Q102), (Q201, Q202), (Q301, Q302)
2	BJT	2N3906	Q501, Q502
1	BJT Matched Pair	2N3906	(Q401, Q402)
5	JFET	MPF102	Q103, Q203, Q303, Q403, Q404
3	JFET	PN4391	Q2, Q3, Q4

ICs

Qty	Description	Value	Designator
2	Logic Chip	4001B	U701, U801
4	Logic Chip	40106B	U703, U803, U901, U908
2	Logic Chip	4066B	U705, U805
1	Opto-Isolator	6N139N	U902
2	Voltage Regulator	78L05	U505, U903
1	Pre-Programmed Ultimate CPU	ATMEGA328P-PU	U905
4	JFET Quad Op-Amp	LF444CN	U4, U101, U201, U301
2	Dual Transcond	LM13700	U402, U501
2	1W Audio Amplifier	LM386N-4	U503, U504
1	DAC	MCP4922	U907
1	Dual JFET Op-Amp	OP275	U906
1	Echo Delay Processor	PT2399	U506
3	Op-Amp	TL071CN	U2, U3, U5
13	Dual-Op-Amp	TL072	U1, U102, U103, U202, U203, U302, U303, U401, U502, U601, U602, U702, U802
2	Quad Op-Amp	TL074	U704, U804
1	Voltage Reference	TL431CLP	U904

Miscellaneous

20	8-pin Turned IC Socket		
15	14-Pin Turned Pin IC Socket		
3	16-Pin Turned Pin IC Socket		
1	28-Pin Turned Pin IC Socket		
1	Crystal	16MHz	Xtal901
1	PCB	Main MIDI Ultimate board	
1	Standoff Fixings kit, Pk of 15, 10mm Long, 4.1mm ID Panel Fixing		

Component designations relate to each module on the main PCB to aid locating them when assembling the PCB.

Designator No.	Module
<100	White Noise, Mixer, S&H, Repeat Gate
1xx	VCO 1
2xx	VCO 2
3xx	VCO 3
4xx	VCF
5xx	VCA, Headphones Amplifier, Echo
6xx	LFO 1, LFO 2
7xx	ADSR 1
8xx	ADSR 2
9xx	MIDI

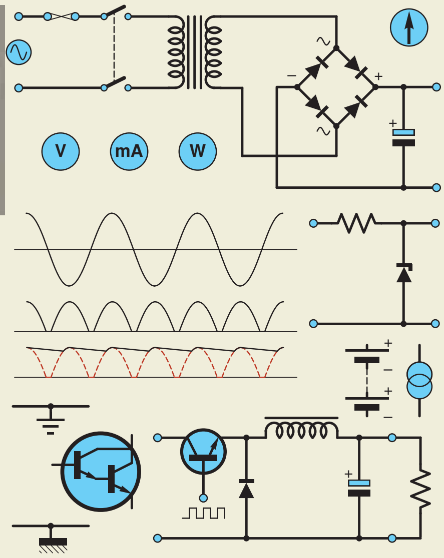
Kits of parts associated with each monthly issue are available from soundtronics.co.uk – approximate cost of parts for the complete MIDI Ultimate synth is:

Main PCB components including pots and switches	£195
Power Supply components including housing and heatsinks	£20
UK plug top 12VAC 500mA power supply	£9
PCB set consisting of main PCB, jack sockets PCB and MIDI sockets PCB	£76
Power Supply PCB	£8
Switchcraft jack sockets. MIDI sockets	£25
Laser Engraved front panel	£58
CNC-routed aluminium back panel	£45
Optional laser-cut acrylic back panel, only required if not using the aluminium back panel	£11
Knobs (the style of knobs is a personal preference) – from	£40
Optional hardwood case	£72

Teach-In 2019

Powering Electronics

Part 3: Linear voltage regulators



by Mike Tooley

Your project is finished and ready to go, but the job isn't done until you've found an appropriate source of power. This could be as simple as choosing a suitably rated mains adapter or as complex as designing a switched-mode power supply with multiple outputs and battery backup. Our latest series – *Teach-In 2019* – is here to help, and will provide you with insight into all aspects of powering your electronic projects and designs.

In this third part we introduce linear voltage regulators. These low-cost, easy-to-use chips can form the basis of very simple but effective power supplies. This month, we have two *Practical Projects*. The first is a fixed linear voltage regulator, while the second is a variable bench power supply with an output that's variable from 1.5V to 13.5V at 0.6A. Together with last month's *Practical Project* (a raw DC supply) this will make an excellent bench power supply for testing and hardware development.

Voltage regulation

Arguably the most obvious solution to the problem of providing a fixed voltage supply is with the aid of a simple linear voltage regulator. This can be based on discrete technology, a dedicated integrated circuit regulator, or a combination of both. Regulation of the output of a power supply is important in nearly every application. Depending on requirements, this can be achieved in various ways, but the most basic is just a Zener diode shunt regulator, as shown in Fig.3.1. Unfortunately, this very simple arrangement has several limitations and is generally only suitable for low-current applications (100mA, or less). In practice a circuit of this type can be expected to produce a regulation (see last month) of about 10% or better with an output resistance of less than 20Ω. To put this into context it's worth looking at a simple example.

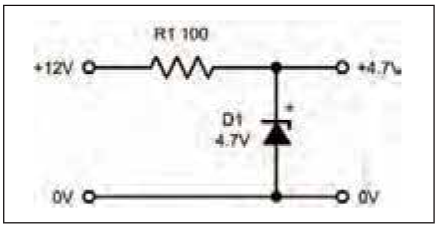


Fig.3.1. A simple Zener diode shunt voltage regulator.

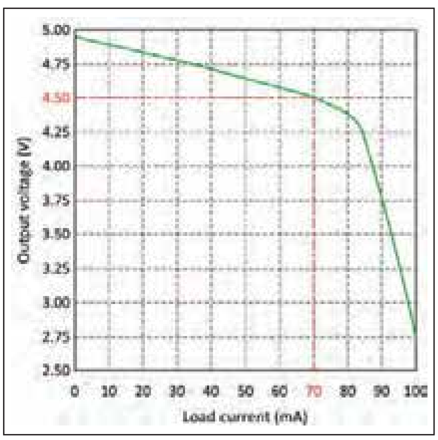


Fig.3.2. Load regulation curve for the Zener diode shunt voltage regulator shown in Fig.3.1.

In Fig.3.1 the 4.7V Zener diode is in parallel (shunt) with the output, so the sum of the diode and load current will flow in the 100Ω series resistor (R1). The load regulation curve is shown in Fig.3.2. This suggests that the circuit's maximum load current (at the point at which regulation fails) is around 70mA. At this point, the output voltage has fallen to around 4.5V (note that the off-load output voltage is just less than 5V).

Using the relationships that we introduced in Part 1, and the information gleaned from Fig.3.2, we can determine the load regulation and output resistance. These amount to 9.1% and 6.4Ω respectively. These values will be adequate for some applications, but the limitations of the simple Zener diode shunt regulator can be summarised as:

- The circuit is only suitable for relatively small output currents (typically less than 100mA)
- Efficiency will be poor (significant power is dissipated in the Zener diode and series resistor – even when no load is present)
- Output resistance is relatively high (for many applications it can be desirable for the output resistance to be very low (often no more than 1Ω or so)
- Regulation (both line and load) is relatively poor (but is easily improved with a few additional components).

A more complex linear regulator is shown in Fig.3.3. This is based on an operational amplifier used as an error amplifier (IC1) and a series transistor (TR1) which acts as a current amplifier and is sometimes referred to as a 'series pass transistor'. Note that IC1 must be able to supply sufficient current to drive the base of TR1 when it, in turn, is having to supply maximum current to the load. At high values of collector current the current gain of TR1 can be expected to be rather low and so this can limit the performance

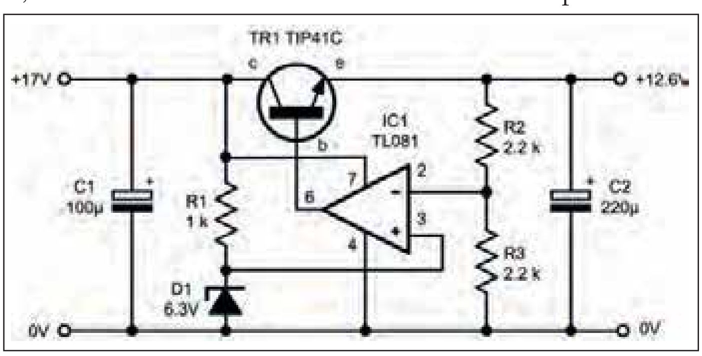


Fig.3.3. A simple linear voltage regulator.

of the circuit. It is worth illustrating this important point with an example.

Let's assume that we need to deliver a load current of 1A and that the operational amplifier can only deliver a maximum output of 20mA. The current gain of TR1 might typically fall from about 80 at a collector current of a few tens of mA to less than 50 at a collector current of 1A so we would need the current gain to be at least 50 (1000/20). Hence TR1 will need to be selected with care. Alternatively, a Darlington transistor or MOSFET device could be used to provide a much higher value of current gain. We will be revisiting this important topic later in the series when we discuss high-current and high-voltage supplies.

In Fig.3.3 a reference voltage is derived from the simple Zener shunt regulator (R1 and D1) that we met earlier. The reference voltage (a reasonably constant 6.3V) appears across D1 and is fed to the non-inverting input of the comparator. The output voltage is applied to the potential divider formed by R2 and R3. Note that, in this example, the values of R2 and R3 have been chosen so that 50% of the output voltage will appear at the inverting input of the comparator.

The op amp (IC1) compares the divided output voltage with the Zener reference voltage. If the output voltage exceeds the reference voltage, the output of IC1 will fall and less current will be applied to the base of TR1. Consequently, the output voltage at the emitter of IC1 will fall. Conversely, if the divided output voltage falls below the reference voltage, the output of IC1 will rise and more current will be applied to the base of TR1. Consequently, the output voltage at the emitter of IC1 will increase. Hence, the circuit automatically compensates for variations in load demand, maintaining the output voltage at, or very near, twice the reference voltage. The output voltage can be easily changed by simply varying the ratio of R2 to R3. Alternatively, a variable potentiometer can be used to provide a continuously variable output voltage control.

Table 3.1 Component selection for common fixed-voltage regulators (see Fig.3.6)

Output voltage	IC1	Input voltage Max.	Input voltage Min.	Input voltage Typ.	Voltage rating for C1 and C4 in Fig.3.6	R1 in Fig.3.4(d)
5V	7805	20V	7.5V	9V	25V	330Ω
9V	7809	25V	12V	13V	25V	680Ω
12V	7812	30V	15V	17V	35V	1.2kΩ
15V	7815	30V	18V	20V	35V	1.5kΩ
–5V	7905	–20V	–7.5V	–9V	25V	330Ω
–9V	7909	–25V	–12V	–13V	25V	680Ω
–12V	7912	–30V	–15V	–17V	35V	1.2kΩ
–15V	7915	–30V	–18V	–20V	35V	1.5kΩ

Three-terminal voltage regulators

Happily, there is no need to resort to designing circuits like the one shown in Fig.3.3 since the problem has been very neatly solved with a wide range of three-terminal voltage regulators. These integrated circuit devices are extremely simple to use, and they are available in both fixed and variable versions.

The most popular series of fixed voltage regulators employs a TO220 plastic package and the series is prefixed with 78 (for positive input and output voltages) or 79 (for negative input and output voltages). These devices are available in a range of voltages (5V, 9V, 12V, 15V, 18V and 24V) and they are usually rated for maximum load current of 1A. The internal arrangement of these devices is based on the circuit that we met earlier (Fig.3.3) but with the addition of thermal and safe operating area (SOA) protection. Note that the fixed voltage reference is internal and cannot be changed.

Some basic arrangements for 78 series regulators are shown in Fig.3.4. In Fig.3.4a the regulator's common connection is connected to 0V at the input and 0V at the output. It is important to note that the worst-case unregulated DC input voltage should normally be at least 2.5V greater than the nominal regulated output voltage. In other words, the differential between the input and output voltages needs to be greater than 2.5V for effective regulation, but low-drop out (LDO) fixed-voltage regulators are available if needed. The penalty for not observing the minimum threshold voltage will be poor regulation, sometimes coupled with an unacceptable level of residual mains hum superimposed on the supposedly regulated output. Another important design consideration is that the unregulated input voltage must not be too great, otherwise the regulator dissipation may become excessive. For this reason, a suggested input voltage range has been quoted in Table 3.1 for some of the most common fixed-voltage regulator types.

Circuit variations

In Fig.3.4b we have added two low-value capacitors (C1 and C2) to prevent instability and oscillation. (Note that these components must be connected in close proximity to the regulator's terminals, otherwise they will be ineffective). These two components should always be fitted whenever an integrated circuit voltage regulator is used.

In Fig.3.4c a reverse-connected diode between the output and input terminals of the regulator has been added. This diode provides protection for the regulator in the event that the output voltage might exceed the input voltage. This situation can arise if the output remains connected to a voltage source (eg, a battery) when the input voltage is disconnected.

Fig.3.4d shows how a simple LED indicator can be added to signal the presence of an output voltage. The value of R1 can be selected from Table 3.1.

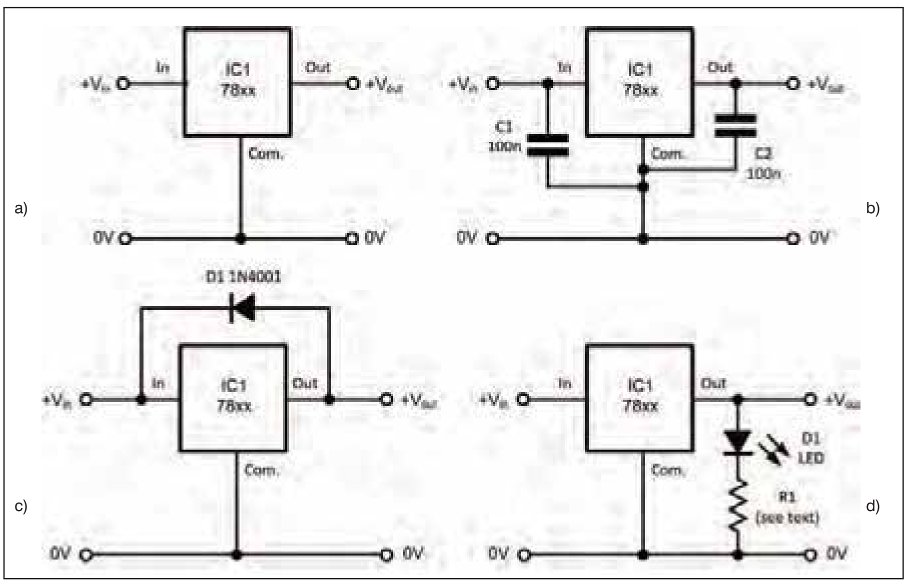


Fig.3.4. Three-terminal fixed-voltage regulators.

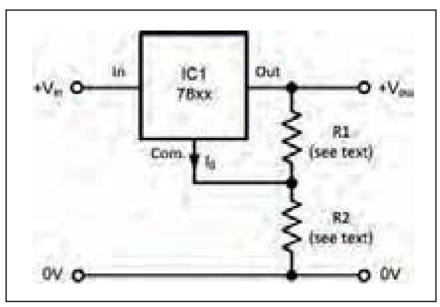


Fig.3.5. Fixed voltage regulator with output voltage adjustment.

If necessary, the output voltage from a fixed voltage regulator can be set to a value that's greater than the rated voltage. This makes it possible to design a regulator for any desired voltage, such as 7.5V, 11V or 13.8V. Fig.3.5 shows how this is done. The two fixed resistors (R1 and R2) form a potential divider. If the regulator has a fixed voltage rating of V_{xx}, the output voltage of Fig.3.5 will be given by the relationship:

$$V_{out} = V_{xx} + \left(\left(\frac{V_{xx}}{R1} + I_0 \right) \times R2 \right)$$

The common current (I_0) tends to vary with device, but is typically around 4.3mA. Let's assume that we need a 7.5V 1A regulated supply. If we choose a commonly available value of 1kΩ for R1 we can calculate the required value for R2 from:

$$R2 = \frac{(V_{out} - V_{xx})}{\left(\frac{V_{xx}}{R1} + I_0\right)} = \frac{(7.5 - 5)}{\left(\frac{5}{1000} + 0.0045\right)}$$

$$= \frac{2.5}{0.0093} = 269\Omega$$

The nearest preferred value (270Ω) can then be selected. If adjustment is required (or if the common current is different from the expected value) R2 can be replaced by a pre-set variable resistor. In this case, a value of 500Ω would do the job nicely,

Fixed voltage regulators are generally available for use with either positive or negative input and output voltages. Fig.3.6 shows comparable positive and negative three-terminal voltage regulator circuits. Two additional capacitors, C1 and C4, have been added to reduce noise. They should be appropriately rated in terms of working voltage, and since they're electrolytic, do note the polarity of their connection (see Table 3.1 for recommended values).

Another very simple way of increasing the output of a fixed voltage regulator in increments of 0.7V is shown in Fig.3.7. In this arrangement, two forward-conducting silicon diodes are connected in series with the regulator's common connection. The output voltage of the regulator becomes effectively raised by (2 × 0.7V) to become (5 + 1.4) = 6.4V. This little trick can be used with all the circuits that you met earlier. For example, Fig.3.8 shows how a standard 12V fixed three-terminal voltage regulator can be modified to provide an output of 13.4V with the addition of just two diodes.

For higher output voltages it can be more convenient to replace several silicon diodes with a single Zener diode, as shown in Fig.3.9. This circuit shows how a 5V fixed-voltage regulator can be used with a 2.7V Zener diode to provide an output of 7.7V. The arrangement shown in Fig.3.10 shows how outputs of 10.6V and 20.6V can be obtained when a 5.6V Zener diode is used with 7805 and 7815 regulators respectively.

The same 'jacking-up' technique can be used to provide a variable output by inserting a pre-set variable resistor in the regulator's common connection, as shown in Fig.3.11. This handy circuit will provide outputs adjustable from 5V to 8V with a 7805 or 9V to 12V with a 7809 device.

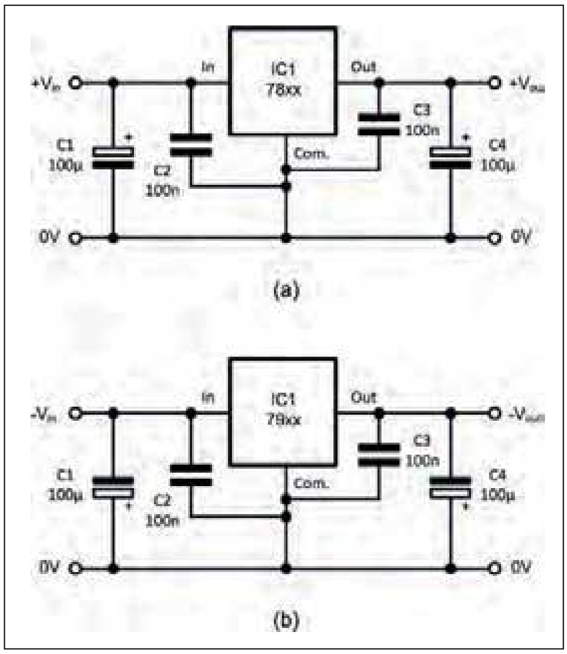


Fig.3.6. Comparable positive and negative three-terminal fixed-voltage regulators.

Increasing the output current

When more than 1A is required, a fixed-voltage regulator can be augmented with the aid of an additional series-pass transistor, as shown in Fig.3.12. The output of this arrangement will be approximately 0.7V less than the regulator voltage. So, in this case the output will be appriximately14.3V. Note also that the output will not have the same over-current and thermal protection enjoyed by the regulator chip

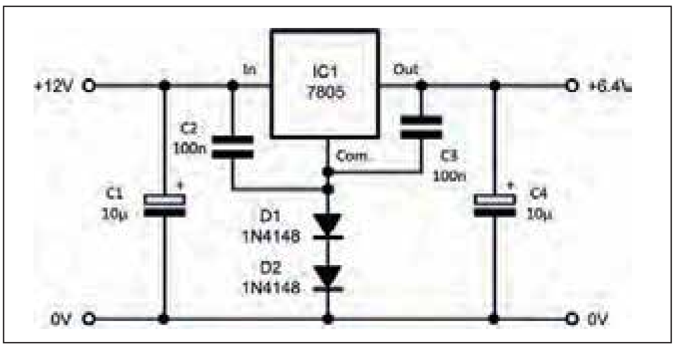


Fig.3.7. Using diodes to increase the output of a 5V fixed-voltage regulator.

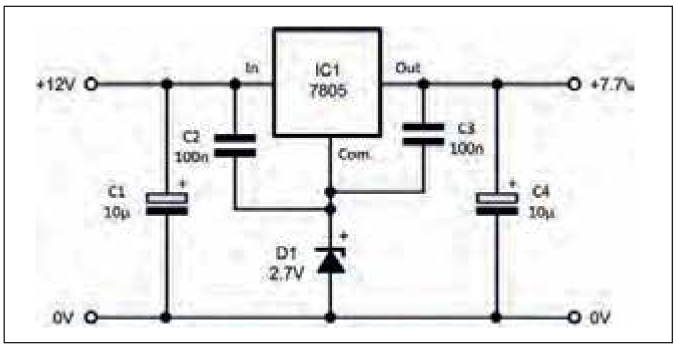


Fig.3.9. Using a single 2.7V Zener diode to increase the output of a 5V fixed-voltage regulator.

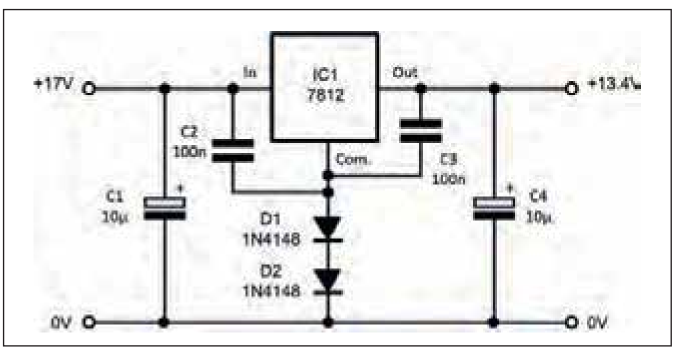


Fig.3.8. A 13.4V regulated supply using a 12V fixed-voltage regulator.

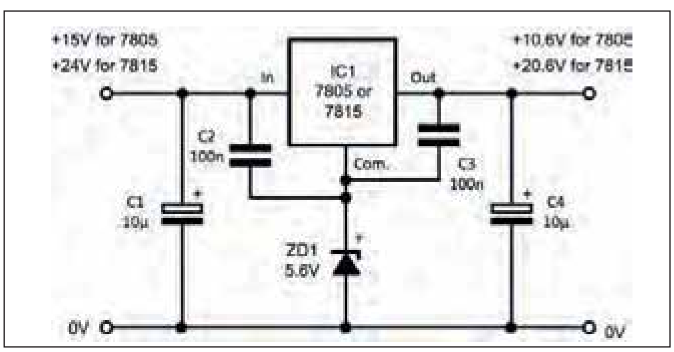


Fig.3.10. Using a single 5.6V Zener diode to increase the output of a 5V/15V fixed-voltage regulatorr.

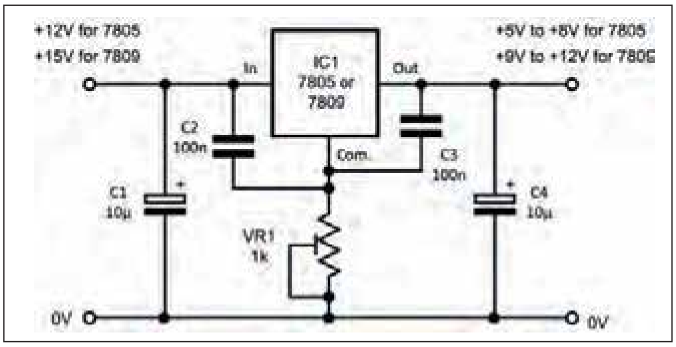


Fig.3.11. An adjustable output from a fixed-voltage regulator.

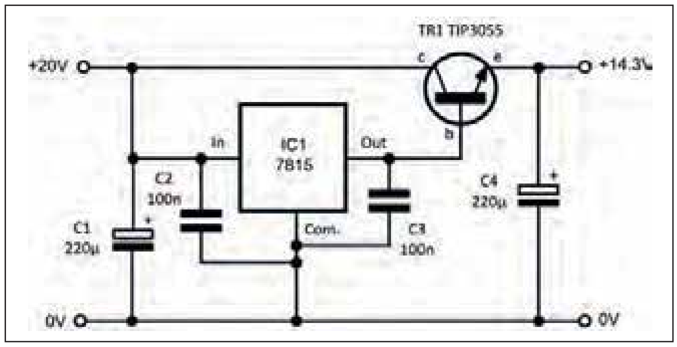


Fig.3.12. A current boosted three-terminal fixed-voltage regulator capable of supplying loads up to about 5A.

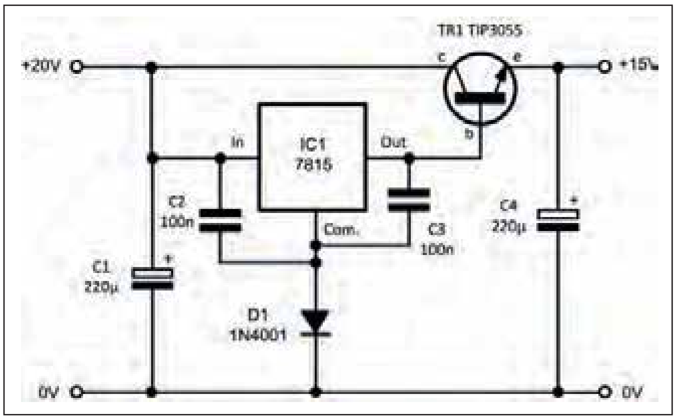


Fig.3.13. Adding a diode to compensate for the drop in output voltage for the circuit in Fig.3.12.

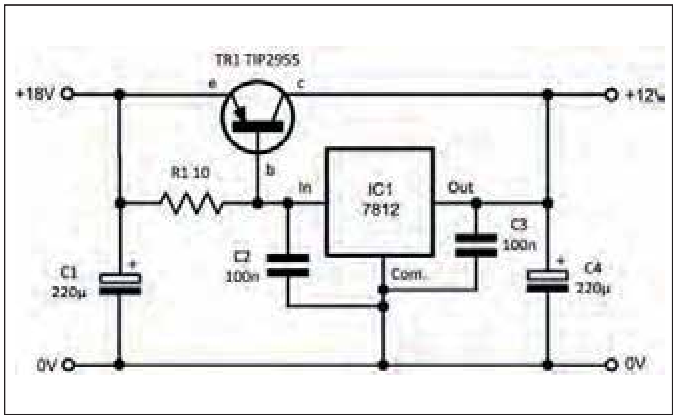


Fig.3.14. An improved current-boosted three-terminal fixed-voltage regulator.

when used on its own. In some applications this might not be important, but in others it could be crucial. Note that the 0.7V reduction in output voltage can easily be overcome by inserting a silicon diode in the regulator's common connection, as described earlier (see Fig.3.13).

A better augmented three-terminal voltage regulator is shown in Fig.3.14. This circuit uses a PNP device rather than the NPN device used in the two previous circuits. Note that there is no need for an additional diode in the regulator common connection. To protect TR1 and limit the output current to a safe value an additional transistor can be added, as shown in Fig.3.15. In this arrangement, the load current is sensed by means of R1 and the sensed voltage is fed to TR2 which conducts when the load current exceeds approximately 4.5A. If I_{lim} is the required current limit, then the required value of R1 can be found from: $I_{lim} = 0.7/R1$

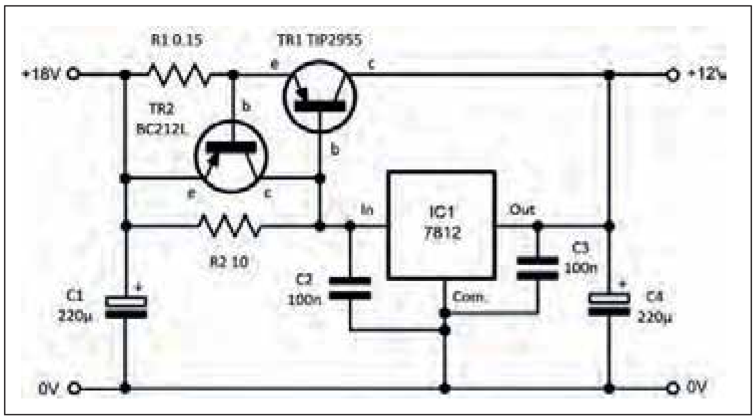


Fig.3.15. Adding an extra transistor to provide current limiting.

Practical Project: 1A fixed-voltage regulator module

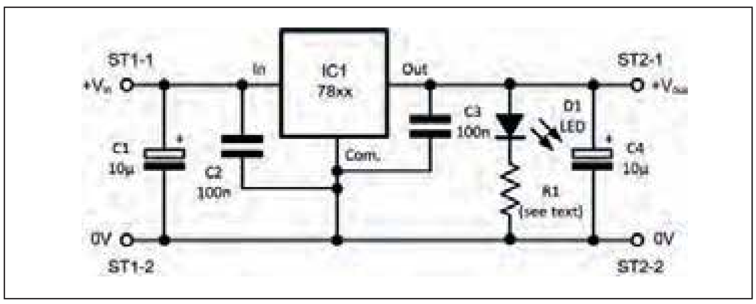


Fig.3.16. Circuit of the 1A fixed-voltage regulator module.

The first of our two *Practical Projects* this month is another building block that can be used with several of our other projects. It's a low-cost fixed-voltage regulator that can supply load currents up to 1A. Depending on the regulator chip used, the module can be built in variants that will supply 5V, 9V, 12V and 15V.

The circuit of our 1A fixed-voltage regulator module is shown in Fig.3.16. This follows the design concepts introduced earlier and includes an LED power indicator. The correct value for the LED series resistor R1 should be chosen according to the values quoted earlier in Table 3.1.

You will need...

1 Perforated copper stripboard (9 strips each with 25 holes)
2 2-way PCB screw terminal connector (ST1 and ST2)
1 1kΩ resistor (R1) (see text)
2 10µF 35V capacitors (C1 and C4)
2 100nF capacitors (C2 and C3)
1 78xx three-terminal voltage regulator (see text)
1 red LED
1 small TO220 heatsink (see text)
4 stand-off pillars and mounting screws

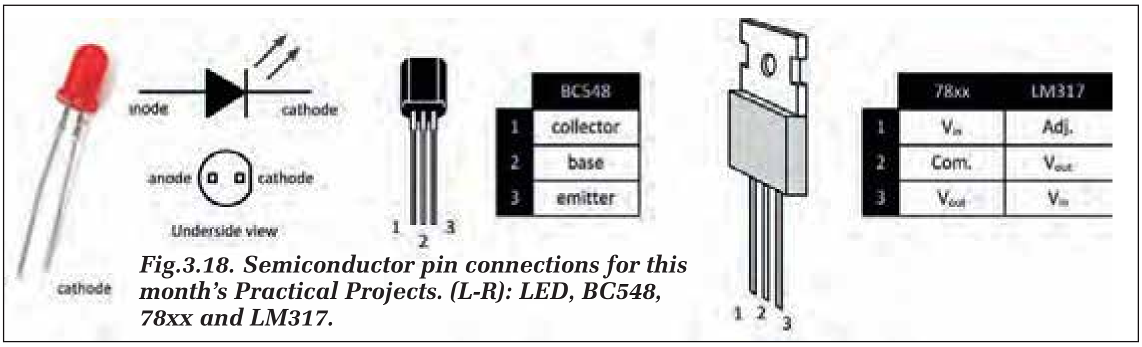


Fig.3.18. Semiconductor pin connections for this month's Practical Projects. (L-R): LED, BC548, 78xx and LM317.

The three-terminal voltage regulator should be mounted on a small TO220 heatsink (for clarity this has been removed in Fig.3.19). A heatsink rated at better than 13.5°C/W will be adequate for most purposes, but if the module is to be operated continuously at full-load current a heatsink of 7.8°C/W is recommended. The heatsink can be fitted using a nut and bolt, or you can make use of an appropriate mounting clip. In a later part we will be discussing this topic in more detail. To promote heat conductivity, we avoided the use of insulating washers and instead bolted the tabs of the regulator chip directly to the heatsink. The tab is connected internally to common so the heatsink body will *also* be at 0V.

Construction

The layout of the low-cost fixed-voltage regulator is shown in Fig.3.17. Note that there are 15 track breaks and five links. The pin connections for the semiconductor devices are shown in Fig.3.18. Note how C2 and C3 are mounted close to the pin connections for IC1. These two capacitors are required to prevent possible oscillation caused by stray reactance in the circuit wiring.

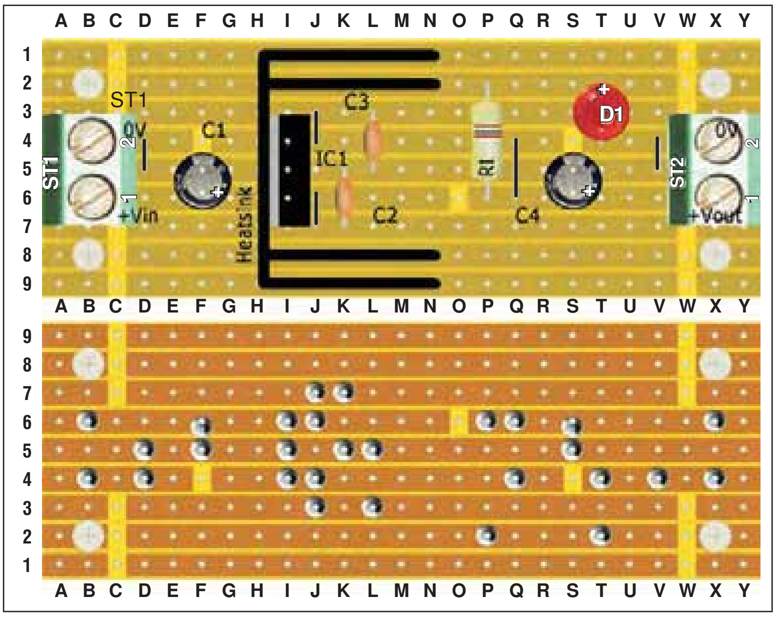


Fig.3.17. Stripboard layout of the 1A fixed-voltage regulator module: top component side view, (below) copper track view.

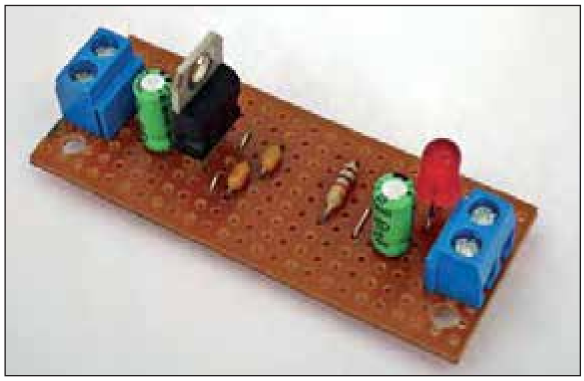


Fig.3.19. Finished 1A fixed-voltage regulator module.

Practical Project: Simple variable regulated DC power supply

Our second *Practical Project* this month is a simple variable regulated DC power supply. This unit is ideal for use with the raw DC supply that we described last month, and it will provide an output that can either be pre-set or made continuously variable over the range 1.5V to 13.5V at currents of up to 0.6A. This could make the basis of a useful bench power supply incorporating overload protection to limit the output current.

The circuit of the variable regulated DC power supply is shown in Fig.3.20. The three-terminal voltage regulator (IC1) is designed specifically for providing a variable output and the LM317's common connection is therefore referred to as an 'adjustment' connection. This is arranged in a similar manner to that described earlier (see Fig.3.5). The circuit can be configured for pre-set or continuously variable adjustment by means of links on the input/output connector, ST1 (see Fig.3.22). It incorporates a simple over-current protection circuit formed by R1, TR1 and D1, in which the output current is sensed by the 1Ω resistor connected in the 0V line. When the voltage drop across this resistor exceeds 0.6V, TR1 begins to conduct, taking the voltage at IC1's adjustment pin low. When TR1 conducts, D1 becomes illuminated, providing a useful visual indication of the over-load.

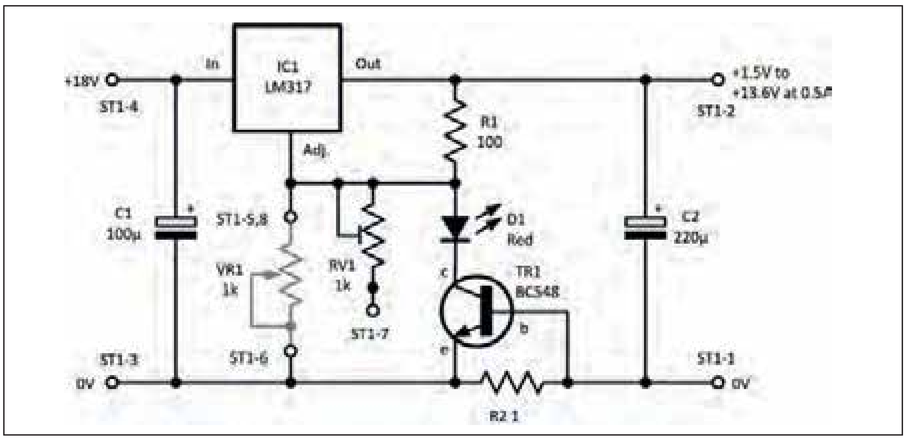


Fig.3.20. Circuit of the variable regulated DC power supply.

You will need...

- 1 Perforated copper stripboard (24 strips each with 37 holes)
- 4 2-way PCB screw terminal connectors (ST1)
- 1 100Ω 0.5W resistor (R1)
- 1 1Ω 0.5W resistor (R2)
- 1 1kΩ miniature pre-set variable potentiometer (RV1) (see text)
- 1 1kΩ variable potentiometer (VR1) (see text)
- 1 100µF 35V capacitor (C1)
- 1 220µF 35V capacitor (C2)

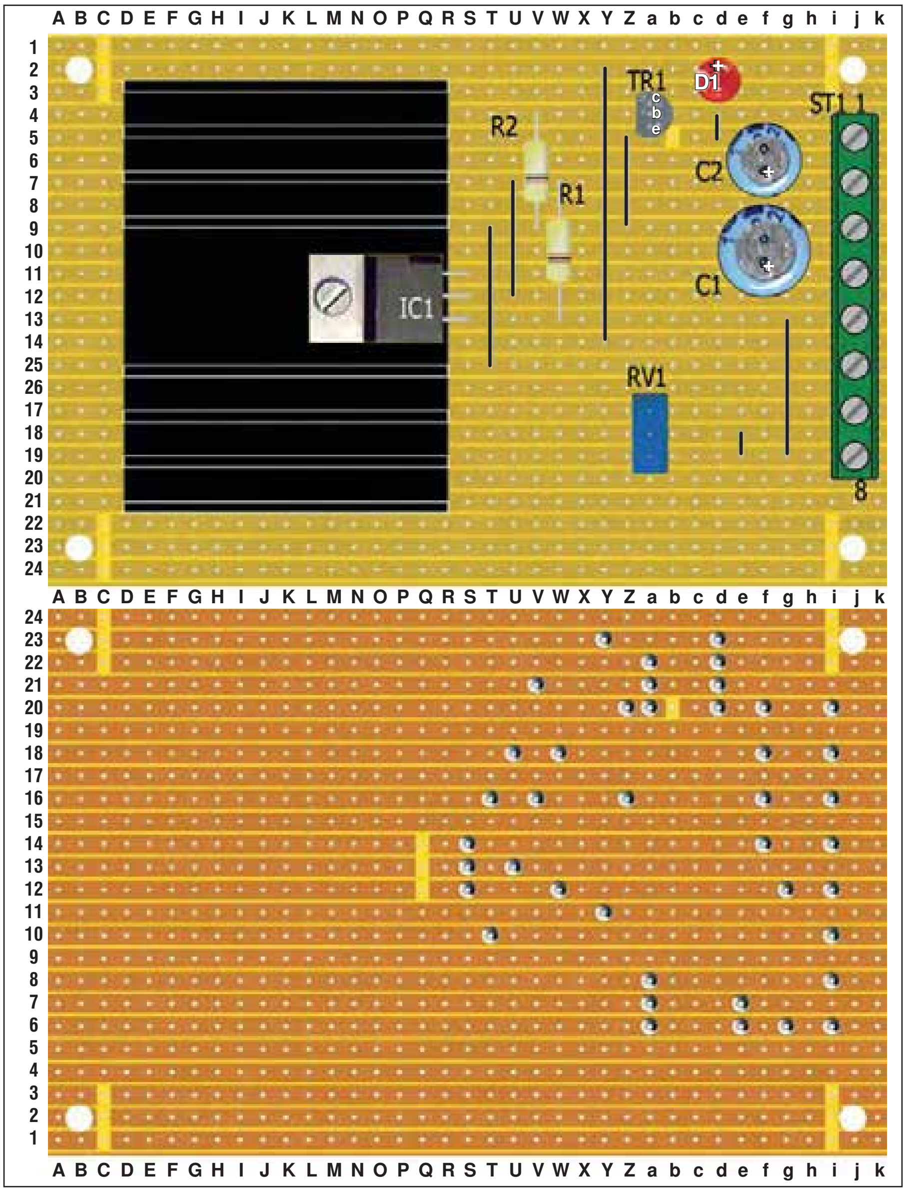


Fig.3.21. Stripboard layout of the variable regulated DC power supply: (top) component side, (below) copper track view (cut tracks marked in yellow)

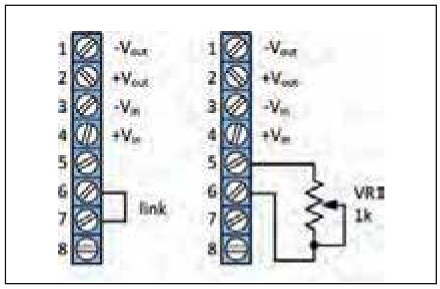


Fig.3.22. Connections to ST1 (left) for pre-set voltage adjustment and (right) for continuously variable voltage adjustment.

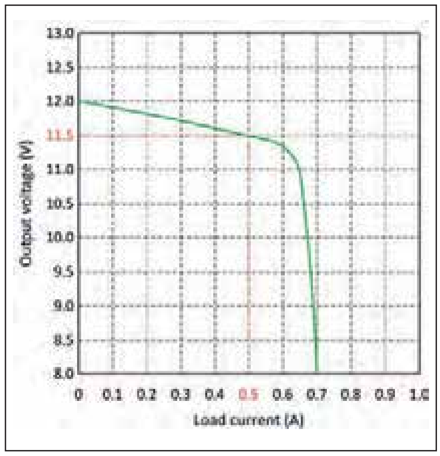


Fig.3.24. Load regulation curve for the variable regulated DC power supply.

1 BC548 NPN transistor (TR1)
1 red LED (D1)
1 TO220 heatsink (see text)
4 stand-off pillars and mounting screws

Construction

The layout of the variable regulated DC power supply is shown in Fig.3.21. Note that there are 16 track breaks and seven links. The pin connections for the semiconductor devices are shown in Fig.3.18. The three-terminal voltage regulator must be mounted on a finned heatsink. Once again, to promote heat conductivity, we avoid using an insulating washer and instead bolt the tab of IC1 directly to the heatsink – *which must be insulated from any metal enclosure.* (Note that the tab of the TO-220 package is directly connected to the positive output connection).

As always, once assembly is complete it is well worth carrying out a careful inspection of the circuit board, particularly checking the off-board wiring and links to ST1 (see Fig.3.22). The load characteristic of the prototype power supply is shown in Fig.3.24. Note how the current limit starts to operate at 0.6A and how, beyond this value, the output voltage is rapidly reduced as the over-load protection becomes effective.

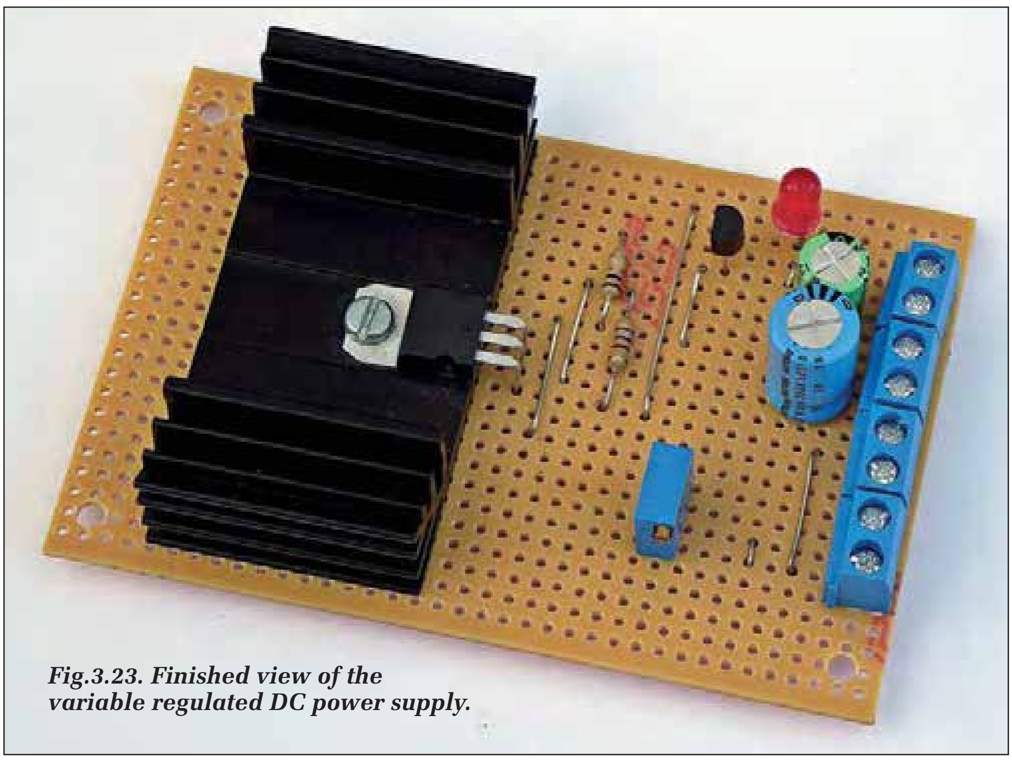


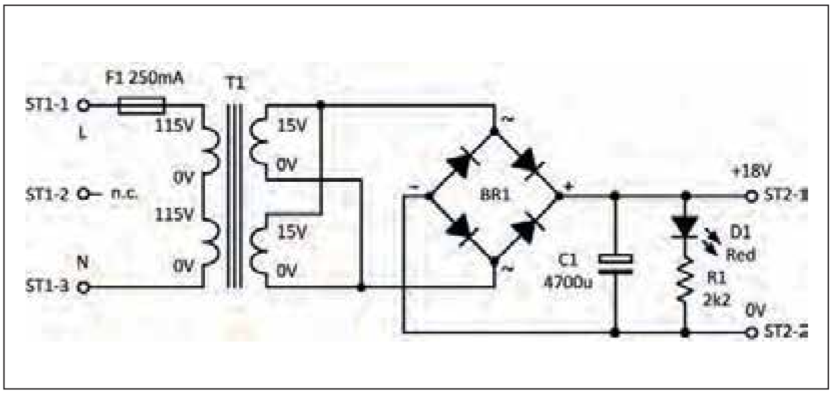
Fig.3.23. Finished view of the variable regulated DC power supply.

Next month

In next month's *Teach-In 2019* we will introduce switched-mode power supplies and our *Practical Project* will take the form of a high-efficiency voltage booster that uses simple switching techniques.

Errata

The circuit shown in Fig.2.18 (page 43 of January *EPE*) is incorrect. The two secondary windings should be shown connected in parallel and not in series (see opposite for the corrected circuit diagram). The stripboard wiring layouts (Fig.2.19) are correctly shown.



Get it Right! – Connecting to the mains

Fig.3.25. Always use an IEC mains lead fitted with a moulded plug and correctly rated fuse

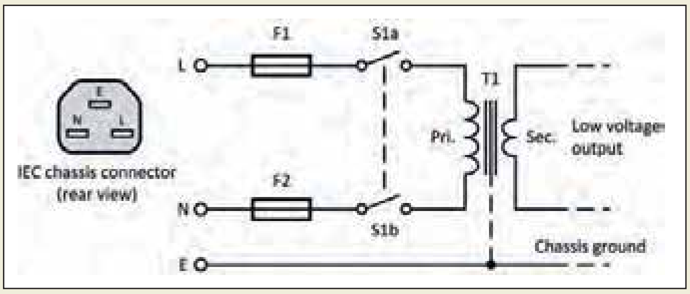


Fig.3.28. Recommended mains input circuitry using a double-pole switch and two equipment fuses

Fig.3.26. An IEC (male) chassis/ panel connector with a built-in equipment fuse

Fig.3.27. Three IEC (male) chassis/ panel connectors viewed from the rear. The screw-terminal version (on the right) should be avoided as it is difficult to insulate the screwed connections.

As mentioned in *Part 2*, you will need to take extra care when it's time to connect a power supply to the AC mains. Most of the projects featured in this series use safe, low-voltage DC, but working at mains potential requires special precautions in order to minimise the risk of electric shock and other hazards. In this *Get it Right!* we introduce four essential precautions that will help keep you safe.

1. Always use an IEC mains lead fitted with a moulded plug (Fig.3.25) and a correctly rated fuse (by default these are usually fitted with a 5A fuse and this is adequate for most electronic applications). Note that the standard colours used in the UK for 230V AC mains cabling are: brown for live (L), blue for neutral (N) and green/yellow for protective earth (E).

2. At the equipment end, use an IEC (male) chassis/panel connector (see Figs.3.26 and 3.27). These are available in various forms, including those that have in-built fuses and switches.

3. If you are fitting a panel-mounted switch and separate equipment fuses they should be connected along the lines shown in Fig.3.28. Note that the mains switch must be suitably rated and be suitable for full AC mains voltage operation. The switch should be a double-pole on/off type so that both sides of the supply (L and N) are switched. This could be important in the event that the live and neutral lines become inadvertently reversed.

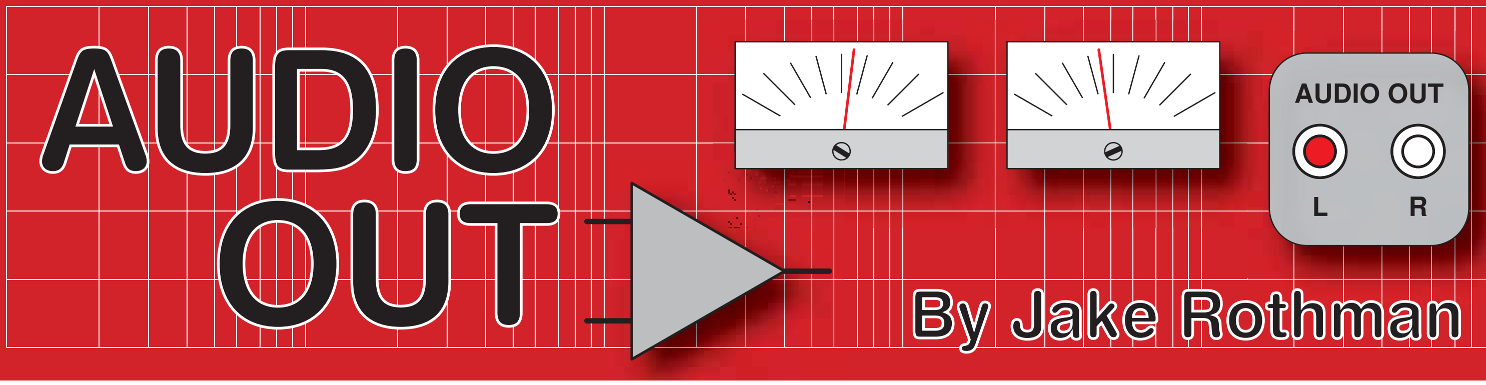
   In order to prevent contact with high AC potential, connections to switches and fuses should be insulated using heat shrink sleeving, as shown in Fig.29.

4. Ensure that all metal chassis parts and any outer metal enclosure are properly earthed (see Fig.30). The earth connection must be taken to the protective earth (E) tag on the IEC mains chassis/panel connector.

Next month's *Get it Right!* will look at selecting the correct fuse(s) for your projects and equipment.

Fig.3.29. Use heat shrink sleeving to insulate connections made to switches, fuses and connectors.

Fig.3.30. A good earth connection should be made to all metal case and chassis parts



Low-level power supplies in audio systems – Part 1

What's the best way to power a pre-amplifier from a power amplifier power supply? As an audio adjunct to Mike Tooley's *Powering Electronics Teach-In 2019* series, I'll explain my approach. I regularly discuss power supplies in audio but because I've seen so many burnt PCBs and problems from this part of the system, I feel I've got to address it. Pre-amplifier power circuits account for a significant number of the failed integrated Hi-Fi amplifiers, sound bars and active loudspeaker failures that come to me for repair.

Most audio power amps usually have some accompanying low-level circuitry for pre-amplifiers, filters, balanced inputs and other blocks. If these designs are based on op amps, then positive and negative supplies between ±5 and ±20V are needed. For discrete component circuits running on a single-rail then a 12-40V supply is required, which simplifies matters because only one regulator is needed.

Op amps can have their own separate power supply, but the additional transformer and associated mains wiring is expensive. To keep costs down, an op amp supply can be derived from the power amplifier supply, as shown in Fig.1. However, a power amplifier will have power supply rails several times higher than low-voltage rails. Their rails are typically ±30 to ±37V for bipolar transistor-based designs, and ±50V for ones using MOSFETs. This means there is the problem of dissipating power caused by the drop in voltage to the op amp rails.. This can be minimised by running the op amps at their highest safe power supply, typically ±17.5V. 5532 op amps are even happy with ±20V. Precision voltage stability is not required for these power supplies, but low noise and ripple are vital.

The first thing to establish for a design is the current consumption for the op amp circuitry. Some op amps (like my favourite, the 5532) consume a relatively high current of 8mA to achieve their low noise and distortion. More standard op amps, such as the TL072 and 4558 consume around 2 to 4.5mA. This is the minimum (quiescent) power consumption for dual devices, and this will increase several times if the circuit is overdriven or if their outputs are feeding low-impedance loads. For example, if an op amp is being driven hard with an output of 10V RMS into 1kΩ, the extra current will be 10mA. This is an extreme case, a more typical scenario would be a line level 775mV RMS into 10kΩ, which would only add 0.775mA. A good tip is to deliberately overdrive the low-level circuitry with white noise just to check what the maximum current will be.

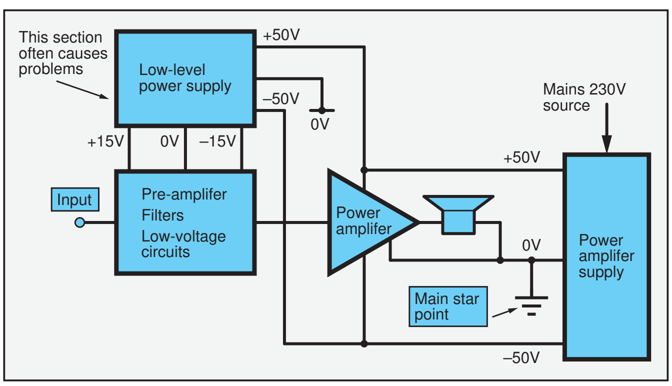


Fig.1. In audio, it is often necessary to power low-level circuitry off the high-voltage power amplifier power supply. The power amplifier supply is very heavily modulated by the audio, so a good low-level regulator is needed.

There are several approaches to deal with the op amp supply. For a design example, I'll base the circuits around a pre-amplifier for the low-gain version of the *MX50 Power Amplifier* (described in *EPE*, December 2017) which represents a typical design scenario. If we assume a minimal pre-amplifier circuit with just an active volume control using two 5532s, the current consumption will be 2 × 8mA, plus, say 4mA for loading, giving 20mA. (A suitable circuit is Fig.14 from Part 5 of *Speaking Volumes*, *EPE* April 2016.)

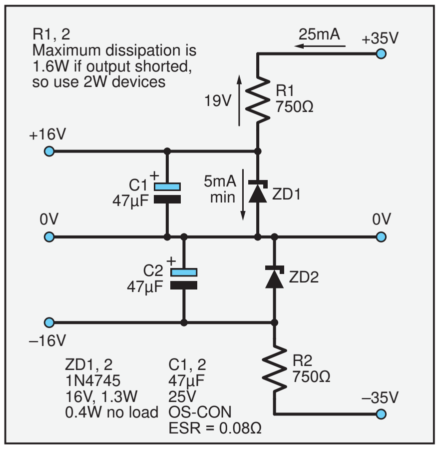


Fig.2. The simplest way of powering op amps off a high voltage supply is the classic Zener regulator.

Zener regulator

The simplest op amp supply regulator circuit is a couple of Zener diodes fed by resistors, as shown in Fig.2. Unfortunately, these regulators are a common source of failure, usually from heat damage to the board, as shown in Fig.3. On the up side, since this design is a shunt regulator, it 'fails safe' if the Zeners go short – the resistor will overheat, but limit the current supplied. The trouble with shunt regulators is their high quiescent power dissipation. Any current not used by the op amps is dumped in the Zener diodes. This can lead to the bizarre situation of smoke arising if the load is removed. The Zener dissipation in this situation must be calculated for the full resistor current going through it. Also, a minimum current through the Zeners of 5mA is required when fully loaded or regulation will be lost. Thus the resistor should supply 5mA more than the required load.

Fig.3. Zener regulators often dissipate a watt or two. Make sure the board doesn't get cooked – put resistors on stand-offs and well away from electrolytic capacitors.

One advantage of shunt regulators compared to series types is that circulating distorted supply currents drawn by the op amp are confined to a local loop. Let's calculate a suitable supply for delivering ±16V at 20mA from ±35V. There will be 19V across the resistors; so, using Ohm's law R = *V*/*I* we need 19V/0.025A = 750Ω. The dissipation will be 0.475W in the resistors and 0.4W in the Zeners with no load. The total for the whole system is 1.8W – quite a lot. If the output is shorted, the resistor dissipation rises to 1.6W, so I would use 2W resistors and 1.3W Zeners. Fig.4 shows the typically large resistors and Zeners required for this approach. Do remember when

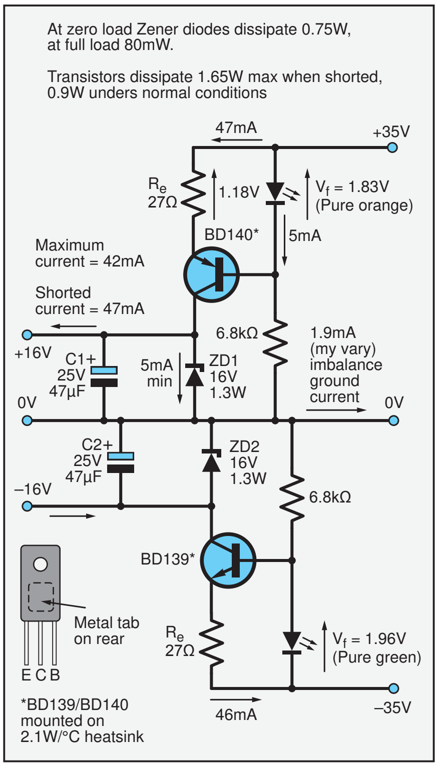
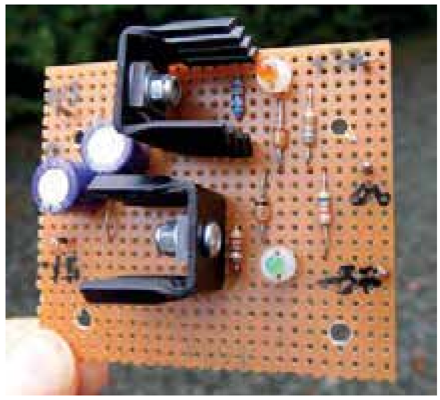


Fig.5. a) (above) A Zener regulator can be greatly improved by using constant-current sources, rather than resistors; b) (above right) the assembled circuit.

installing potentially hot components on a single-sided PCB, it is important to provide mechanically sound stand-offs to stop the joints cracking.

Constant current

Supplying Zener diodes with constant current sources rather than resistors is beneficial. If the output is shorted, dissipation is reduced compared to the resistor method because the current delivered doesn't rise (it's a *constant* current source). The regulation of the Zeners is also improved, reducing the ripple voltage by a factor of four to 10mV when loaded. The noise can also be reduced by wiring polymer capacitors, which have very low ESR, across the Zeners.



In the design, shown in Fig.5a and assembled in Fig.5b, we can up the output current a bit to ±42mA. The constant current is calculated by working out the emitter resistor (R_e) value needed to give the required current with 1.18V across it. This comes from subtracting the transistor's V_{be} of 0.65V from the LED forward voltage (1.83V for the orange led I used). (It was shown in the 1970s by designers like Douglas Self that LEDs are pretty stable voltage references and you get the added bonus of power indication.)

'Wattless' dropper

The high dissipation in the Zener series resistors can be eliminated by using capacitors to provide reactive voltage drop from the power amplifier transformer secondary. The reactance at 50Hz should be calculated to equal

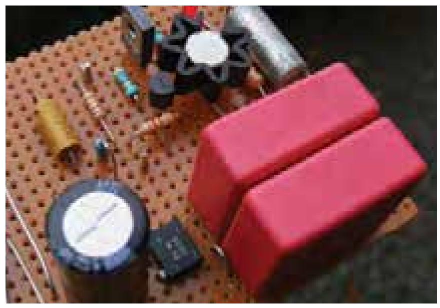


Fig.6. Capacitive droppers are big, but at least they don't get hot – see the circuit in Fig.17.

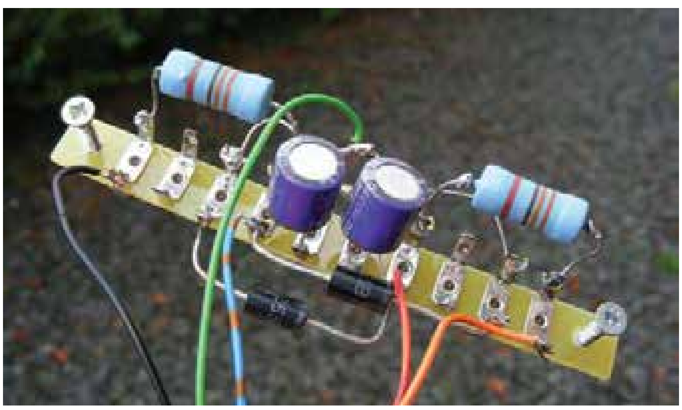


Fig.4. The high dissipation in power resistors and Zener diodes means they are often quite large. Old-fashioned tag strip construction works well, facilitating cooling.

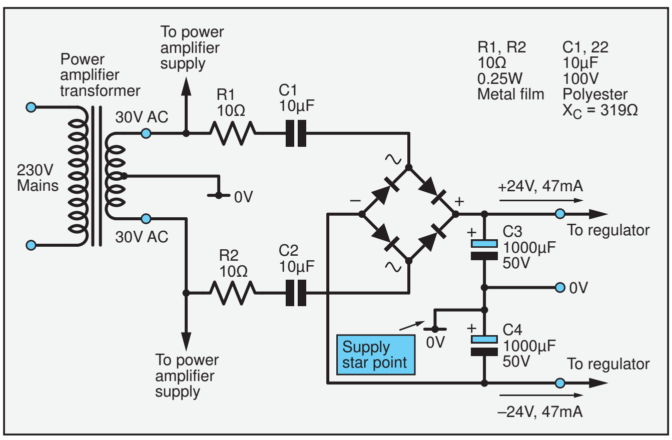


Fig.7. Capacitive dropper circuits avoid the heat associated with dropper resistors.

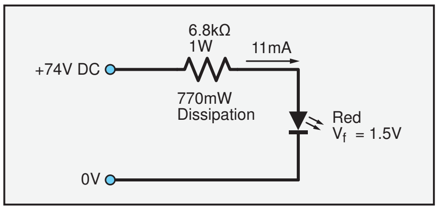


Fig.8. Dropper resistors associated with LEDs can waste a lot of power when fed from power amplifier power supplies. Nearly all the voltage is thrown away.

Fig.11. Guitar amplifier – the three TL072 dual op amps are fed from a ±30V supply using Zeners. Note the over-rated 680Ω 2W resistors (in black) – a good long-lasting design.

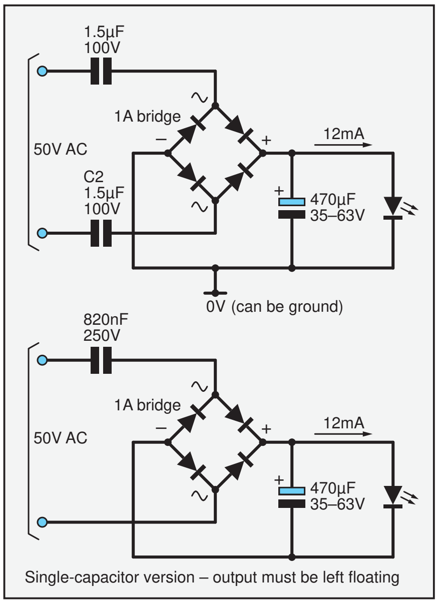


Fig.9. (Above) Getting rid of hot LED resistors using capacitors, and (below) minimising the capacitor count.

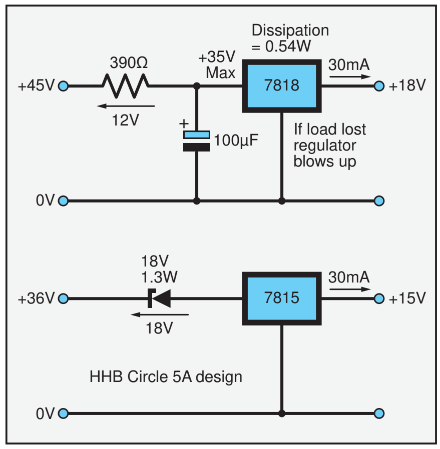


Fig.12. To protect voltage regulators from excessive voltage drop, resulting in over dissipation, a series resistor is often used. A Zener diode can also be used, which will provide over-voltage protection as well. The system may blow-up if the Zener fails to short circuit, as it did in some HHB Circle 5A active speakers.

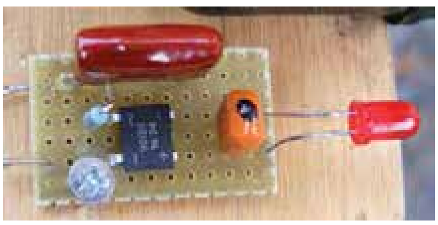


Fig.10. Single-capacitor LED circuit.

the resistance of the resistor to be replaced. Because the current and voltage are phase shifted relative to each other, there is no heat generated. Since this operates on the AC side, an additional bridge rectifier and pair of smoothing capacitors is needed. Note the dropper capacitors must be robust. I use 100V DC metallised polyester types, which very rarely fail short. (I once tried a pair of non-polarised electrolytics for cheapness, but they didn't last very long.) When choosing capacitors for this role, their long-term ripple current rating is very important and remember that the AC voltage rating of capacitors can be only half the DC rating. Such reactive systems are generally more complex and the capacitors can be big and expensive, but I think it's worth it just to get rid of the heat. (I used to have an Arcam amplifier where the biggest heat source when idling was the op amp regulators – more than the rest of the amplifier combined.) The component size can be judged from Fig.6.

One thing that has to be watched with capacitive droppers is the switch-on current surge. This is normally absorbed by the smoothing capacitor (C3 and C4, Fig.7) but it's a sensible precaution to include a couple of low-value metal-film (R1 and R2) resistors as limiters. These will also act as 'fuses' if a capacitor goes short. Fig.7 shows the capacitor dropper needed to feed the constant-current circuit just described (Fig.5) for use with a MOSFET amplifier with ±45V (30-0-30VAC) supplies. This greatly reduces the transistor dissipation to around 400mW in normal use, and 1.12W shorted, so that heatsinks are not required. For commercial manufacturers the high labour cost associated with attaching heatsinks means that in practice, the capacitor circuit adds no overall cost.

A similar heat problem to dropper resistor dissipation may arise with power-on indicator LEDs. I have seen a wasteful 1W resistor feeding an LED from a 74V rail, as shown in Fig.8. This could be replaced by the upper circuit shown in Fig.9, which runs cool. A further advantage of this circuit is that the LED turns off quickly when the mains is switched off, unlike an LED driven off the main smoothing capacitor, which can hang on for up to 15 seconds. One capacitor can be removed from this design as shown in Fig.9 lower circuit, but the output must then be left floating and not connected to ground. A completed LED circuit is shown in Fig.10.

Voltage regulators

For all its limitations, the Zener diode method is acceptable if a design uses just a few op amps; for example the three dual op amps (TL072) for the guitar amplifier board shown in Fig.11. However, if the current consumption goes over 30mA then dissipation becomes unacceptably high. Using a series regulator can reduce this. However, the input voltage of most regulator chips is generally limited to around 36V max. This can cause problems if the input voltage is much higher, say 50V. One way round this problem is to put a voltage-dropping resistor in series with the inputs to the voltage regulator, as shown in Fig.12.

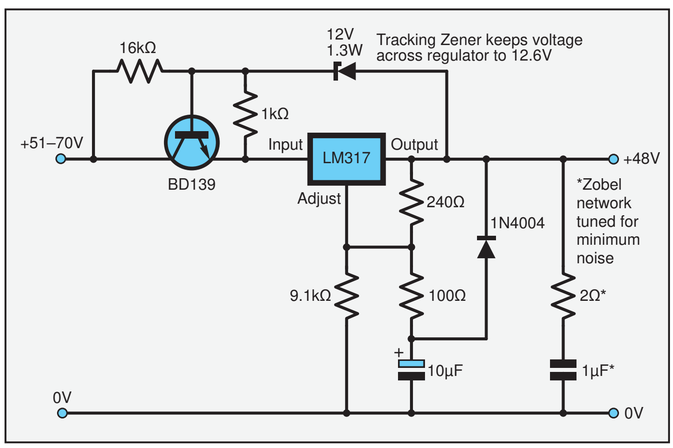


Fig.13. This Rane Phantom power PSU uses a 'tracking Zener'.

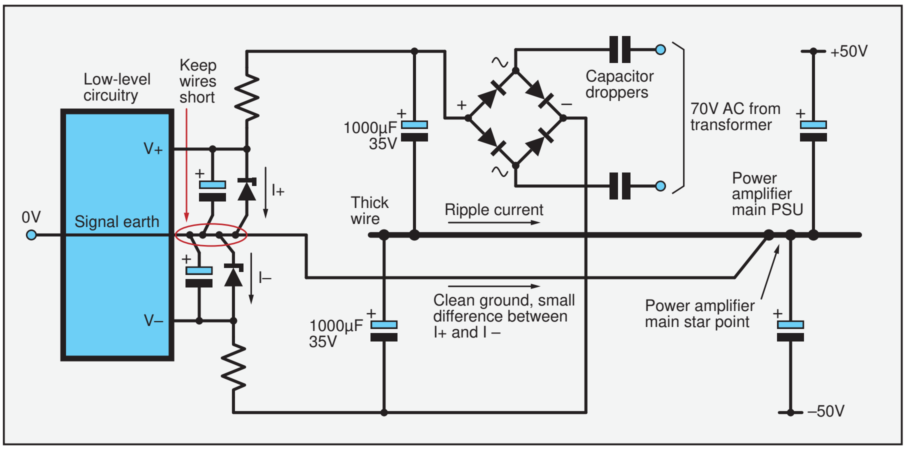


Fig.14. Suggested earthing layout for a low-level supply.

Fig.15. Occasionally, an extra winding can be added to a toroidal transformer to produce an extra 'free' low-voltage supply. It's a bit labour intensive, but it's got me out of a hole occasionally!

This is not a guaranteed solution. Series resistors can cause problems with the regulator seeing a higher source impedance. The 78/79-series regulators can oscillate if a 100Ω resistor is inserted before their inputs. One solution is to connect a large decoupling capacitor (say 100µF or more) across the regulator's input and ground – see upper diagram, Fig.12.

An alternative is a series Zener diode which has a much smaller impedance than an input resistor. Do note that a Zener used this way needs to have a higher power rating to protect it from turn-on surge current, for example a 1.3W device, not a standard 400mW one. A tracking emitter follower can be used to boost the power rating of a Zener, as shown in Fig.13, which essentially creates a 'power Zener', maintaining 12V across the regulator at all times.

The audio industry standard voltage regulators are the LM317 and LM337. These give an output ripple of about 1mV, whereas the 78/79 series regulators have about 4mV of noise.

One vital check with all voltage dropper systems is to ensure the regulator input voltage is not exceeded when there is no load. This could occur if the op amp section is unplugged or the board is powered up with no op amps inserted. Protection will be described later.

Earthing layout

The regulator is always best placed near the op amps, minimising source impedance. The ground reference for the regulator should be connected to the op amp signal ground rail to avoid earth loop hum. There is very little DC current flow into the ground to worry about because the currents from the positive and negative rail Zeners or regulators cancel out, as detailed in Fig.14, which shows the correct earthing layout. However, the grounds of the big input decoupling capacitors should not go to the signal ground because they will inject ripple current. These should go to the star earth point on the power amplifier power supply.

Transformer overwind

Most power-amps have a big *toroidal* transformer. It is a fairly simple matter to add 30 turns of wire to make a low-voltage secondary winding. Measure the output and you can then work out the induced voltage per turn to calculate the number of turns you need to get, say, 15V. I use twisted-pair telecom cable to get two equal voltage secondaries for the dual-rail – see Fig.15.

Dual-rail from single-rail

Occasionally, you may need to feed a dual-rail op amp circuit from a single-rail power amplifier supply. A suitable circuit is shown in Fig.16. This system can be dangerous to the power amplifier if the speaker ground is shorted to the signal ground because there is a 35V potential difference between them. The resulting very high currents will destroy the upper output transistor of the power amplifier. This approach is acceptable if enclosed in say an active speaker. The risk of blowing things up can still occur in testing because of confusion between the two earths.

Ultra-low-noise single-rail regulator

The power supply circuit shown in Fig.17 was designed for the single-rail *MX50 Power Amplifier* described in *EPE*, March 2018. This had a power rail of 74V. I wanted to drop this down to

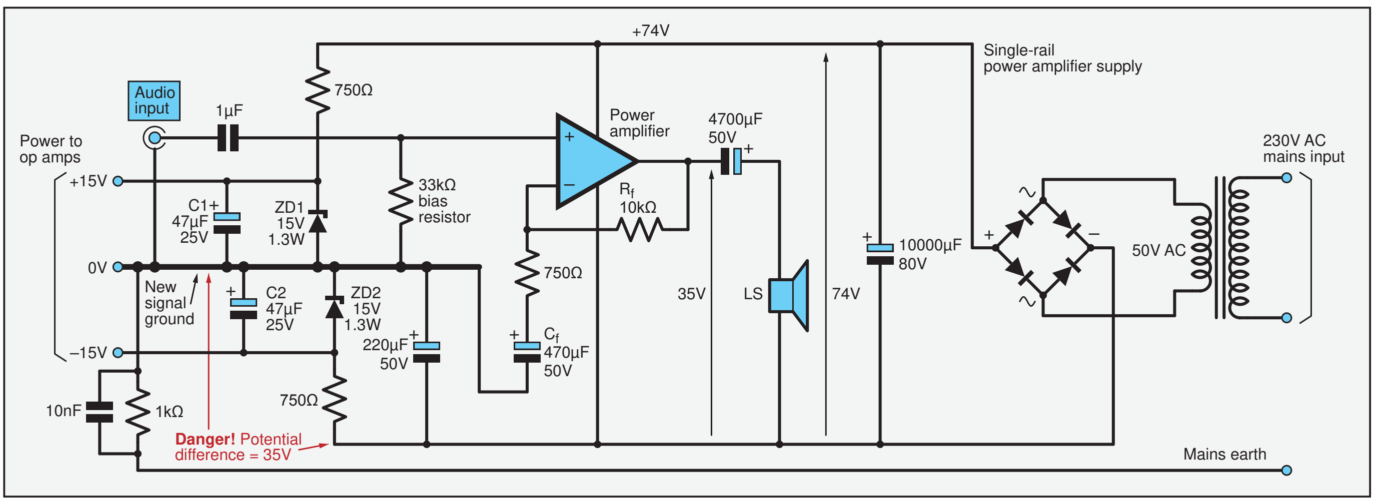


Fig.16. Sometimes it is possible to power a dual-rail pre-amplifier off a single-rail power-amp. This is not recommended if the power amplifier and pre-amplifier earths are inadvertently connected together.

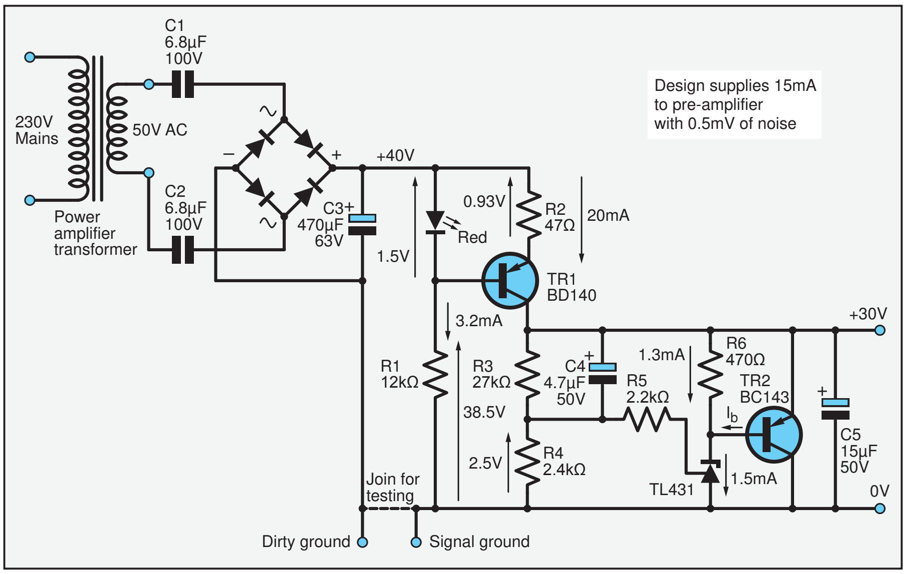


Fig.17. Ultra-low-noise shunt power supply. I put my special little circuits here to stop big companies patenting them! (See photo in Fig.6.)

30V for a discrete single-rail pre-amplifier consuming 15mA. This circuit uses a capacitive dropper consisting of two Wima MKT4 6.8µF capacitors and a shunt regulator. It does not use a Zener diode; instead it has a TL431 shunt regulator/programmable Zener, which gives four-times better regulation than a Zener. The noise is much lower too, at around 0.5mV.

Zener diodes higher than 6.8V are not really Zener diodes at all, but avalanche diodes, which are quite noisy. To achieve low noise with the TL431 at the supply's high (+30V) voltage, a bypass capacitor is needed across the feedback resistor R3 to reduce the closed-loop AC gain to unity. If the reference pin is bypassed to ground, as is often done with voltage regulators, a perfect noise generator is created due to the AC gain going open loop. Indeed, I use this technique in noise sources for synthesisers – a design I will show soon in a future issue. The relatively high value for C4 is necessary to give good transient response. Unfortunately, the energy stored in this capacitor is sufficient to put too much energy into the reference pin under power on/off conditions, so R5 limits the current to a safe value. To prevent excessive dissipation in IC1 it is buffered by emitter-follower transistor TR1. This circuit only works for a positive rail, since a negative version of the TL431 isn't available. I might develop this into a dual-rail design later, by using an inverter to drive an emitter follower on the negtive side.

Vital check

It is important to ensure all regulators maintain regulation when the power amplifier is driven to full power. This is necessary because the power amplifier power supply feeding the regulator is heavily modulated by the music and may droop by as much as 20%.

Next month

In the next issue we'll describe and build a universal low-level circuitry audio power supply.

Summing amplifiers

We have received an email from reader Chris Hinchcliffe about the article on differentiators in September's issue. This article followed from one the previous month concerning a post by Michele Oliva on the EEWeb forum (**www.eeweb.com/forum**). Chris wrote:

'I read with much interest and enjoyment your terrific coverage of op amp based differentiators in September's *Circuit Surgery*. However, I am under the impression that differentiator operation is not entirely relevant to Michele Oliva's circuit [Fig.1] as published. Whilst I appreciate that an input capacitor and feedback resistor form, as you describe, a differentiator; the configuration of Michele's circuit is in fact a classic two-channel mixer design. There are, as far as I am aware, two classic op amp mixer configurations.

Configuration 1 – a separate DC blocking capacitor in series with each input resistor (without the capacitor C1 connected to the op amp's inverting input, which it is in Michele's design). In this case the series *R* and *C* can be connected in either order and the frequency response of each input (channel) can be set individually and is given by $f_{-3dB} = 1/(2\pi RC)$.

Configuration 2 – This is Michele's design, where only a single capacitor is used which is connected at the op amp's inverting input. This design has the disadvantage that all the inputs (channels) have the same frequency, response which is also given by $f_{-3dB} = 1/(2\pi RC)$ but in this case R equals the parallel combination of the input resistors. This is true no matter how many input resistors (channels) there are.

Perhaps you might consider 'op amp based mixers' to be a possible topic for a future *Circuit Surgery* topic.'

First, thank you to Chris for his positive comments about the September article. I agree that mixers are a good topic, so that is we will be looking at this month; but first, a few comments on what Michele's circuit might be and the aims of the earlier articles.

The fact that Michele's circuit has both summing and differentiating behaviours was mentioned in articles in August and September 2018. The circuit was referred to primarily as a differentiator in the articles because that was how it was referred to in Michele's original post, *Help with Op-amp Differentiator Circuit*. Apart from this title, Michele gave no information on the intended application, but the title indicates that the differentiating behaviour was particularly relevant to Michele. As Chris's formula indicates, the (high-pass) cut-off frequency of Michele's circuit is around 3kHz, which indicates that it is not a standard audio mixer, where the cut-off related to coupling capacitors would typically be much lower. The circuit could be several things other than an audio mixer, including a section of a filter, or even part of an analogue computing circuit. The follow-on article in September covered differentiators, but apart from Michele's description of the circuit as a differentiator acting as the inspiration, the September article was not related to Michele's circuit.

Mixing circuits

The term 'mixing circuit' can mean more than one thing, depending on the context. In the audio field it typically refers to adding multiple signals together, possibly with control of their relative levels (contribution to the final mix), as is done by the mixing desks used in recording studios and at live performances. Of course, modern mixing desks may use fully digital signal processing, but analogue mixing, which is of relevance to this article, is still widely available and tends to be available at lower cost than digital. Chris's email is referring to the basic op amp circuits on which analogue audio mixing can be based. However, adding signals is a common requirement in general signal processing, so the topic is not limited to audio. In general, such circuits may be referred to as: 'additive mixer', 'voltage adder' or 'summing amplifier'.

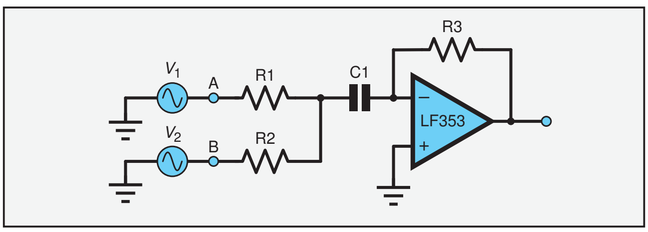


Fig.1. Michele Oliva's circuit from *Circuit Surgery*, September 2018.

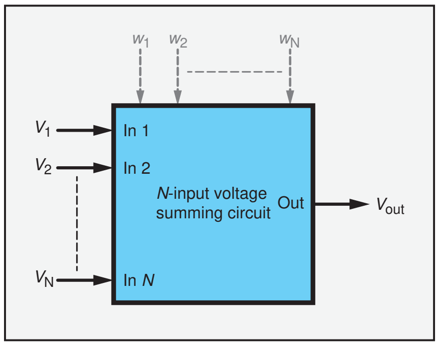


Fig.2. Additive mixer concept and block symbol.

Another type of mixing circuit is one that multiplies, rather than adding the signals. These can be used to manipulate signal frequencies – multiplying signals produces sum and difference frequencies. We discussed an application of such mixers, also known as 'modulators', in the context of chopper amplifiers in the Jun 2018 issue, but we will only be looking at additive mixers this month.

Basic mixer properties and behaviour

The concept of an additive mixer, or voltage summing circuit, is shown as a block symbol in Fig.2. In it most basic form, this circuit takes any number (*N*) of input voltages, labelled V_1, V_2 through to V_N and outputs a voltage, V_{out}, equal to the sum of the input voltages: $V_{out} = V_1 + V_2 + \ldots + V_N$. However, each input voltage may be scaled by a weighting

Simulation files

The LTSpice files discussed in *Circuit Surgery* are available for download from the *EPE* website.

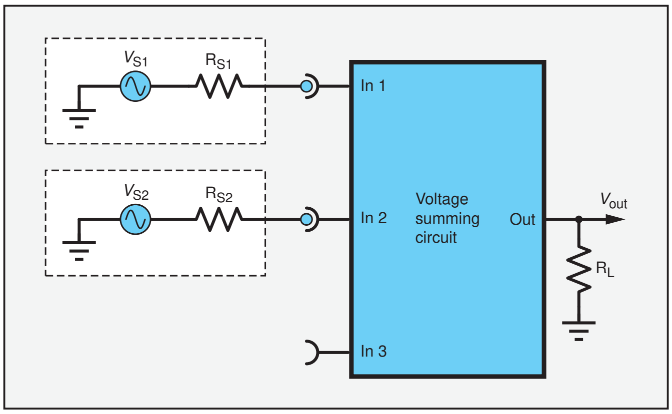


Fig.3. Additive mixer with input sources (or not as the case may be) and load.

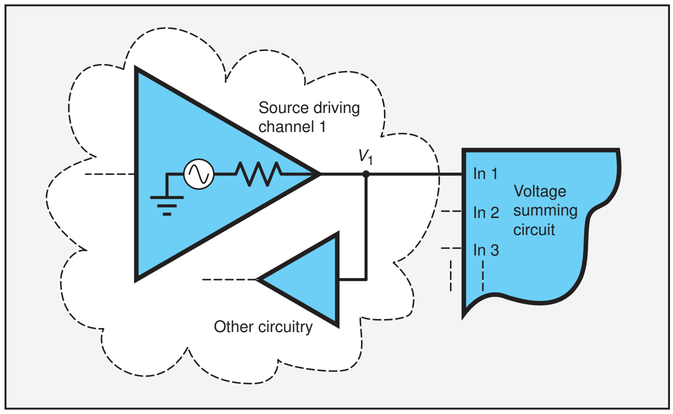


Fig.4. If signals from other inputs can change V_1 then the mixer inputs are showing unwanted interaction (crosstalk).

factor (w_i) to set its relative contribution to the output. The output is then $V_{out} = w_1V_1 + w_2V_2 + ... + w_NV_N$. The weighting can be negative; so in general, an additive mixer could add some inputs and subtract others.

The weighting may be fixed in the circuit design (by selection of appropriate component values), or may be variable under manual or electronic control. In basic audio mixing circuits, and similar applications, the weighting is controlled manually by slider or rotary potentiometers. Electronic control can be achieved in a number of ways, for example using motorised slider potentiometers or digitally controlled electronic potentiometers.

In general, an additive mixer or summing circuit will process signals of any frequency, including DC or very low frequency signals. As Chris mentioned, for audio applications it is common to use coupling capacitors to block DC (typically below around 20Hz). DC is unwanted in audio systems for a number of reasons – it can disrupt biasing of transistors in amplifiers, it causes problems if applied to loudspeakers and it may lead to unwanted sounds such as loud clicks when signals are switched. However, mixing/summing circuits may be used in other contexts in which DC or very low frequency signals are required and in those applications coupling capacitors will not be used.

When looking at the behaviour of mixing circuits – and any other signal processing circuit – we need to take into account the properties of the signal sources to which it is connected. For example, in Fig.3 inputs 1 and 2 are connected to sources with sources resistances R_{S1} and R_{S2}. Similarly, any load connected to the mixer's output may influence its operation (R_L in Fig.3). Some additive summing circuits have fixed, hardwired inputs, others, such as typical general purpose audio mixers may have signal sources connected and disconnected from any of their inputs. At any given time some inputs may be left floating (eg, input 3 in Fig.3) – this may also influence the circuit's operation.

Ideally, a summing circuit's output would not be influenced by source and load impedances, or whether or not inputs were floating, but this is not always the case. For example, disconnecting an input which was driving 0V into an input should not change a mixer's output. However, if change does happen then one channel is influencing others – they are not isolated or independent. Another potential issue is signals from one input finding their way into the circuitry connected to other channels (crosstalk). This is illustrated in Fig.4. Ideally, V_1 would depend only on the source driving channel 1, but if this source's impedance is not zero and V_1 can be influenced by other channels, then signals from other channels can get into the circuitry connected to channel 1. Again, we say, 'the inputs are not isolated or independent'. This is the situation we were looking at in the article on Michele's circuit in August 2018.

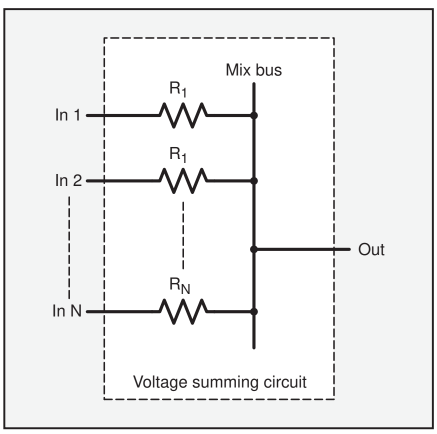


Fig.5. Passive mixer using resistors.

Passive mixer

The simplest approach to adding voltage signals is to just connect then all together via resistors, as shown in Fig.5. In audio in particular, this is referred to as passive mixing, and the connection point may be referred to as a 'mix bus'. This circuit is useful in some circumstances, but has a number of drawbacks. We can do some circuit analysis to understand it properties.

Fig.6 shows an example of a passive mixer with three inputs, all connected to signal sources, V_{S1} to V_{S3}, each of which has a corresponding source resistance. The mixer's output is connected to a load resistor R_L. From this schematic we can see that the source and mixer resistances are in series and add together to make the effective mix resistance for each channel. It follows that the mixer resistors should be much larger than the source resistances to prevent the source resistance from having a significant effect on the circuit. Alternatively, you could argue that if you just connected the sources together their source resistances would provide the mixing. Although this is true on one level, it is unlikely to be a workable approach in many situations. Sources such as op amp outputs have low impedances and would drive high currents if their outputs where shorted together. Even if no damage was done it is likely that significant signal distortion would occur.

Similarly, the structure of the circuit indicates that unless R_L is much larger than the mixer resistors it will have a significant effect on the circuit. This circuit might be connected to an amplifier input with a very high input impedance, in which case loading would be unlikely to be a problem.

Superposition

To determine the output voltage from the circuit in Fig.6 we can use some circuit theory that uses the superposition theorem. For a linear circuit we can find a voltage or current of interest by taking all the sources in turn, setting all the other sources to zero, working out the relevant circuit values with just that one source active, repeating this for all

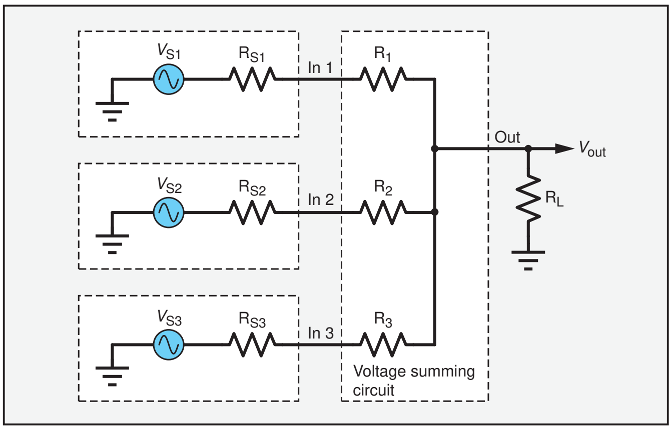


Fig.6. Three-input passive mixer with sources and load.

the sources, and then adding the results from the individual sources to get the required value.

As an example, consider this approach applied to the circuit in Fig.6. To keep things simple we will assume that all of the source resistances are zero and that the load resistance is infinite, so we just have the three mix resistors. To work out the contribution from V_{S1}, we set $V_{S2} = V_{S3} = 0$, which results in the circuit in Fig.7. We have a potential divider with R_1 as the upper resistor and the parallel combination of R_2 and R_3 as the lower resistor. If all the resistors have the same value (R), then the parallel combination of R_2 and R_3 will be R/2. Using the potential divider formal we find the contribution of V_{S1} to V_{out} as:

$$V_{out} = \frac{R/2}{R/2 + R} V_{S1} = \frac{1}{3} V_{S1}$$

The symmetry of the circuit (with equal resistors) means the contributions of V_{S2} and V_{S3} follow the same pattern, so adding the contributions we get $V_{out} = \tfrac{1}{3}V_{S1} + \tfrac{1}{3}V_{S2} + \tfrac{1}{3}V_{S3}$. This fits the general form of a weighted voltage adder, where all the weights are ⅓. Calculations for non-equal resistors follow the same basic approach but are more laborious because a different value of other-channel resistors in parallel has to be calculated each time.

If we have *N* channels (Fig.5) the calculation follows the same pattern. Each channel resistor forms a potential divider with the parallel combination of all the other channel resistors. If all these resistors have the same value then the contribution of channel *x* to V_{out} is V_{Sx}/N. This shows us that the symmetrical passive mixer attenuates the signals by a factor of $N20\log_{10}(N)$ attenuation in dB.

Interaction and crosstalk

What happens to a passive mixer if a channel is disconnected? Fig.8 shows the circuit from Fig.7 with channel 3 disconnected. Again, the relationship between V_{S1} and V_{out} is set by a potential divider, but this time with two equal resistors (assuming all resistors are equal). R_3 is disconnected at one end, so it is not involved. Thus $V_{out} = \tfrac{1}{2}V_{S1}$. Completing the superposition analysis gives $V_{out} = \tfrac{1}{2}V_{S1} + \tfrac{1}{2}V_{S2}$. If we have V_{S3} connected with $V_{S3} = 0$ the previous result gives $V_{out} = \tfrac{1}{3}V_{S1} + \tfrac{1}{3}V_{S2}$. This shows that disconnecting an input causes a significant change in the output signal levels from the *other* inputs. This is an undesirable interaction between the inputs.

What happens if a channel has non-zero source resistance? First, if the source resistance is not significantly smaller than the mix resistor then its value should be added to the corresponding mix resistor in calculations. Another effect is crosstalk. Fig.9 shows Fig.7 redrawn to include a source resistance for channel 2. We can use this to calculate the voltage at the channel 2 input due to the input to channel 1. From Fig.9 it can be seen that R_{S2} and R_2 form a potential divider connected to V_{out}. This situation is very similar to the scenario we looked at in the August 2018 article, so we will not go into further details – it is sufficient here to note the crosstalk problem. The problem can be solved by driving each mix resistor directly with a buffer amplifier, but this increases system cost and complexity.

Looking at Fig.7, and considering a non-infinite load resistance, this will be in parallel with the 'other channel' resistors, and is reasonably easy to account for in any calculation. A lower R_L will increase the attenuation of the signal. The attenuation due to passive mixing, and the effect of low R_L is easily overcome using a high input-impedance amplifier, such as a non-inverting op amp configuration, as shown in Fig.10. For a mixer with *N* equal resistors the amplifier gain ($1 + R_F/R_G$) can be set to *N* to compensate for the attenuation, but of course other gain values can be set if required. Despite the use of an op amp, the circuit in Fig.10 is still a passive mixer. The issues with crosstalk, signal level changes if inputs are disconnected, and input interaction in general are not solved by adding the output amplifier.

Adding currents

To find a way to overcome the problems with mixer input interaction we can start by considering the currents in a mixer with the output shorted to ground via a single wire. This is illustrated in Fig.11. The currents in each resistor flow into the junction and add together to give the total current flowing to ground as $I_{out} = I_1 + I_2 + \ldots + I_N$. This is an example of Kirchhoff's current law – the sum of currents flowing into a node is equal to the sum of the currents flowing out. If an input is at 0V, then the current in that channel's resistor will be zero. If we disconnect the source, then the current will still be zero – the output current will not change – unlike the passive voltage mixer's output, disconnecting inputs has no effect on other signals. The current in channel number *x* is given by V_x/R_x. A key thing here is that the current only depends on that channel's resistor, if we change the number of channels, or the resistor values in other channels, the current in a given channel does not change – it is totally independent of the other channels by virtual of fact that one end of the resistor is held at a fixed voltage (0V). For the same reason, there is no crosstalk from one channel to another.

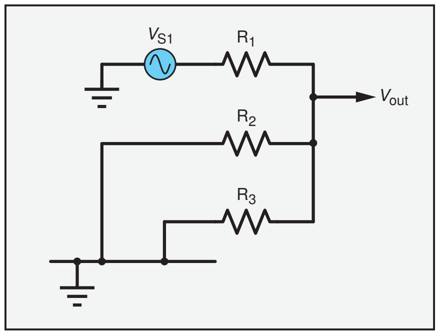


Fig.7. Part of using the superposition theorem on the circuit in Fig.6. Sources V_{S2} and V_{S3} are set to zero to calculate the contribution of V_{S1}. This example also ignores source and load resistances.

The preceding discussion indicates that using the summed currents in Fig.11 would allow us to make a mixer with much more independent inputs than the circuit in Fig.10. To do this, we can convert the summed currents to a voltage using an op amp transimpedance amplifier (see Fig.12).

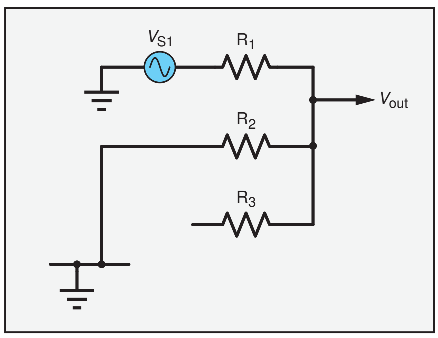


Fig.8. Circuit to reanalyse Fig.7 with one input disconnected.

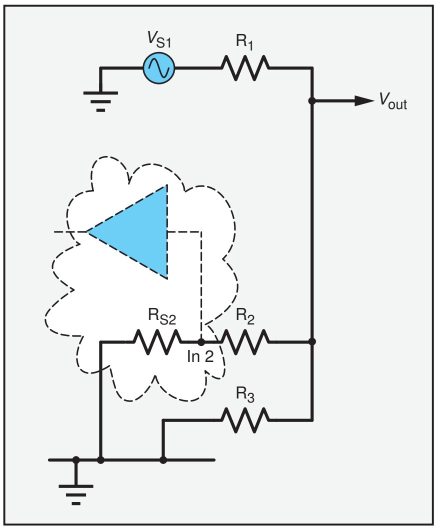


Fig.9. Circuit to reanalyse Fig.7 considering non-zero source resistance in channel 2. The signal from V_{S1} will cause a voltage at In 2 (crosstalk).

A transimpedance amplifier has an input of current and an output of voltage, so the gain V_{out}/I_{in} has units of ohms. The negative feedback applied to the op amp in Fig.12 means that it is attempting to keep the voltage difference between its inputs at zero volts. As the non-inverting input is grounded, the inverting input will be controlled to 0V and behave as if it is grounded. This is known as a 'virtual earth'. Assuming the op amp has very low bias currents and very high input impedance, effectively all of I_{in} will flow through R. and the output will be $V_{out} = -RI_{in}$.

Active mixer

Fig.13 shows a three-input mixer (voltage summing) circuit formed by combining the circuits in Fig.11 and 12. The three input voltages V_1, V_2 and V_3 are connected to the virtual earth point via the resistors. The action of the virtual earth means that each input resistor can be treated as if it was connected to 0V – the current in each input resistor is simply obtained from the input voltage

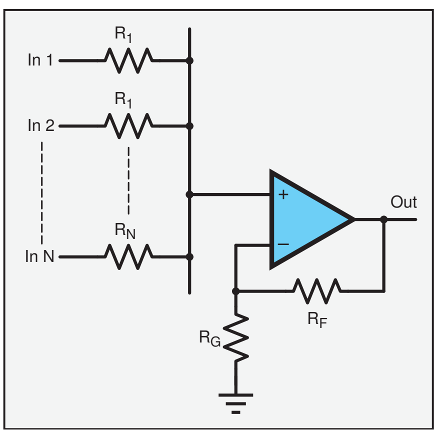


Fig.10. Passive mixer with buffer amplifier.

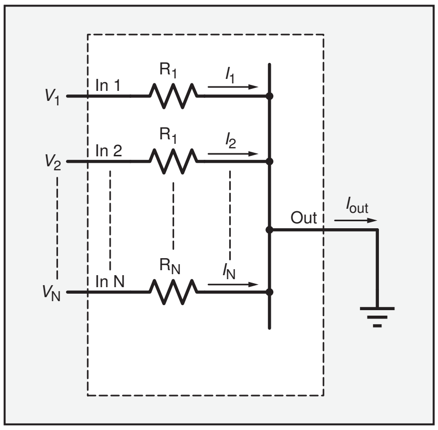


Fig.11. Currents in the mixer circuit with grounded output.

and resistor value, that is $I_1 = V_1/R_1$, $I_2 = V_2/R_2$, $I_3 = V_3/R_3$. As discussed for the circuit in Fig.11, the inputs do not interact or influence one another.

In the circuit in Fig.13 the three input currents add together and flow through the feedback resistor R_F. This gives us $I_f = I_1 + I_2 + I_3$. The feedback resistor is connected between the virtual earth point and the output. So one end is at 0V and the other is at V_{out}, with the voltage across the resistor being given by I_fR_F. With the current flowing in the direction indicated the virtual earth will be the positive end of the resistor, so V_{out} will be negative, that is $V_{out} = -I_fR_F$, so $I_f = -V_{out}/R_F$

We now have equations for all four currents (three inputs and the feedback) and we know that $I_f = I_1 + I_2 + I_3$. If we replace the currents in this equation with the 'voltage over resistance' equivalents we get:

$$\frac{-V_{out}}{R_f} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_2}{R_2}$$

Or

$$V_{out} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_2}{R_2}\right)$$

From this equation we see that if we make all four resistors equal we get an output voltage equal in magnitude to the sum of the input voltages, but opposite in sign due to the use of the inverting configuration. We can also use different values of each resistor to scale the values to be added. Thus, the circuit acts as an inverting additive mixer or voltage summing circuit.

Applications

The analysis is easily extended to N inputs – the circuit sums all the inputs with weights set independently for each channels by that channel's input resistor. This circuit is sometimes referred to as an active mixer because the op amp

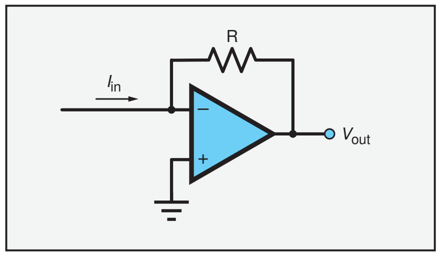


Fig.12. Op amp transimpedance (current in, voltage out) amplifier circuit.

is directly involved in the mixing; it is not just a buffer, as in Fig.10. The circuit configurations in Fig.10 and 13 can be combined to create circuits which both add and subtract signals.

Use of the virtual earth to isolate multiple input signals to an op amp is fundamental to many op amp circuits. The operational amplifier is so called because its initial applications (decades ago) were in analogue computing, where circuits implemented and hence solved equations, typically differential equations. The need for an accurate addition of various voltages is very important here, as it is with audio mixing. Other circuits also make use of this property, for example some filters have multiple signal paths to an op amp input, which must be combined. For this reason, the virtual earth point is also referred to as the 'summing junction'.

The circuit in Fig.13 is the basis of a typical op-amp-based audio mixer. An audio mixer is also likely to have a potentiometer on each channel to set its mix level. Usually, each channel will have a separate input coupling capacitor. The arrangement in Fig.1 could be used, but at low frequencies, where the capacitor has high impedance, interaction (crosstalk) between the channels can occur. Furthermore, the cut-off frequency due to the coupling capacitor will change depending on the number of inputs which are connected or floating – this is similar to the effect on attenuation for the passive mixer discussed earlier. Decoupling the inputs in this way removes some of the advantages of an active mixer's input independence and isolation.

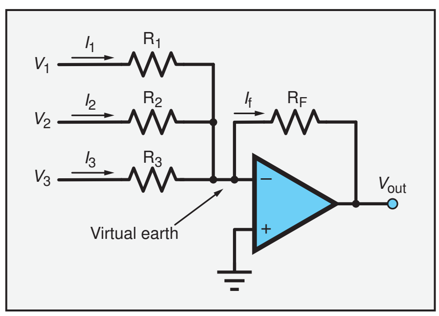
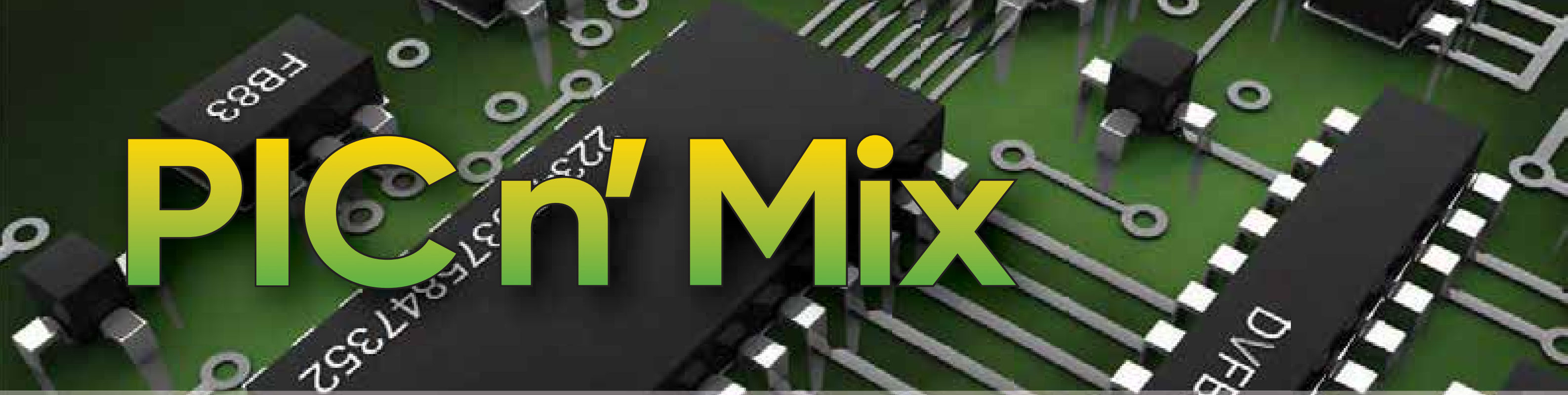


Fig.13. Three-input active mixer or voltage summing circuit.



PIC n' Mix

Mike Hibbett's column for PIC project enlightenment and related topics

Building circuits with SMDs – Part 1

In last month's issue of the magazine we started a series of articles explaining how to use a CAD (computer-aided design) program for designing circuit boards for your projects and purchasing a PCB (printed circuit board) from a professional PCB manufacturer. In parallel to this we thought it would be interesting to explore an interesting side effect of using a PCB – introducing the use of SMDs (surface-mount devices) rather than traditional through-hole components.

When etching your own PCBs, one of the main downsides to the manufacturing technique is the need to drill holes for all the through-hole components. There is nothing worse than starting to drill a board on a Saturday evening, expecting to have a working board that weekend, only to find your drill bit snap and you have no spares. Although you may think that buying a fully etched and drilled board means through-hole components are now the perfect solution, as these holes are drilled for you, SMDs do offer some compelling advantages. If you have not used them before, it's also an interesting skill to learn.

Size matters

One of the main advantages that SMDs offer over through-hole components is space saving – SMDs can in many cases be significantly smaller than their through-hole versions, and yet perform identically. Fig.1 shows a typical 0.25W (¼-watt) through-hole leaded resistor with the identical value in a range of SMD sizes. There are seven resistors in this picture; don't miss the smallest!

Just as with through-hole components, there are industry standards for most surface-mount component footprints (the copper pattern printed on the PCB to hold the component and connect to its pins) although custom parts such as connectors will not necessarily follow any standard. The footprint codes for the resistors shown below are, in order of decreasing size: 1206, 0805, 0603, 0402, 0201. There is a package size even smaller than 0201, named 01005, but that's a very specialised device and hard to get hold of – it's impossible to hand solder, so only supplied in reels for machine placement. Although 0201 and 01005 parts are not intended to be soldered by hand, the author has replaced an 0201 part – but only for a PCB prototype board. The four larger packages, however, can be assembled reliably onto a PCB with low-cost tools available to the hobbyist.

Transistors, diodes and some PIC microcontrollers are shown in their through-hole and surface mount versions in Fig.2. Notice how the diode and transistor do not have the part number printed on them; this means your storage system for SMD components needs to be well organised.

Differences – good and bad

The resistors in Fig.1 are the same value, but they do not share the same physical characteristics. It should come as no surprise that as the size goes down, the power rating also decreases. Also, as the working voltage drops, so the clearances between the terminals is much smaller. Since the devices are physically smaller, dissipating any heat generated can get tricky too – you cannot simply slip a heatsink onto the metal tab of a surface mount transistor, it doesn't have one!

The smaller packages can be more susceptible to moisture ingress, and this is a particular concern for thin ICs. When heat is applied to the board to solder the components (for production PCB assembly, boards are placed in a large oven to melt the solder,) moisture within the IC package can turn rapidly into steam, expanding within the package and lifting pins from their contacts with the silicon die. This is more of a concern for automated soldering processes; hand soldering is more forgiving, when done properly.

If these negatives give you a poor impression of SMDs, don't forget that it's exactly the same concern with leaded components. For example, you wouldn't design a circuit when you expect to need to dissipate 10W in a TO-92 transistor; you would use a TO-220 package with a whopping heatsink. The difference

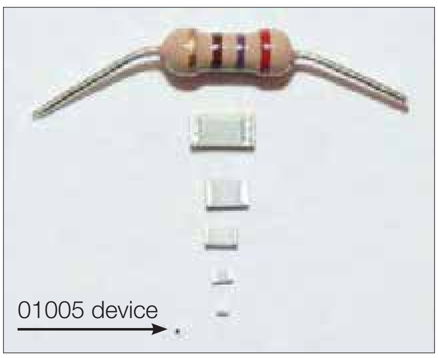


Fig.1. Through-hole and surface-mount resistors of identical value.

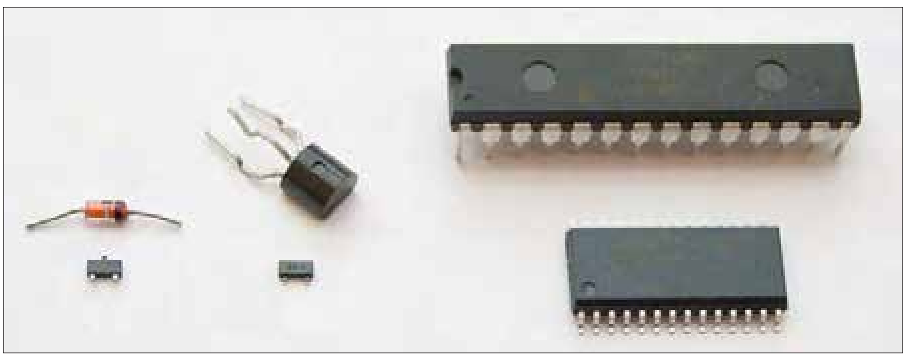


Fig.2. Diodes, transistors and microcontrollers – the two ICs shown are the same silicon internally, but packaged differently for through-hole and surface-mount designs.

Table 1: Component parameters for different sizes of the same value SMD resistor.

Type	CRGCQ0402	CRGCQ0603	CRGCQ0805	CRGCQ1206
Power rating @ 70°C	0.0625W	0.1W	0.125W	0.25W
Jumper rated current	1A	1A	2A	2A
Max. jumper current	2A	2A	5A	10A
Max. working voltage	50V	75V	150V	200V
Max. overload voltage	100V	150V	300V	400V
Dielectric withstand	100V	300V	500V	500V
Jumper resistance	<50mΩ			
Temperature range	–55°C ~ +155°C			
Ambient temperature	70°C			

when working with SMDs is that you now have to think about the power dissipation in your devices – where you would happily use a 0.25W through-hole resistor in series with an LED without hesitation, you now have to go the datasheet of a 0402 package resistor to see if it can handle the power.

Let's try an example, driving a red LED (which drops 1.8V) at 20mA from a 5V source. First, calculate the value of the resistor required, using Ohm's Law:

$R = V/I = (5.0 - 1.8) / 0.02 = 160\Omega$

Next, calculate the power that is being dissipated by the resistor:

$P = I^2 \times R = 0.02 \times 0.02 \times 160 = 64\text{mW}$

Let's take a look at the datasheet for a typical SMD resistor supplier, TE Connectivity. In Table 1 you can see that the maximum power dissipation for an 0402 resistor is only 62.5mW – so clearly not suitable. In cases like this, you would either move up a package size, or simply double up on two 330 resistors in parallel, to split the power between each resistor.

On the plus side, we have already mentioned how size differences allows the same circuit to be constructed on a significantly smaller board, which may or may not be desirable.

The final benefit worth mentioning is to do with the AC characteristics of SMDs – small, short-leaded components will naturally have lower stray capacitance and lead inductance, which means they can operate at much higher frequencies – even into the microwave frequency range for specialised devices. You won't find a 5GHz power amplifier transistor in a TO220 package for example. For you digital folks, you should be aware that it's not uncommon to see a microcontroller have its operational clock speed limit jump 20% higher in a surface-mount variant compared to a leaded example – and that can be a deal breaker in some designs.

So now you see the benefits of using surface-mount components, let's look at how this series of articles will continue – taking an existing breadboard design, and giving it a boost by constructing it on a PCB with SMDs.

Spectrum analyser

You may remember our *Spectrum Analyser* that appeared last year (*EPE*, April – July 2018), a sensitive guitar tuner constructed on a breadboard, and then souped-up with a spectrum analyser display, as shown in Fig.3.

Although this design was intended to serve as a demonstration of the application of the Fast Fourier Transform (FFT) algorithm in a cheap microcontroller, the end effect – an inexpensive low-frequency audio spectrum analyser – really piqued our interest, and triggered thoughts on expanding it, and perhaps building it up into an enclosure for day-to-day use. There are also some limitations in the original design that could be improved, and a design error, found by reader Dennis Wright, to be corrected. Thanks Dennis, well spotted.

If you missed that series of articles the design evolved into the system shown in Fig.4. It had an LED which illuminated when the A string of a guitar was plucked, and a display which showed the audio spectrum power, from DC to about 1kHz. It was super sensitive; you could tune a guitar with the sensor from across the room. It served its purpose, but the electronics within the design can cover the enter audio spectrum (with some hardware changes,) and with the right PCB design could be compact enough to fit into an enclosure. For those of you with access to a 3D printer, we might even be able to make that enclosure design ourselves and assemble the project into a very compact, ergonomic device.

The plan for this series of articles is to modify the original circuit to work up to about 25kHz, update the FFT algorithm to work with audio signals from DC through to 25kHz, and then design a board that will fit neatly behind the current LCD. We won't be discussing designing the PCB – that topic is being covered in a separate article series – but we will focus on the design changes, and the tools and techniques required to assemble the PCB. At the end of the series you will be able to order the parts and try assembling one yourself, if you wish. The production design files for the PCB will be made available on the website, so you can order a PCB from whichever PCB manufacturer you choose.

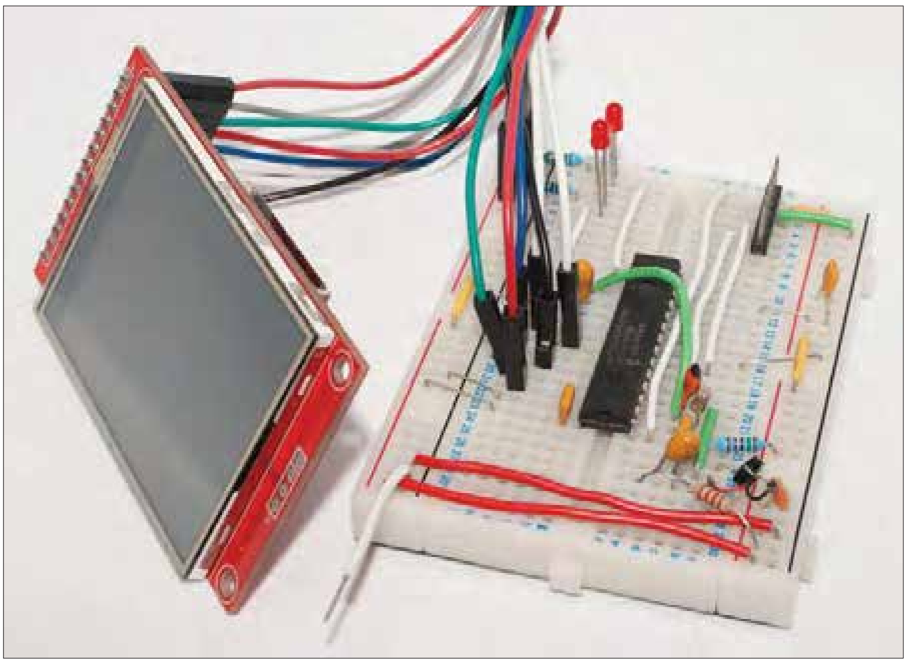


Fig.3. Our original guitar tuner breadboard assembly with spectrum analyser display.

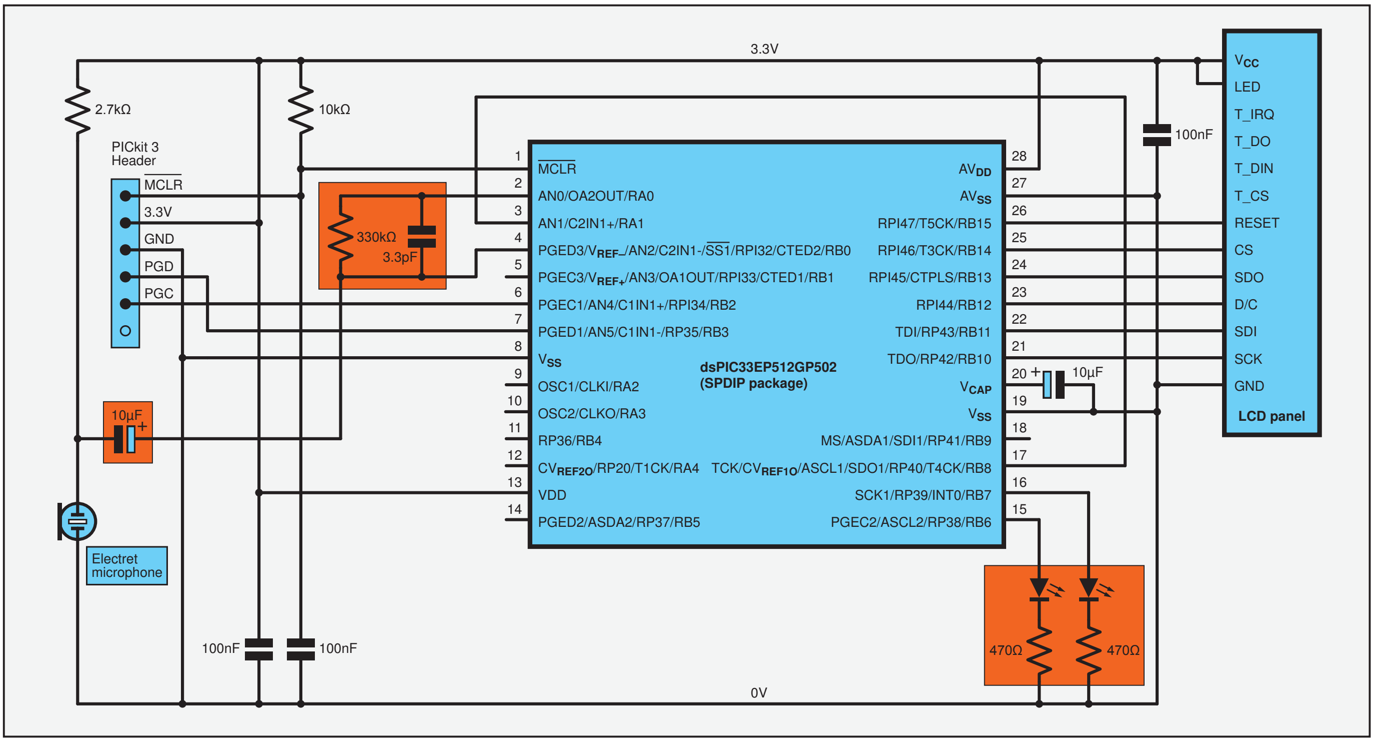


Fig.4. The original circuit schematic from July 2018 – the areas for improvement and modification have been highlighted.

Design changes

The original circuit for the spectrum analyser is shown in Fig.4, with our initial changes highlighted. On the right, we have the two LEDs previously used to show 'tuned' status. These will be removed and replaced with two buttons, with pull-up resistors, which will be used for any future user-interface functions. To the left of the processor are the two components that limit the bandwidth of the input from the microphone before going into the operational amplifier peripheral within the processor. These component values were originally selected for a maximum frequency of around 1kHz. We will re-calculate the values to allow a 25kHz cut-off. (The microphone we are using is not designed to work at such high frequencies, but you are free to select other microphones.) On the far left of the circuit is a 10µF polarised capacitor. This is shown the wrong way round in the schematic and should be reversed. In our new design we will simply replace it with an un-polarised capacitor, so the polarity problem disappears.

We will also add one new feature to the design – an improved power supply. The original breadboard design operated from two AAA batteries. These have a capacity of 1000mA/h, and as the design draws about 90 mA, they should be good for 11 hours continuous operation. That capacity rating however is specified for operation of each cell to its end point, when the internal voltage reaches 0.9V, meaning the circuit is supplied at 1.8V by these two cells. Our electronics will stop working when the combined voltage of both batteries drops below around 3.0V, so we are effectively wasting more than half of the capacity of the batteries.

This was fine for a prototype circuit, but for the improved circuit we want to make use of all the battery capacity. Two options are immediately apparent: use a lithium-ion battery, which provides a constant voltage or include a DC/DC converter, which can boost that 1.8V to 3.3V.

Using a lithium-ion battery is a good idea – a lithium-thionyl chloride battery, for example, provides a constant 3.7V and has excellent capacity – but they are very expensive. A better solution is to use a DC/DC converter specifically designed for this task – the Texas Instruments TPS61097A-33DBVT 3.3V boost regulator IC for example. This requires a very simple support circuit – two capacitors and a small inductor – to provide a regulated 3.3V supply from an input supply of 5.5V down to just 900mV – meaning that you could power this circuit from a single AAA battery, which would help us make a small device. The chip costs a couple of pounds, but overall this approach offers a cheaper option than using a lithium-thionyl chloride AAA battery costing around £9. Even though that battery can deliver two-and-a-half-times the power of an alkaline AAA battery, it's not worth the cost in this application. The maximum output current of the regulator IC is 100mA, 10% above our consumption rate, which is good enough for a hobbyist design (for a consumer product we would have preferred a little more spare capacity within the regulator, perhaps 30%. Cost and space constraints in production devices often limits an engineer's ability to provide more conservative 'headroom'.)

Besides these hardware changes we will also take advantage of the shorter wiring traces between the PCB and the display to increase the speed of communications between the display and the processor. This will increase the rate at which our display will update and increase how much time we have to run the FFT algorithm because we will spend less time writing data to the display. Remember, a simple microcontroller cannot do two tasks in parallel; at best, it can jump quickly between both tasks and appear to be doing both in parallel. In reality, if the processor is busy writing data to the display, slowly, it cannot be doing other useful things such as converting the time domain input signal into a frequency domain plot for display.

We will also 'tweak' the gain of the operation amplifier within the processor to give us a fuller-range signal swing across the ADC input range. This will come in useful because the design now has a new source of noise, and we want to minimise the impact of that noise by having a strong 'wanted' signal. That noise source is the oscillation of the newly added DC/DC converter. We will examine this issue in detail with an oscilloscope once we have built the PCB. Knowing that a noise source will be present in advance means that we can do some things to help mitigate the issue. Minimising the impact of a known noise source in the circuit involves (at least) three tasks:

1) Reduce the noise on the microphone power supply signal. The output of the microphone is very low level, so any noise on the power supply input will be easily superimposed on it.
2) Reduce the noise on the ADC peripheral reference voltage. Any variation in that voltage will pass straight through to the output value calculated by the ADC.
3) Minimise noise induced on the board power supply rails. There is no point having a clean ADC reference voltage if its PCB trace runs close to a noisy signal line before entering the processor – the noise will be induced from one signal to the other, through capacitive coupling, and introduce a new source of noise. See point 2.

Thankfully, we are not designing a Hi-Fi amplifier, so we don't have to go to extremes to eliminate noise, but being mindful of the issues can result in a significantly better implementation – as we saw in last year's articles. To be on the safe side, we will allow for the placement of additional filtering components on the PCB 'just in case' we find additional noise reduction is called for. If nothing else, it will be fun experimenting!

Choosing component sizes

For microprocessor ICs, and Microchip devices in particular, there are often several surface-mount package options available for each device type. Some packages are so small that all the pins are exposed as pads on the underneath of the device, making construction with a soldering iron impossible. These small packages allow for significantly smaller or more densely packed PCBs but increase the cost of the PCB because it must have many internal conductive layers. For us hobbyists, the ideal package is the 1.27mm pin pitch Small Outline IC (SOIC), as shown in Fig.2. They are a direct replacement for DIL packaged parts, and are often slightly cheaper, due to the simpler manufacturing process required when assembling the chip's die into the package. SOIC is the author's favourite package for hobbyist-use microcontrollers.

For resistors and capacitors, preferred packages for hand soldering are 1206, 0805, 0603 and 0402. For someone learning how to solder SMDs, 0805 offers the best compromise between ease of soldering and miniaturisation.

Equipment

Working with surface-mount components will require investment in some new tools, and some new consumables.

Thin solder wire is essential. 0.5mm or 0.38mm multicore solder is recommended. Being thin, the wire is easier to accurately position when applying with the soldering iron to a junction. Solder wire is not cheap, but lasts forever, so it is a good investment. eBay is a great source for low-cost solder, given that from traditional distributors a 250g reel of solder can cost £100. You should also get a small chisel-head iron tip for your soldering iron; 2.5mm wide is ideal. Farnell stock these, although for popular brands of soldering iron they can be found on eBay. Solder wick, a small roll of copper braid, is essential for cleaning up the inevitable solder splashes. This is available in a variety of widths, and it's worth getting thin and thick versions – 1.5mm and 3.0mm wide are fine, and suitable supplies can be found on eBay for a few pounds. Solder wick gets used up fairly quickly, especially during the learning phase, so buy a couple of reels in each size.

Solder flux pens, a liquid flux dispenser that look like a whiteboard marker can be found on eBay for a few pounds. These are used to apply flux to PCB pads just before soldering a component. Unlike whiteboard marker pens, these last for years as the fluid does not evaporate. Don't bother buying one with a thin tip, flux is applied liberally and with no precision. Needless to say, by the end of assembly your board will be a sticky mess, but this can be cleaned off with water. On that subject, de-ionised water is great for keeping your soldering iron wipe-pad damp in addition to cleaning the flux off boards. De-ionised water can be purchased from Car DIY stores in gallon containers very cheaply. A gallon container will last for years. It is the preferred choice to minimise corrosion of soldering iron tips and contaminates being left on your PCB. For hobbyist projects it's not a major requirement, but you'll replace soldering iron tips less frequently and have PCB designs that work trouble free for longer. A stiff hairbrush – we use a 1-inch paintbrush, cut back to 2cm from the end – is good for scrubbing the flux away.

Fig.6. SMD assembly tools.

Fine point tweezers are a necessity. Our favourite pair of tweezers came free with an iPhone screen repair kit, but, again, you can buy these cheaply on eBay. Don't use eyebrow-plucking tweezers, you really do need a very fine point tip to hold components that are only a few millimetres in size.

Finally, unless you are young with super eyesight, an eye magnifying glass is essential. Avoid the cheap 'watch maker' glasses available on eBay; these are poor quality, fit badly, and have too narrow a field of view. Three times magnification is ideal. A better option than an eye magnifying glass is a 'helping hands' magnifying glass which comes on a small stand and costs around £10. This gives you magnification without having to hold the lens – you need both hands for soldering – while not forcing you to bring your face very, very close to a hot soldering iron! These magnifying glasses are also available with an 'Anglepoise' stand and even a light source within the lens surround, which is an excellent option if you have space. The choices of glass and stands are varied and eBay is a good source for these – expect to pay £20 to £60. Avoid the 'PCB Inspection Digital Camera' products on offer though. These provide high magnification but have a very short focal distance, which means you would not be able to get your tools in to work on the PCB. Specialised camera solutions are available for PCB assembly, but these generally start at around £600. If you find a cheap one that actually works, let us know, and we will review it!

Next month

By next month we will have received our PCB back from the manufacturer, along with our surface-mount parts and we will explain the assembly process. We will also discuss any design changes, the capabilities of this new design, and consider the options for an enclosure. Perhaps even make our own, on a 3D printer. Find out next month.

Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 1 – Introducing the Micromite

Have you ever dreamt up a fantastic idea for an amazing constructional project, only to find out that you didn't really know how to convert your idea into a working solution?

There are endless low-cost modules available to choose from that will likely provide you with the necessary building-blocks. Also, there are numerous Raspberry Pi HATs, Arduino Shields, and MikroElektronika Click modules that can add some high quality features. But once everything is connected to an intelligent controller, how do you go about programming it in a way that is quick, easy, and achievable (especially if you haven't written code before)? After all, you just want to see your brilliant idea come to life; and not get bogged down in having to learn some complex coding environment.

Sure, there are many platforms available to choose from; but they typically require you to spend considerable time initially setting things up, and then working through the potentially steep learning curve of a new development tool. Perhaps you manage to write some code for your amazing project, only to find out that things don't quite work in the way you expected. Is it a bug in your code? – or is it a bug in somebody else's code within a library that your project relies upon? Hours pass as you try and get everything working the way it should.

If only there was a platform that literally anyone – young or old – can learn and use with ease. Enter the Micromite. We know you're going to love this, so read on…

The mighty Micromite

First, a little background – the Micromite is the creation of a remarkable Australian inventor, Geoff Graham. He frequently writes articles for *EPE's* partner magazine *Silicon Chip*. It's well worth visiting Geoff's website (**geoffg.net**) where you will see just some of his inventions. MMBASIC was his creation, and with the help of Peter Mather (UK based), the features of MMBASIC have been expanded into a phenomenal product. We thank Geoff and Peter for their tireless and devoted work, which they give for free.

Reading many of the recent issues of *EPE* magazine, you will likely have seen mention of the Micromite. It has been featured numerous times; either as a standalone development module, or as the 'brains' behind a project – and for good reason.

If you have not yet used a Micromite, then you may well be asking questions such as: what exactly is the Micromite, what advantages (if any) are there in using it, why has it been so popular, and how could I actually use one in *my* next project?

This series intends to answer these questions in a step-by-step approach; and show you just how easy the Micromite is to learn, use, and incorporate into your own projects.

Even though this series is aimed at newcomers, there will hopefully be some tips that existing Micromite users will find useful too. The intention is to provide a 'building blocks' journey covering many of the Micromite's powerful features, in the hope it encourages you to get creative with the Micromite.

Initially, you will build your very own *Micromite Keyring Computer* (yes, a *keyring* computer! – see Fig.1). This will comprise just a handful of through-hole components mounted on a small piece of standard stripboard. We will also show you how to build a plug-in *Development Module* which will allow you to program the Micromite (by using a connected computer). This simple (and cheap) setup will form the perfect foundation for you to follow any of the topics covered in the rest of the series. For those of you that already own a Micromite, you can also work through all the topics covered; however, you may find it fun to build your own *Micromite Keyring Computer* too!

Micromite Keyring Computer main features

- Powerful, easy-to-learn coding platform, allows rapid prototyping of your ideas*
- Just 10 low-cost through-hole components (plus connectors and case)
- Quick and simple DIY assembly on standard stripboard
- Two rows of female sockets – breadboard friendly (with jumper wires), or stackable with plug-in stripboard modules
- 19 input/output connections to easily control external hardware
- Standard 5V micro-USB power input – with power indicator LED
- Separate plug-in Development Module – insert when exploring software features and developing code (remove when code works as required)
- Professional-looking ABS enclosure provides circuit protection; anti-slip with coloured, flexible silicone sleeve

* Requires a computer running a Terminal app such as TeraTerm, and a USB-to-serial module (such as the plug-in *Development Module* described next month)

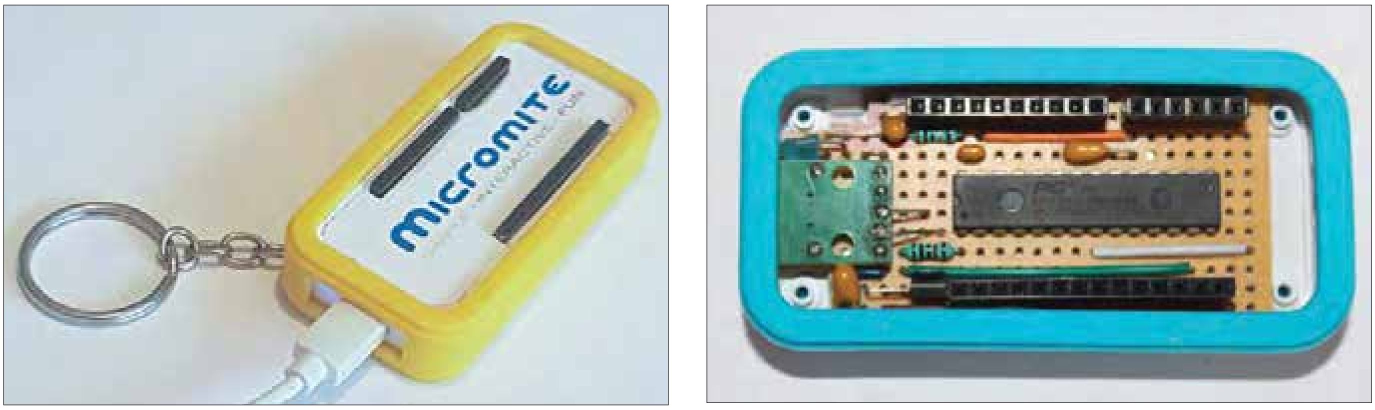


Fig.1. Inside and out – the *Micromite Keyring Computer;* built on stripboard with a handful of inexpensive components.

Whether you prefer to construct your projects on breadboard, strip-board, matrix-board, or your own PCB design, the *Micromite Keyring Computer* (*MKC*) we present here can easily be integrated into them. However, we recommend that you use the *MKC* as your development tool and once everything works, simply copy your code into a new 28-pin Micromite DIP chip. This will free up your *MKC*, allowing you to develop further great ideas.

Throughout the series, brief examples will be shown; and with just a handful of low-cost components and modules, and a few lines of code, we aim to enthuse you and unleash your creativity.

The series will take a modular approach in terms of hardware. A few mini-projects will inspire you and help you generate your own ideas by customising the techniques discussed. Most important of all, we want to make this series *fun*, and help you become creative with the Micromite.

So what exactly is the Micromite?

Short answer: It's a very powerful microcontroller (IC), which is extremely easy to program and use. You can connect external hardware to the available input/output pins, and can very quickly convert an idea into a working solution with just a few lines of very simple code.

Slightly longer answer: The Micromite is a powerful 32-bit microcontroller with a built-in BASIC interpreter called MMBASIC, all housed in a single IC, which in this series is a 28-pin DIL chip. Back in the 1980s, BASIC was the language used in many of the home computers that suddenly flooded the market. You simply hooked up your (big!) TV, plugged in the power supply, switched on, and you were *instantly* presented with a cursor. You were then able to start typing something. Typically, you would then enter a few lines of BASIC code such as:

```
10  INPUT NAME$
20  PRINT "Hello "; NAME$
30  GOTO 10
```

The big advantage when you looked at this kind of code was that it was pretty easy to understand what the code was doing; even if you'd never used a computer before. Sure, it was 'basic', but it was reasonably intuitive and meaningful.

So because the Micromite also uses BASIC, it is as easy to learn to program as it was with those home computers back in the 1980s (such as the Sinclair ZX80/81/Spectrum, Commodore VIC 20 / C64, BBC Micro, Amstrad CPC).

The venerable BBC Micro aside, those 1980s home computers usually didn't control external hardware (yes, there was an 'expansion bus' somewhere on the rear of the computer, but you didn't really use it to control hardware unless you were proficient in hardware design). The Micromite on the other hand is very much aimed at controlling external hardware; and thanks to its easy-to-learn coding language, hardware control is extremely straightforward.

There are many microcontrollers available that MMBASIC could (and does) run on. However, the majority of these microcontroller ICs are surface mount devices (SMD), but not all! To make this series accessible to as many readers as possible we wanted a true DIY approach, which meant there were two design criteria we set ourselves for the Micromite keyring computer – it must be built using:

- Through-hole components (no SMDs)
- Standard strip-board (no PCBs)

To explore MMBASIC, we could have simply recommended an existing 'small' Micromite module (built with SMDs), but we really want to encourage a 'total self build'. For this reason, we will be using a 28-pin DIP version of a Microchip PIC microcontroller – the PIC32MX170.

Taking the above design criteria into account, next month we will begin by showing you how to build your very own *MKC*, comprising just a handful of low-cost components (IC, 3 resistors, 4 capacitors, LED, voltage regulator, some connectors, and an attractive enclosure).

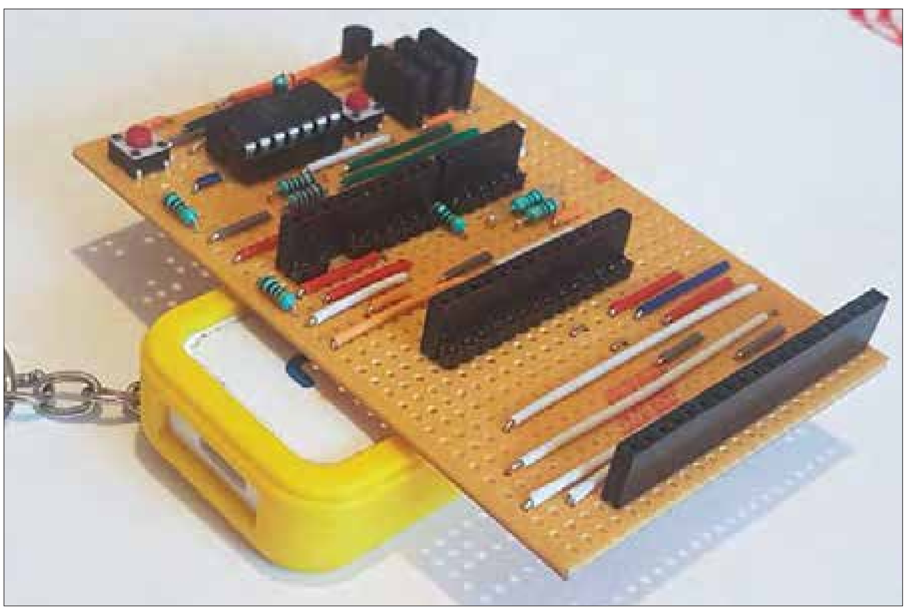


Fig.2. The plug-in *Development Module on top of the Micromite Keyring Computer*.

Parts List – Micromite Keyring Computer

(cost excluding case: approx. £12)

Stripboard (24 strips x 12 holes)

PIC32MX170F256B-50I/P * (see below)

MCP1700 3v3

10Ω

470Ω

10kΩ

100nF MLCC capacitor

3 off 10µF tantalum capacitors

3mm LED (blue is nice!)

micro-USB break-out board (with 0.1-inch header pins)

6-way female header

10-way female header

14-way female header

Selection of wire links (11 needed)

Parts List – plug-in Development Module

(cost: approx. £12)

Stripboard (24 strips x 37 holes)

PIC16F1454-I/P (pre-programmed with the MicroBridge firmware)

MCP1700 3v3

7 off 470Ω

2 off 10kΩ

2 off 10µF tantalum capacitors

3mm red LED

3mm green LED

14-pin DIP socket

2 off 6mm tactile button

3 off 4way female header

6-way female header

10-way female header

14-way female header

Pin strips (2-way, 2 off 6-way, 14-way)

Selection of wire links (41 needed)

* It is recommended that you buy a pre-programmed 'Micromite Keyring' PIC because it contains a short program that will flash an LED on powering up the module. This will indicate that you have assembled the Micromite keyring computer correctly – a very useful check.

All of the above parts are available individually, or as complete kits, from my online shop at: **micromite.org**

The observant among you will have noticed the word 'instantly' emphasised earlier. This is an important feature of the Micromite. As soon as you power it up, it is 'ready'. There is no waiting around for software to be loaded. This is a huge advantage that will become clearer as we work through the series.

The Micromite has another big advantage compared with the many other development platforms out there. The BASIC code you write is stored within the Micromite itself. When you make a change to your code, you can instantly run it and see the affects of the change. Almost all other platforms require you to recompile your code after any change, and then download the newly generated file to the microcontroller. If this means nothing to you, then don't worry – just rest assured that writing, editing, and testing your BASIC code on a Micromite is extremely easy and quick.

What will the series cover?

As already mentioned, next month we will show you how to build your *MKC*. We will also build the plug-in *Development Module* (Fig.2) so that you are in a position to start exploring the many powerful features that MMBASIC offers.

We will then start our journey of exploration over the following months, starting with the basics of inputs and outputs. The various protocols that many modules, HATs, Shields, and Clicks use will be covered, including UART, I²C, and SPI. We will show working examples, including how to connect a mini OLED display (Fig.3), and also other hardware modules such as an RFID reader.

You will start to see just how easy it is to connect a Micromite to virtually any module and get instant results. One-Wire temperature sensors will be covered, as well as how to read button presses from infrared remote controllers. We will show you how to add a real-time clock (RTC) module and along with the mini OLED display, we will build a simple clock. This project will need under ten lines of code; try doing that with any other platform! Add a buzzer, a capacitive touch-button, some more code, and you'll then have made an alarm clock.

Want a nice touch-screen interface for a project? Lets swap the mini OLED for a larger colour touchscreen. Two lines of configuration and you'll be set up to create a nice touchscreen user interface. Then we'll attempt to recreate a simple arcade game (maybe Pong). But we need a controller for our game – so why don't we show you how to connect a Nintendo NunChuk controller.

Towards the end of the series we will explain how to remotely access your Micromite via BlueTooth (as opposed to a USB lead). This will set us up perfectly for our final project, a *Micromite Robot Buggy*.

Hopefully this has whetted your appetite. One last point – this series will not be a course in BASIC programming; there are many tutorials readily available on the web. However, we will explain the lines of code used in all examples and this will allow you to modify them for your own use.

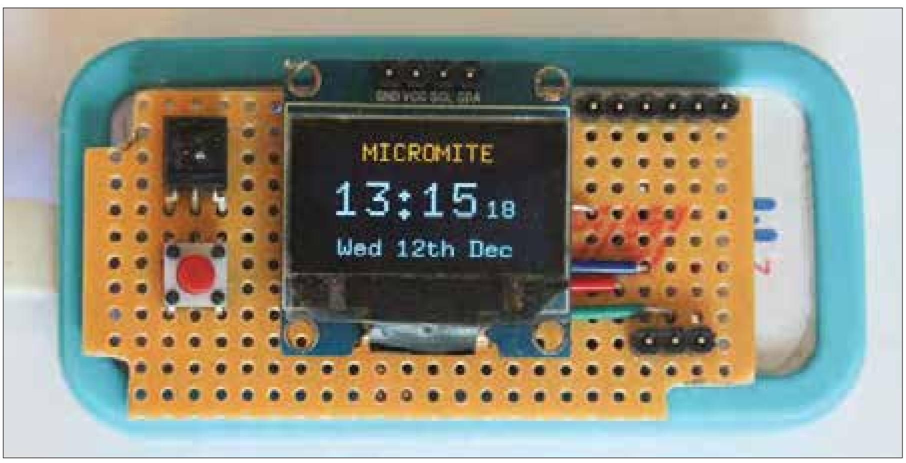


Fig.3. The *Micromite Keyring Computer* is plenty powerful enough to drive displays.

Preparations

Prior to building anything, we need to prepare a device on which we can interact with the Micromite. There are two physical items that are essential for interacting with a Micromite:

1. A *keyboard*, so we can:
- Configure the Micromite
- Issue instructions
- Type in (and edit) our code

2. A *screen*, so we can:
- View our code
- Read any error messages
- See any other visual output

The best device for this task is a computer. We could use a phone, or a tablet, or even a Raspberry Pi; but for now we will begin to describe how to set up a Windows computer (referred to from here on as the 'PC').

Note that the PC will only be acting as a 'Terminal' – there is no intelligence required from the PC since all the intelligence is contained within the Micromite.

Anything we type on the PC's keyboard we want to be sent to the Micromite (via a serial input connection); and anything that the Micromite needs to display we want sent from the Micromite (via a serial output connection) to the PC's screen.

The keyboard (input), and screen (output) connections on the Micromite are referred to as the 'Micromite Console' connections. For the technically minded, this is just an Rx/Tx UART interface on the Micromite, operating at a default speed of 38,400 baud (baud rate can be changed).

Micromite

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COMPETITION!

This month, *EPE* and **micromite.org** are giving you a chance to win one of three mini OLED displays. This high contrast, wide viewing-angle mini display will be used to demonstrate some of the Micromite's output capabilities, and will also form the basis of the real-time clock mini-project in this series.

To enter, send an email to **epe@micromite.org** with the email subject as: MM1-OLED

Please ensure you email before the closing date: 31 January 2019

The names of the three lucky winners will be published in a forthcoming edition of *EPE*.

Look out for future competitions to win other fantastic Micromite products.

Terms and conditions

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 shipping address to which their prize will be shipped
5. UK winners – prizes sent via Royal Mail's Special Delivery service
6. Overseas winners – prizes sent by Royal Mail's International Tracked & Insured service.

GOOD LUCK!

Terminal software

So what software is needed on the PC to make it act as our terminal? We just need a VT100-compatible program to allow responses to and from the Micromite's input and output console connections. This may sound scary, but it is really just a matter of loading a single program (which you may even already have installed). For Windows users we recommend TeraTerm or PuTTY. Both are readily available for free download from the Internet, and either will give your PC the software required to communicate with your Micromite. (Mac users can use the built-in Terminal and Screen applications).

And what additional hardware do we need to make the physical link? The physical connection between the PC and the Micromite (the two console pins) is simply made with a 'USB-to-serial' module. The USB end is plugged into the PC, and the serial end is connected to the Micromite. When the USB-to-serial module is connected to the PC (plugged into a USB port), the PC will internally assign what is called a Virtual COM Port number. This number is important, as it needs to be referred to in the aforementioned Terminal program running on the PC. (More on this next month).

Once you have your Terminal program loaded and set up, and have your USB-to-serial module correctly connected, then anything typed on the PC's keyboard will be sent to the Micromite; and any relevant results from the Micromite will be displayed on the PC's screen (in the Terminal program).

As already mentioned, next month we will also be describing how to build the plug-in *Development Module*, a single-chip design which will have two modes of operation. The default mode is that of a USB-to-serial module, which meas the *Development Module* will be acting as our physical interface between the Micromite and the computer. For those that are wondering, the other mode is as a 'Firmware updater' allowing you to update MMBASIC as and when new releases are issued. For regular Micromite users, the *Development Module* is simply a 'MicroBridge' built onto stripboard.

Recommended reading

Please ensure that you visit **http://geoffg.net/micromite.html** and download the *Getting Started With the Micromite* guide (scroll to the bottom of the page and look under the Downloads section. It is usually the first item in the list.)

While there, also download the *Micromite User Manual*, which is immediately under the *Getting Started With the Micromite* guide. (Note: there is no need to download the *Micromite Plus Manual* – this manual does not concern the 28-pin DIP Micromite in any way.)

Save copies of the two PDFs locally on your computer. They will be very useful references for you throughout this series, especially when we start our coding examples. And please do not be put off by the quantity of pages in these manuals (there is no need to print them all either!). These manuals are extremely thorough in their detail and are regularly used by advanced Micromite users for reference purposes.

For now, run your eyes over *Chapter 1* in the *Getting Started With the Micromite* guide. Don't panic if there is something you don't understand; we will cover items as and when we need them in the series. Pages 10-11 briefly describe how to load and configure TeraTerm.

Also look at *Chapter 2*. It is a good refresher for anyone who has used BASIC before. Again, no need to panic if there is something that appears complex to you at this stage.

Remember, the whole idea of this series is to show just how easy it is to use a Micromite. Stick around, follow this series, and you will soon be able to design and build some amazing projects.

Preparations for next month

To get you ready for next month, we have provided two lists of the components which you will need. Some parts you probably have already, but if not, then it is worth getting hold of them in advance. This will mean that you will be able to immediately start building the *MKC* (and the plug-in *Development Module*) as soon as next month's *EPE* is published.

Finally, why not enter our competition to win a mini-OLED display. We will be using this in some of the upcoming articles.

Until next month, do enjoy getting things ready for your first two Micromite circuits – the *MKC* and its accompanying *Development Module*.

Questions? Please email Phil at:
contactus@micromite.org

Max's Cool Beans

By Max the Magnificent

They say you can't teach an old dog new tricks, but I'm here to tell you this isn't true, because I learned a couple of really cool tricks just the other day.

Fig.2. Paul Parry Nixie tube Bombe clock, with Dalibor Farny's R|Z568M tubes.

It's the Final Countdown

Do you remember the film *Tomorrowland*? There's one scene where we see the disillusioned inventor Frank Walker (played by George Clooney) watching a Steampunk timer counting down the years, months, days, hours, minutes, and seconds until the end of the world. Not surprisingly, Frank is a tad gloomy, which explains why he isn't invited to many parties.

Frank's timer employed 12 large Nixie tubes to display his countdown data. Dating from the 1950s and 1960s, these are a bit like a cross between vacuum tubes and neon lights. The glass tube is filled with a gas like neon at a low pressure. Each tube also contains a wire-mesh anode and 10 wire cathodes shaped like the numbers 0 to 9. Applying a strike voltage of about 170V DC to a cathode causes it to be surrounded by a glowing orange discharge.

Nixie tubes come in all shapes and sizes. I think Frank's timer was using large Z568M tubes, which are about 50mm wide and 100mm tall. These are beautiful to look at, but also rather expensive. Until recently, the only sources were to buy old tubes reclaimed from vintage equipment costing ~US$250, or 'new old stock' (unused tubes from the 1960s manufactured in East Germany or the USSR) that can cost US$500 or more a tube. More recently, a guy called Dalibor Farny (**https://bit.ly/2FAcI6K**) has started hand-crafting brand-new R | Z568M tubes. These are pin-compatible with the original Z568M tubes, but cost only ~US$145, which is incredibly cheap when you consider the amount of expertise and effort involved in creating them (Fig.1 and Fig.2).

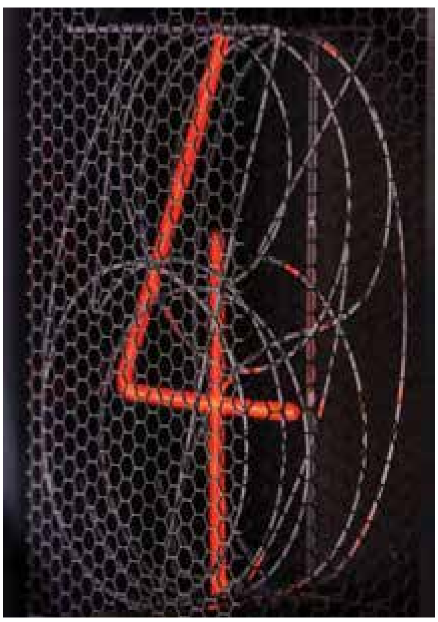

Fig.1. Inside a handmade Dalibor Farny Nixie.

One of my hobby projects is to create my own *Countdown Timer*. In this case, however, I will be counting down the time to my 100th Birthday (mark your calendars for 29 May 2057). Rather than use 12 large, expensive Nixie tubes, I opted for their LED-based Lixie equivalents. Created by Connor Nishijima (**https://bit.ly/2Aj2rrl** and **https://bit.ly/2mwQ3tc**), these bodacious beauties are much more affordable at ~$35 each. In addition to requiring only 5V, Lixies can be daisy-chained together, which means I can control all 12 in my *Countdown Timer* using a single pin from an Arduino microcontroller (see Fig.5).

I almost dropped the ball

Suppose you had a single Lixie display and you wished to use it to display a count from 0 to 9, with the transitions occurring once a second. When we get to 9, the next count will return us to 0, at which point we'll start all over again. So, how would your program handle this?

I'm afraid that I almost dropped the ball here, because my original solution was to simply turn the new digit on at the same time as I turned the old digit off. Furthermore, when we reached 9, on the next count I simply transitioned to 0. If you want, you can take a look at my code for this count (**https://bit.ly/2DRR4Jt**) and see a video of it running on a Lixie (**https://bit.ly/2zkHvie**). All I can say is that I was young and foolish, but – as you will read below – I'm much better now.

Actually, I should also note that all of the code referenced in this column makes use of the `delay()` function. This is *not* the way we would want to implement this in a real-world application, because we can't do anything else while the `delay()` function is executing. The only reason I used it here is that it's easier for beginners to wrap their brains around what's happening. If you are interested in learning more, I actually discussed this in excruciating detail in two columns (**https://bit.ly/2PLscJH** and **https://bit.ly/2DSv1m0**).

A gaggle of geeks

I bounce over to England a couple of times each year to see my dear old mom. On the last Friday before my return to America, a bunch of my maker friends travel from all over England to visit me. Everyone brings their latest and greatest creations for our techno-geek equivalent of a 'show and tell.' We all meet up at my brother's house, with my mother in attendance to provide 'Ooh' and 'Aah' sound effects, as required.

On my most recent trip, my chum, Paul Parry (**https://bit.ly/2KphoLt**) brought one of his Nixie tube Bombe clocks. In addition to displaying the time, four rotating drums on the front

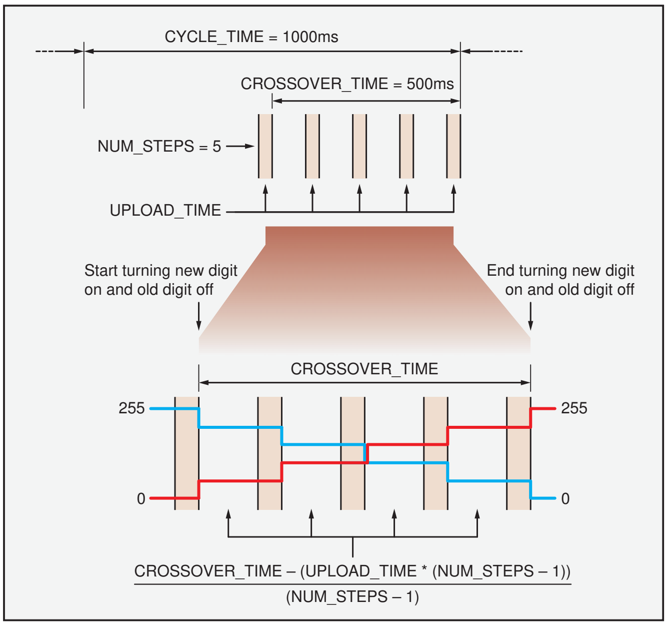

Fig.3. Crossfade effect timing diagram.

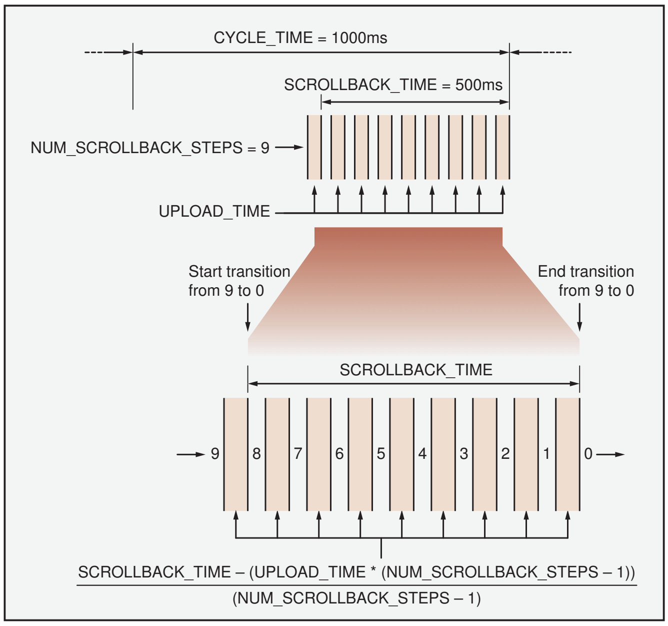

Fig 4. Scrollback effect timing diagram.

spin around decrypting a message in the same way that the Bombe device used by British cryptologists helped decipher German Enigma-encrypted messages during World War II – see Fig.2.

We were all happily sitting around watching Paul's clock perform its magic when I noticed some subtleties in the displays that had previously escaped my conscious mind. Take a look at a video of the clock running, focus on the seconds digit on the right-hand side, and see if you can spot what I'm talking about (**https://bit.ly/2OWOHGq**).

The crossfade effect

In fact, there are a whole bunch of effects here, but we will focus on only two for the purposes of this column. The first effect is what I call a crossfade. When transitioning from 0 to 1, 1 to 2, 2 to 3… Instead of simply turning the new digit full on at the same time as the previous digit is turned full off, the new digit fades up while the previous digit fades down.

Now, since Nixie tube digits can only be fully on or fully off, this fading effect is achieved by turning the digits of interest on and off very quickly, and by varying the amount of time they are on compared to the amount of time they are off. Having a digit on for only 50% of the time makes it look half as bright (give or take), for example. Things are much simpler for my Lixie displays, because each of the tri-color WS2812 LEDs contains three pulse-width modulators (PWMs) that are used to control the red, green, and blue channels.

I'm a visual person, so I started by sketching out a timing diagram illustrating what I wanted to do (Fig.3). I always find that having a diagram like this makes it much easier for me to create the code to achieve the desired effect. This figure shows only five steps (because this was easy to draw), but I actually ended up using 50. Also, when I started out, I thought a crossover time of 50 to 100ms would be acceptable, but I ended up making this bigger and bigger until I reached 500ms, which is half of the 1-second cycle time. I was a little doubtful about this, but I asked the programmer at PV Electronics (**https://bit.ly/2AsndmA**) – which creates the electronics for Nixie tube clocks around the globe – and he confirmed that they use a crossover time of 400 to 500ms depending on the size and type of tube. If you wish, you can see a video of this crossfade effect running on my Lixie (**https://bit.ly/2P5Xaad**) and look at the code I used (**https://bit.ly/2E1jvoh**).

The scrollback effect

The second effect I observed on Paul's clock was what I call the scrollback effect. As you may recall from the previous video of my Lixie display, when we reach 9, on the next count I simply roll over back to 0. By comparison, in the case of Paul's clock (which features a board from PV Electronics), when we reach 9, the next count causes the clock to rapidly sequence through 8, 7, 6, 5, 4, 3, 2, and 1 before landing on 0. Once again, I created a timing diagram to reflect this (Fig.4).

Yes, of course you can see a video of the combined crossfade and scrollback effects running on my Lixie (**https://bit.ly/2AzJVJx**) and peruse and ponder the code I used (**https://bit.ly/2BDPTLr**).

The amazing thing to me is that I managed to get as old as I am without realising that these effects were even being used. Now that I am aware of them, however, I really appreciate the added sophistication they bring to the party, and I will be using these little scamps in all of my future projects.

Fig.5. Lixie Displays by Connor Nishijima.

Cool bean Max Maxfield (Hawaiian shirt, on the right) is editor-in-chief at **EEWeb.com** – the go-to site for users of electronic design tools and askers of electronic questions.

Comments or questions? Email Max at: **max@CliveMaxfield.com**

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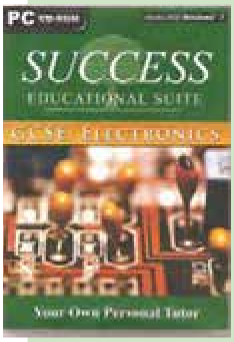

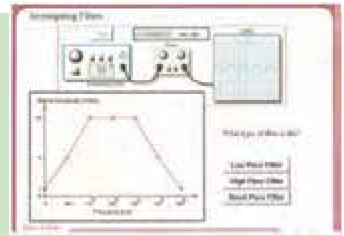

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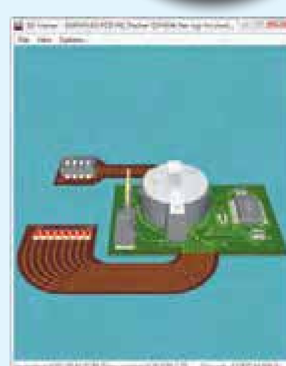

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SOFTWARE

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.

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- Includes MPLAB assembler
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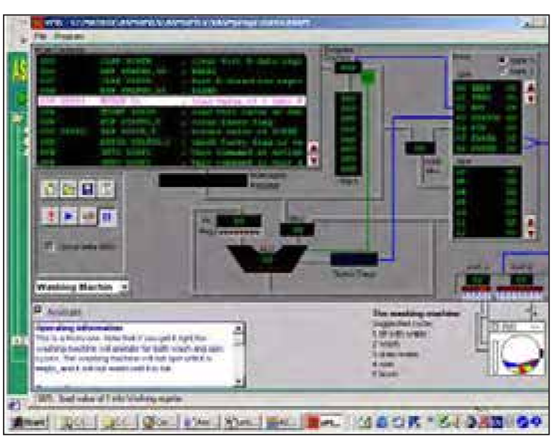

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Flowcode is a very high level language programming system based on flowcharts. Flowcode allows you to design and simulate complex systems in a matter of minutes. A powerful language that uses macros to facilitate the control of devices like 7-segment 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.

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- Allows complex PICmicro applications to be designed quickly
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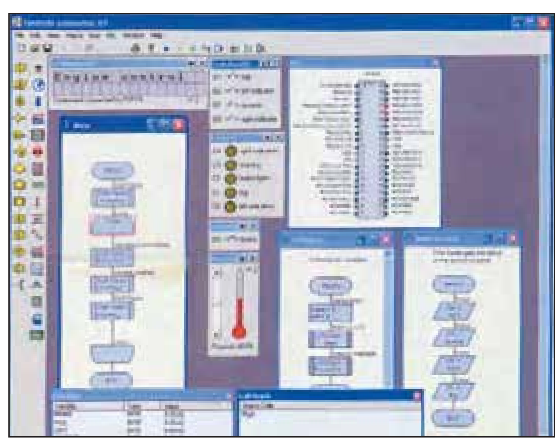

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ELECTRONICS TEACH-IN 2

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 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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ELECTRONICS TEACH-IN 3 CD-ROM

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.

The second section – *Practically Speaking* – covers the practical aspects of electronics construction. Again, a whole range of subjects, from soldering to avoiding problems with static electricity and indentifying components, are covered. Finally, our collection of *Ingenuity Unlimited* circuits provides over 40 circuit designs submitted by the readers of *EPE*.

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Jim Gatenby

Python is the leading programming language, easy to learn and widely used by professional programmers. This book uses MicroPython, a version of Python adapted for the BBC Micro:bit.

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This book is written using plain English and avoiding technical jargon wherever possible and covers many of the coding instructions and methods which are common to most programming languages. It should be helpful to beginners of any age, whether planning a career in computing or writing code as an enjoyable hobby.

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GETTING STARTED WITH THE BBC MICRO:BIT
Mike Tooley

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

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

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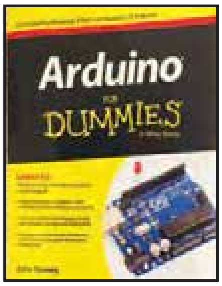
Teach-In 2016

Exploring the Arduino



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John Nussey

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

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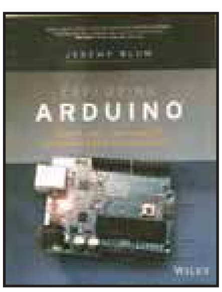

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Jeremy Blum

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

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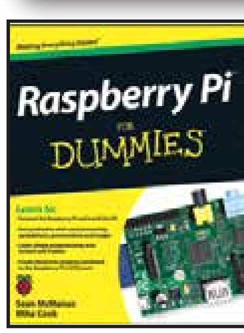

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Sean McManus and Mike Cook

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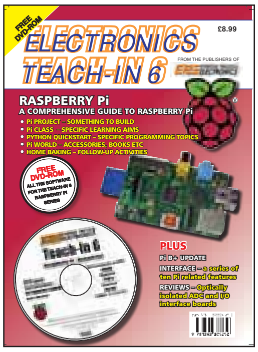

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Mike & Richard Tooley

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This exciting series has been designed for electronics enthusiasts who want to get to grips with the inexpensive, immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. Teach-In 8 will provide a one-stop source of ideas and practical information.

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This book also includes *PIC n' Mix*: PICs and the PICkit 3 - A Beginners guide by Mike O'Keefe and *Circuit Surgery* by Ian Bell - State Machines part 1 and 2.

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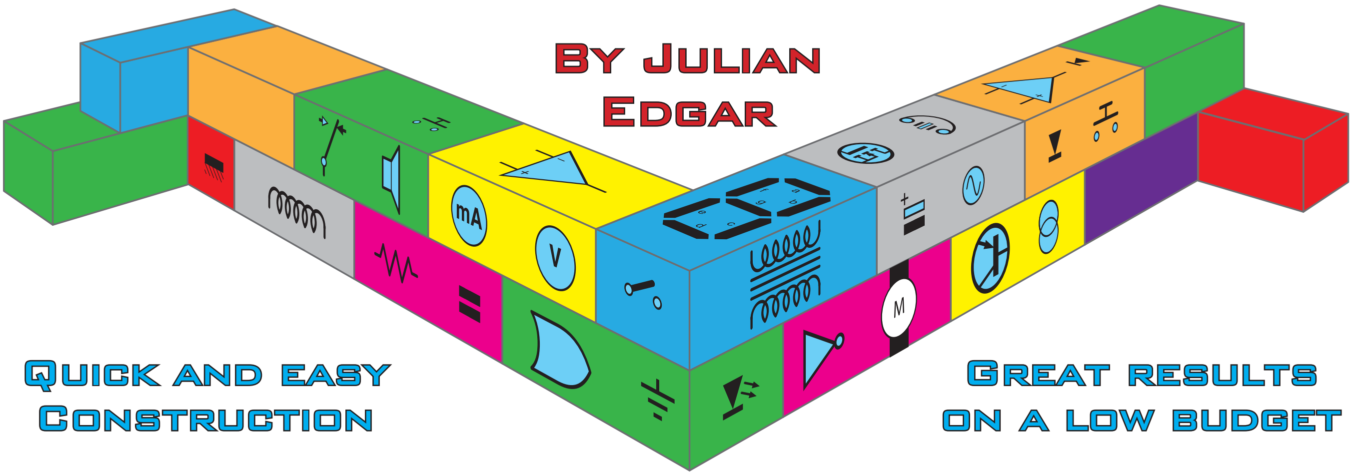

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Great results on a low budget

Versatile panel meter

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

Here is a really versatile and useful DC panel meter. Not only can it read DC voltages up to 75V, but also it can measure current (up to 10A) without an external shunt, and can calculate and display power and amp-hours. It also has user-settable over-voltage and over-current protection, among its six different protection modes. The meter is called the VAM7520P and it is available on eBay for about £18, including delivery. (At the time of writing, eBay items 222692173471 or 173626257710.) It's a highly capable design – but it also has one quite serious shortcoming… more on this in a moment.

This versatile panel meter can measure and display volts, amps, watts, hours and amp-hours. It can be powered by the supply it is measuring (from 10-75V) and cope with up to 10A current.

Flexible power options

The meter can be powered from the source it is measuring; this mode is called the 'two-wire' mode. Powered in this way, the meter is limited to reading and displaying voltages from 10-75V. As you'd expect, it needs at least 10V to operate in this mode. In so-called 'three-wire' mode, the meter is powered from an external source (12-60V DC), and the meter can then read down to 0V. The different modes are selected by an on-board jumper – 2W for two-wire and 3W for three-wire.

The rated current of the meter is 20A, but looking at the connectors and the size of the PCB tracks, I'd suggest that 10A is a more reasonable maximum.

Voltage monitoring

Let's start off with the simplest use you might make of a meter – monitoring a 12V load. This can be done in two-wire mode, so the jumper can be left in the '2W' position. Connect power and the load, and the meter will show on the upper LED display the supply voltage to one decimal place. The lower LED display will show 'OFF'. Press the 'OUT' button and the output is switched on, with current now shown on the lower display.

Voltage is indicated by 'U' (read that as 'V'!) and current by 'A'. By pressing the up and down arrows, each display can be cycled through voltage (U), power (P), current (A), capacity (C) and time (H). Time is shown in in hundredths of hours (ie 0.01 hours – not minutes), with the count starting after the meter was most recently powered-up. Capacity is shown in amp-hours, to 0.01AH. The maximum time able to be displayed is 99.9 hours, and the maximum capacity, 999AH.

Further modes

By pressing the OUT button for a few seconds, a second mode of functionality is enabled. The first two of these modes allow the voltage and current displays to be calibrated. (In my sample meter, both of these displays were accurate enough for everyday use.) The next mode is used to save the revised settings that you may have made, and the mode

One to put on the shopping list!

Here's a real bargain – the Tecsun GR-88 radio. And what a little radio it is!

Four things make the Tecsun impressive. First, the sound quality is fine from the little speaker, and the radio is easy to carry with its strap handle. Second, it's useable across all its bands – AM, FM, and SW1 and SW2. Those last two bands in a small and cheap radio is a rarity, but its good sensitivity and fine-tuning knob means it pulls in signals from literally thousands of kilometres away.

Third, it can be powered in multiple ways – external 4.5V source, internal AA cells or charge the supplied internal nickel-metal hydride battery pack by turning the power generator handle. Finally, the radio includes a white LED light. Like everything else about the design, it isn't flashy (oh, a pun) but it works well.

As an emergency radio – and at around £35 delivered – it's hard to beat. Check eBay.

The additional board on the rear of the meter incorporates an STP75NF75 MOSFET that controls the output. Unfortunately, the meter's over-current protection circuit is not quick enough to save the MOSFET when the output is short-circuited, so treat the over-current protection feature with care.

after that allows you to set whether the output is on or off when the meter is first powered-up. However, it is the next series of modes which are of greatest interest – they are protection modes.

The following protection modes can be set:

- Over-voltage
- Over-power
- Over-current
- Over-charging
- Over-time

Let's look at setting the over-voltage protection – the other modes work in a similar way. Press the OUT button for a few seconds, then press it repeatedly until the over-voltage setting mode ('OUP') is displayed on the upper LED. Press the UP and DOWN keys until the selected voltage is displayed on the lower LED. The setting can be a little fiddly as it is easy to overshoot. Once the correct voltage is selected, press the OUT key until '2-ES' is displayed, then select 'Y' (for yes) on the bottom display and press OUT again.

For example, let's say that we selected 17.0V as the voltage limit. If 17V input is exceeded, the output is turned off and the display shows 'AL' on the upper screen (for alarm), and 'OUP' for over-voltage protection. Either press the OUT button or disconnect power from the meter to reset the alarm – decreasing the input voltage won't reset it.

The other protection modes are set in a similar way.

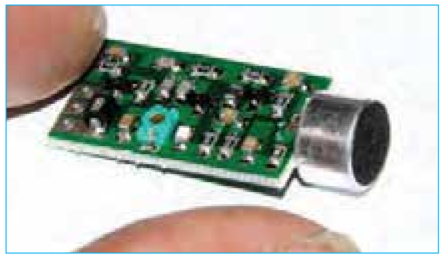
So, what is that shortcoming I mentioned at the beginning? Even if a current limit is set, the meter will not cope with the output being short-circuited! I deliberately did this (oh, to find out everything for you, the glorious reader!) and the STP75NF75 output MOSFET went up in a puff of smoke. After that, I could no longer switch the output off with the 'OUT' switch – it just stayed on all the time. However, the display modes continued to work – but I'd lost the turn-off protection functions.

It's a pity that the meter isn't able to protect itself against short circuits, but even so, it's still a very useful design. For charging batteries, for monitoring voltage and current up to quite high values without the need for an external power supply or shunt, and for displaying amp-hours and power, it works as advertised. It can even be used as a simple timer, switching off the output once the required time has elapsed. To see the meter's functions in more detail, do a search for 'VAM7520P pdf' and you'll find the full nine-page manual online.

A nice product – just make sure that you don't short-circuit the output!

Next month

In March 2019's *Electronic Building Blocks* we'll have some fun looking at 'amateur espionage' equipment!



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.

PROJECT TITLE	ORDER CODE	COST
MARCH '17		
Speech Timer for Contests & Debates	19111151	£16.42
APRIL '17		
Microwave Leakage Detector	04103161	£8.00
Arduino Multifunctional 24-bit Measuring Shield	04116011 }	£17.75
– RF Head Board	04116012 }	
Battery Pack Cell Balancer	11111151	£9.00
MAY '17		
The Micromite LCD BackPack	07102122	£11.25
Precision 230V/115V 50/60Hz Turntable Driver	04104161	£19.35
JUNE '17		
Ultrasonic Garage Parking Assistant	07102122	£10.45
Hotel Safe Alarm	03106161	£8.00
100dB Stereo LED Audio Level/VU Meter	01104161	£17.75
JULY '17		
Micromite-Based Super Clock	07102122	£10.45
Brownout Protector for Induction Motors	10107161	£12.90
AUG '17		
Micromite-Based Touch-screen Boat Computer with GPS	07102122	£10.45
Fridge/Freezer Alarm	03104161	£8.00
SEPT '17		
Compact 8-Digit Frequency Meter	04105161	£12.88
NOV '17		
50A Battery Charger Controller	11111161	£12.88
Micropower LED Flasher (45 × 47mm)	16109161	£8.00
(36 × 13mm)	16109162	£5.60
Phono Input Converter	01111161	£8.00
DEC '17		
Precision Voltage and Current Reference – Part 2	04110161	£15.35
JAN '18		
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Build the SC200 Amplifier Module	01108161	£12.88
FEB '18		
GPS-Syncronised Analogue Clock Driver	04202171	£12.88
High-Power DC Motor Speed Controller – Part 2		
– Control Board	11112161	£12.88
– Power Board	11112162	£15.30
MARCH '18		
Stationmaster – Main Board	09103171 }	£17.75
– Controller Board	09103172 }	
Build the SC200 Amplifier Module – Power Supply	01109111	£16.45
APRIL '18		
Spring Reverberation Unit	01104171	£15.30
DDS Sig Gen Lid	Black	£8.05
DDS Sig Gen Lid	Blue	£7.05
DDS Sig Gen Lid	Clear	£8.05
MAY '18		
High Performance RF Prescaler	04112162	£10.45
Micromite BackPack V2	07104171	£10.45
Microbridge	24104171	£5.60

PROJECT TITLE	ORDER CODE	COST
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High Performance 10-Octave Stereo Graphic Equaliser	01105171	£15.30
JULY '18		
Touchscreen Appliance Energy Meter – Part 1	04116061	£17.75
Automotive Sensor Modifier	05111161	£12.88
AUG '18		
Universal Temperature Alarm	03105161	£7.05
Power Supply For Battery-Operated Valve Radios	18108171 }	£27.50
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	18108173 }	
	18108174 }	
SEPT '18		
3-Way Active Crossover	01108171	£22.60
Ultra-low-voltage Mini LED Flasher	16110161	£5.60
OCT '18		
6GHz+ Touchscreen Frequency Counter	04110171	£12.88
Two 230VAC MainsTimers	10108161 }	£12.88
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NOV '18		
Super-7 AM Radio Receiver	06111171	£27.50
FEB '19		
1.5kW Induction Motor Speed Controller	10105122	£35.00

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.

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

Please check price and availability in the latest issue.
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.

EPE SOFTWARE

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

PCB MASTERS

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

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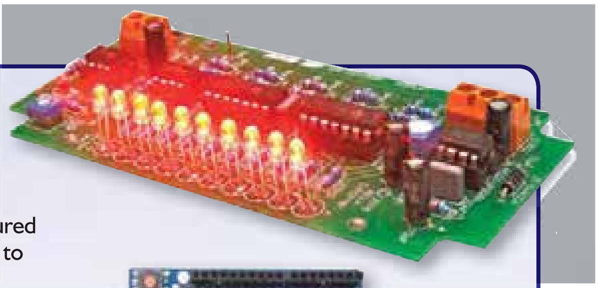
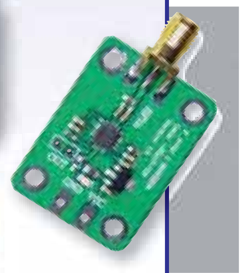
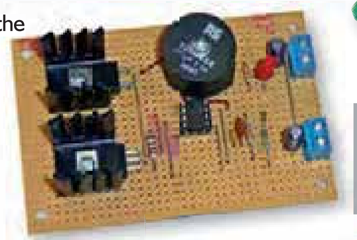
Next Month

Content may be subject to change







10-LED Bargraph

Want a really flexible bargraph? This 10-LED project will fill the bill. It can be configured for dot or bar mode, while for audio signal monitoring, extra circuitry can be added to provide for VU or for Peak Program Metering (PPM).

Earthquake Early Warning Alarm

Earthquakes can strike anywhere… and usually with very little warning. But now there are ways to receive an early warning, which may mean the difference between getting to safety and possible injury or death. So how do you get these earthquake early warnings? Find out next month!

Low-cost Electronic Modules – Part 14

Next month, we'll look at a nifty RF Detector module from Banggood that can measure the power of RF signals from 1MHz to 8GHz, over a range of 60dB using the AD8318 chip.

Teach-In 2019 – Part 4

In the March issue, we'll introduce switched-mode power supplies and our *Practical Project* will be a high-efficiency voltage booster that uses simple switching techniques.

MIDI Ultimate Synthesiser – Part 2

Following February's project introduction, next month we'll start construction with the power supply, VCOs, VCF and mixer. Lots to look forward to!

PLUS!

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

MARCH 2019 ISSUE ON SALE 7 FEBRUARY 2019

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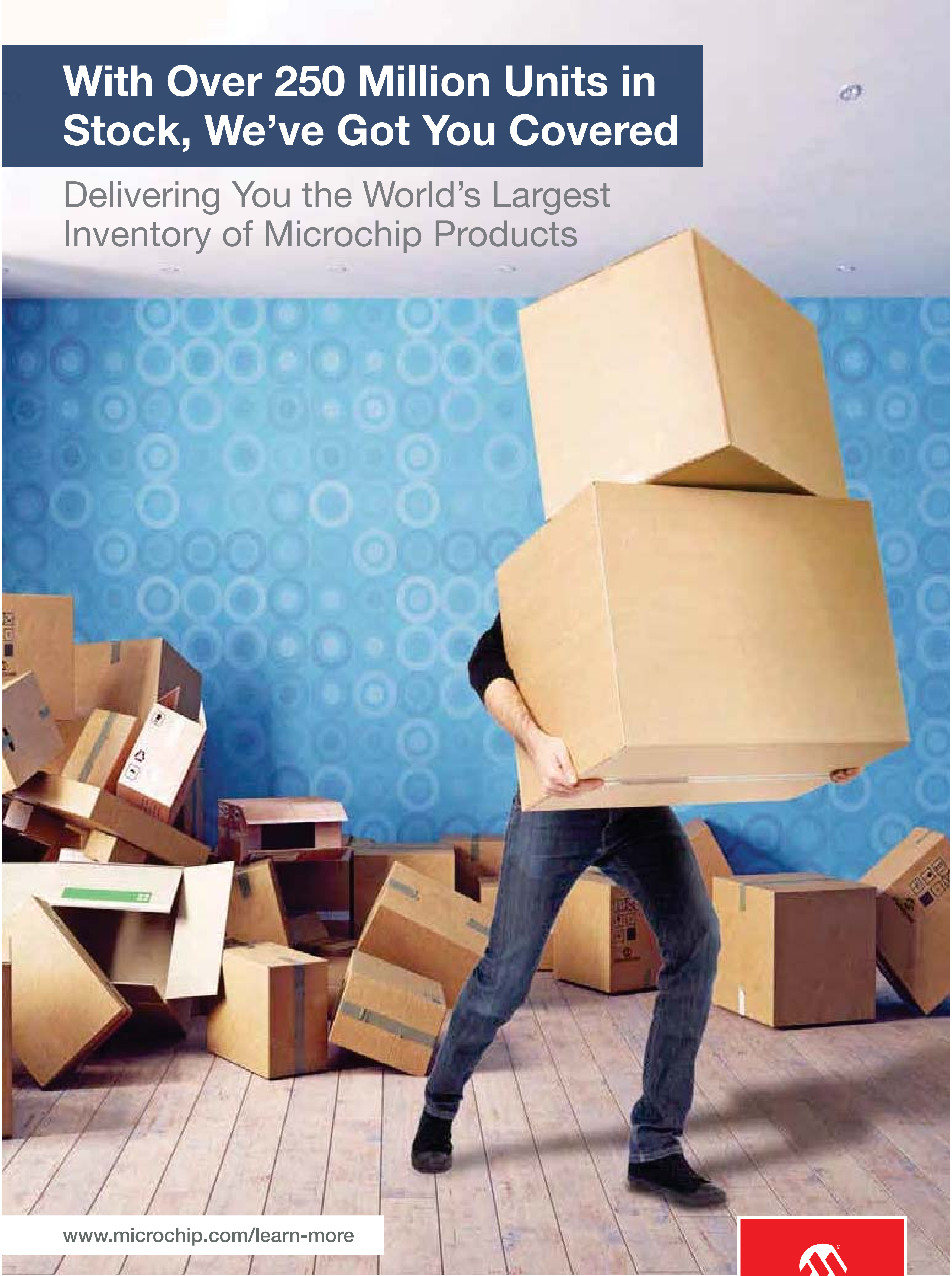

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