SILICON CHIP

MARCH 2020

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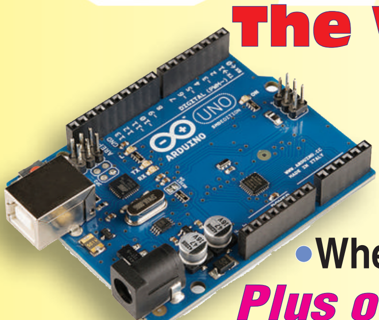

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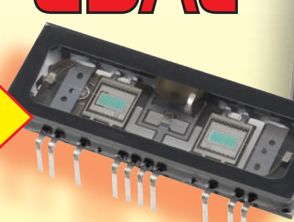

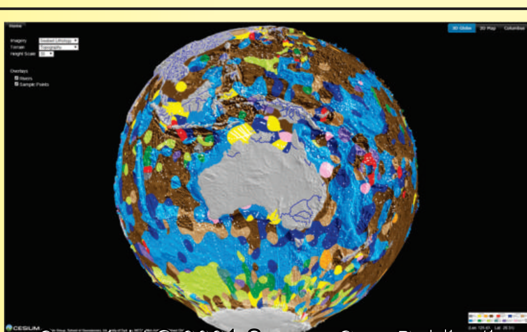

How DO they make today's maps?

DIGITAL CARTOGRAPHY

and Geographic Information Systems

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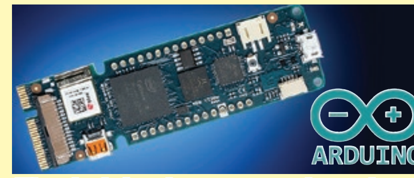

The Arduino has come a long, long way in just 15 years. With all its variants it's arguably the world's favourite micro platform – Page 14

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Modern ignition systems can develop way over 60kV making them very difficult to measure. If you work with ignition systems you need this new 1000:1 AC Ignition System Probe – Page 90

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Editorial Viewpoint

SILICON CHIP PDFs available soon!

We've been working hard to produce electronic versions of our SILICON CHIP back issues for many years now, and we've – finally – almost finished.

It has been a mammoth task reproducing all 390 issues – the total number of pages is close to 40,000 and growing every month!

The issues are all complete, except for some ads which appeared between August 1993 and August 2012. We decided that it isn't worth increasing the file size of these issues to include scans of the out-of-date ads.

For most issues from August 1993 onwards, we have also fixed any errors that we are aware of that appeared in the original magazines.

These issues will be available as high-resolution PDFs on high-quality metal USB3.0 flash drives labelled with the SILICON CHIP logo. You'll get either a 32GB or 64GB drive, depending on how many blocks of issues you order. You can print diagrams or instructions from these files, if you need hard copies.

See page 95 of this issue or visit siliconchip.com.au/shop/digital_pdfs for more details.

Purchasers will also receive perpetual online access to those same issues, so you won't even have to carry the files around with you. You'll be able to access them at any time by logging onto our website.

I think this will be a very attractive offer to anyone looking to 'downsize'. Perhaps you're moving into a smaller home, and you won't have anywhere to keep many years of SILICON CHIP issues arranged in binders. You can replace those with these PDFs, which take up virtually no space, and still have access to the content when you need it.

These are also an excellent option for anyone who's discovered SILICON CHIP in the last few years, as you will be able to get the issues you've missed. You might be surprised how interesting some of the older issues are, and many of our past projects are still perfectly valid today.

We're also planning to make PDF downloads available to online subscribers via our website soon. These will be made available to anyone who has already purchased online issues or online subscriptions. We may have to roll out the PDF downloads gradually, so our servers aren't overloaded. This should happen within the next few months.

Meet us at the Jaycar maker hub

SILICON CHIP will be celebrating **Arduino day, Saturday 21st March**, at the Jaycar maker hub at Central Park Mall on Broadway, Sydney (near Central Station). You can come and ask us questions, get help with an Arduino project or attend a workshop. We'll also be helping people to try to fix broken Arduino boards (see the article on page 61), and there are special offers from Jaycar to purchase Arduino-based kits (we can even help you build them!).

Due to its location, the maker hub is very accessible from just about anywhere in Sydney. Just hop on a train or a bus going to Central, and it's a short walk from there to the Central Park Mall.

You may have seen our article on the Jaycar maker hub in the August 2019 issue. This concept store is well worth a visit, designed for the hobbyist "maker" market but just as applicable if you're involved with electronics at any level. Apart from its great views(!) this "full range" store is also set up for workshops, demonstrations and other tinkering. If you haven't been there before, March 21 would be a good time to see the Jaycar maker hub for yourself!

For more details, see page 37 in this issue.

Nicholas Vinen

Letters and emails should contain complete name, address and daytime phone number. Letters to the Editor are submitted on the condition that Silicon Chip Publications Pty Ltd may edit and has the right to reproduce in electronic form and communicate these letters. This also applies to submissions to "Ask Silicon Chip", "Circuit Notebook" and "Serviceman".

Enhanced HF Preamplifier request

I find the Tunable HF Preamplifier design (January 2020; siliconchip.com.au/Article/12219) to be good, but I think it should have the following enhancements:

- remote control via computer
- 10kHz-30MHz range
- upconversion with a programmable local oscillator frequency (in 1kHz or finer steps) to suit SDR dongles at a given IF frequency
- programmable AGC
- preselector tuning (with one or two varactor diodes)
- RF ranges.

With these enhancements, this unit would be good to use with Cat5/6 network cable with two pairs used for data for remote control, one pair used for a reference oscillator used by the local oscillator and one pair used for upconverted RF and power.

Additionally, a second RF amplifier after the upconverter stage to drive the network cable should ideally be used, and the control program should also store and retrieve constants for preselector tuning along with constants for automatic slope (tilt) control for the RF amplifier and the network cable driver where these constants are all based on frequency and RF range.

Bryce Cherry,
via email.

Response: we put this to the designer, Charles Kosina, and his response was similar to our thoughts. What you are asking for is a completely new design which would require a vastly more complex circuit, a much larger PCB and it would cost many times more to build.

It would be possible to use relays to switch between several different ranges and use varicaps to tune in a particular frequency, like what we did with our Super-9 FM radio design in the November 2019 issue. Mr Kosina does not have the time or resources to produce such a design, so we will have to see if anyone else is interested in doing it.

Saleae Logic 8 available at half price

In the February 2020 article on low-cost USB logic analysers, you mention that the Saleae products Logic 8 costs A$639. However, Saleae also sell this to enthusiasts for US$199, which is around A$300. That is not that much more than the original Saleae logic analyser. I too bought one of these when they were first released. A great bit of kit, and beautifully made with their CNC machined case.

You can see the available discounts at the following website: https://blog.saleae.com/saleae-discounts/

John Bell,
Mt Macedon, Vic.

A custom version of the Super-9 FM radio

I liked John Clarke's Super-9 FM radio design (November & December 2019; siliconchip.com.au/Series/340). But I wanted to put it into a smaller box, rather than use the laser-cut acrylic case you designed. So I re-laid the PCB to be smaller. It works fine and was straightforward to put together. I used bare PCB laminate for the shields to save money. I'm still working on the case.

Phil Prosser,
Prospect, SA.

WA government taking action over mains Neutral failures

In the Mailbag section of your October 2019 issue, you published a reply of mine titled "Tingles should not be ignored". This was in response to a previous Mailbag item in August 2019 by Howard Maddaford of Wanneroo, WA. Howard mentioned he was receiving tingles from bathroom taps.

The Government of Western Australia has recently announced (January 2020) a public safety campaign regarding this very topic. Here is a quote from the announcement:

"A new public safety campaign is urging Western Australians to take potentially life-saving action by immediately reporting any electric shocks or tingles to their electrical network operator. The three-month campaign, launched today, is a collaboration between the State Government's Building and Energy team and network operators Western Power and Horizon Power."

They also mention using a "smart meter" to detect degrading neutral connections, and I quote:

"The State Government is also working with Western Power on the roll-out of an advanced form of meter that can remotely detect degrading neutral connections. Horizon Power has already fitted the so-called 'smart meters' at its customers' homes and businesses in regional Western Australia. The advanced meters can detect changes in the neutral resistance within a circuit and send an alert signal to the network operator."

The full article can be found at: siliconchip.com.au/link/ab0k

Allan Doust,
Erskine, WA.

Android 10 has broken USB audio support

Years ago, when you published the PCM2902-based USB Stereo Recording & Playback Interface (June 2011;


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siliconchip.com.au/Article/1036), I built it, and it worked like a charm. I have successfully used it with my PC and with Android devices using a USB OTG cable.

But after downloading the latest Android 10 software updates, it refuses to work. The USB audio CODEC is detected, but then I get a "device failed to start" message, and it just won't work. I also have a Digitech interface that I bought from Jaycar, which I think is based on the same chip. The power LED comes on, but the same thing happens.

I checked the bus voltage. It drops a little when the Interface is plugged in, but stays between 5.0V and 5.5V the whole time. I also have two other interfaces, the Zoom H5 and the Focusrite 18i8; these still work.

I am an experienced analog hobbyist but pretty hazy on digital and find USB theory of operation quite difficult to understand. What do you think is going on here? I tried contacting the software developer for the apps I use to record on my Galaxy S10, namely "USB audio recorder PRO" and "Audio evolution mobile" (both from the same developer), but he didn't really have a solution.

He suggested that given both PCM2902 units are bus-powered whereas my working ones are battery or DC-adaptor powered, that perhaps there is something about how the latest incarnation of Android 10 interacts with peripherals. But really, I don't know if that is the answer. I am stumped.

I wonder if anyone else has had the same problem. I know the magnificent PCM2902 is used in a few of your projects!

Jonathan Dent,
Gosford, NSW.

Response: this seems like a driver 'regression' in Android 10, breaking functionality that previously worked. We doubt it has to do with the power supply; more likely, it is a protocol error.

You should report an Android bug via the following web page: source.android.com/setup/contribute/report-bugs

DAB+ sound quality is inferior

Alan Hughes (Mailbag, January 2020 p4) must have a tin ear to advocate replacing AM and FM analog transmissions with DAB+. After several years of putting up with the inferior sound quality of digital radio, I have reverted to analog.

I accept that, from an engineering perspective, DAB+ quality can equal analog. However, we no longer live in an engineering managed world, but one where accountants squeeze as hard as they can get away with.

In the AM and FM worlds, bandwidth is fixed, and a wide bandwidth AM receiver can still deliver excellent sound. In the DAB+ world, you can transmit more channels by reducing bandwidth, and this is what has happened.

Mark Baker,
South Perth, WA.

Why is swapping Active & Neutral bad?

In the February 2020 issue, in the Mailbag section on page six, Graham Street says he has an older double adaptor which transposes the Active and Neutral connections. He claims this is not safe. I wonder why.

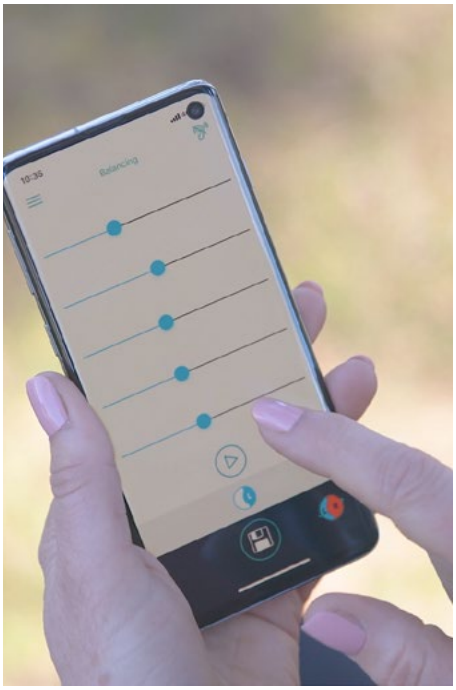
I grew up in Germany and the power plugs there can be inserted either way; there is no "key" to make sure that the Active is always on the same pin of the plug and it really is no problem. In fact, it was very handy to have this. As a service technician there, I worked on lots of 'hot chassis' TVs; there actually weren't any that were not!

Standard procedure was to check if the chassis was live using the touch-and-feel-a-tingle method. If you got a tingle, you just turned the mains plug and bingo, it was OK to work on. Come to think of it, there are many places where power plugs can be inserted either way. So, what is the point? And why might it be dangerous?

Horst Leykam,
Dee Why, NSW.

Response: your own letter suggests the reason why this is discouraged; an appliance with bad insulation could be safe with the plug inserted one way around. Then one day, if the plug was reversed, it could become live. We're pretty sure that modern OH&S folks would frown on your touch-and-feel-a-tingle method! You may not have been electrocuted by doing this but were you just lucky?

In countries with reversible mains plugs, it is good practice to fit appliances with double-pole on/off switches to ensure that the incoming Active line is always cut with the switch off, regardless of the plug orientation. This is also a good idea in Australia, but it



is not required as (assuming no wiring faults) it is known which mains conductor is Active.

Programming Uno board with WiFi

I've just read the letter in the Ask Silicon Chip section of January 2020 (on page 108) titled "Advice on programming ESP8266 boards". I have the following advice to offer.

I purchased one of Jaycar's Uno with WiFi boards (Cat XC4411) in mid-November 2019. After much toing and fro-ing with Jaycar, I found that the sample source code that they provided on their website for this board contained some errors. Eventually, they supplied me with a version with the problems fixed. Hopefully, they also updated the source code on their website.

Uploading code to the "Uno with WiFi" is not as straightforward as with a regular Arduino Uno. Each piece of source code has to be compiled and uploaded separately with the appropriate DIP switches set on the PCB. It is **critical** to follow the instructions in their manual, at: **siliconchip.com.au/link/aaz3**

Additionally, before the ESP8266 code can be compiled and uploaded, it is necessary to configure the Arduino IDE according to the instructions contained within the file "instructions_troubleshooting.txt" which is within the softwareMain.zip file from Jaycar. You must reconfigure the IDE when compiling for the ESP8266 and the Uno.

I purchased my Uno with WiFi to query my Fronius inverter and display the current AC Power output on an 8-digit, 7-segment LED. I am planning on updating the code to display some extra data using an LCD and Altronics Cat K9675 (Inventa Mega Stand for Arduino). I have also programmed some standalone ESP8266 boards to perform simple network-only tasks.

I am using version 1.8.10 of the Arduino IDE on a Windows 10 64-bit PC. I have also used the IDE on my iMac (macOS 10.15.2) with success.

Walter Hill,
Mount Pleasant, WA.

Are hybrid vehicles worthwhile?

Thanks for Roderick Wall's terrific article on the Toyota Hybrid system and the Power Split Device arrangement (December 2019; **siliconchip.com.au/Article/12172**). A lot of research has gone into the best explanation of this system I have seen.

I have some comments on your Editorial in the same issue, also on the topic of Toyota hybrid vehicles. While I generally agree about Toyota reliability over the years (we had a Toyota Corona for many years; it was almost immortal), they have had their problems, like all manufacturers. From my perspective, there are a couple of other Japanese brands that are equally reliable.

But I am not totally convinced about the innovation aspect, as the Atkinson Cycle engine referred to is a very old design (initially from 1882, with many variations since).

While initially seen exclusively in hybrid electric applications such as the earlier-generation Toyota Prius, later hybrids and some non-hybrid vehicles now feature engines with variable valve timing. They can run in the Atkinson cycle as a part-time operating regimen, giving good economy but also plenty of power when running as a conventional Otto Cycle engine.

I would have thought that for a hybrid, where saving weight is so critical, using a smaller Otto Cycle engine would be better than an Atkinson cycle engine.

Also, in many cases, the cost of a hybrid or EV is considerably more than an ICE-powered equivalent, and the fuel saving is relatively small, so the car is not likely to last long enough to achieve a financial advantage.

Many cost/benefit analyses do not take into account battery replacement/disposal costs, environmental impacts from battery manufacturing, recycling and disposal and so on.

I am unconvinced that we have the electricity infrastructure to permit large-scale charging of millions of EVs and plug-in hybrids. There is no doubt that battery technology is improving. I am optimistic that we will see those sorts of improvements in the automotive environment also, and that will make hybrids and EVs more useful, and maybe less costly and thus more of an economic proposition.

Ranald Grant,
Brisbane, Qld.

Comment: some Toyota hybrids cost around $5000 more than the petrol version (eg, the Corolla). For someone who drives say 15,000km/year and saves 3L/100km, with petrol at around $1.40/L, that's an annual saving of about $630. Factor in reduced brake wear and the break-even time is around six or seven years, which isn't too bad. Some people may reach it sooner.

Consider that hybrids aren't just cheaper to run; they have other advantages such as increased range. Of course, taxis are driven a lot more than regular cars which is why so many of them are now hybrids; for them, the advantages are huge. Yes, battery replacement/recycling is a concern but the Toyota hybrid batteries last well, and are quite small, so they are not that expensive to replace.

In summary, hybrids aren't for everyone, but the price premium has come down enough that they are starting to make sense. The widespread adoption of EVs is a different problem and one which may prove to be more difficult to overcome than the large-scale manufacture of hybrids.

Positive experiences with hybrid Toyota Camry

After reading your article on the subject in the December issue, I'd like to comment on the Toyota hybrid system. I bought my first hybrid Camry in 2011. It was a little over a year old, had been driven by the State Govt. and had travelled 63,000km. I was impressed with how quiet and responsive it was, and felt it was a good replacement for my Mitsubishi 380.

The Camry was the first car I can remember that could achieve its rated fuel consumption of 6L/100km, and over the seven years I kept it, it gradually improved to about 5.5L/100km. Even heavy traffic has little effect on this. Unlike some stop/start engine designs that I'd tried, the engine start was only really noticeable when stationary as a mild vibration.

It did take me a little while to adjust to it, as it is designed to continue rolling with no throttle, rather than exhibit engine braking. The transmission does allow it to simulate engine braking, but the effect is really no different to lightly applying the brakes. The hydraulic brakes see little use and the originals still had 70-80% pad thickness at 140,000km.

I did initially worry about battery life, but apparently, the failure rate is far less than 1%. I assume this reliability is related to the fact that the system never fully charges or discharges the battery. The only engine drive belt is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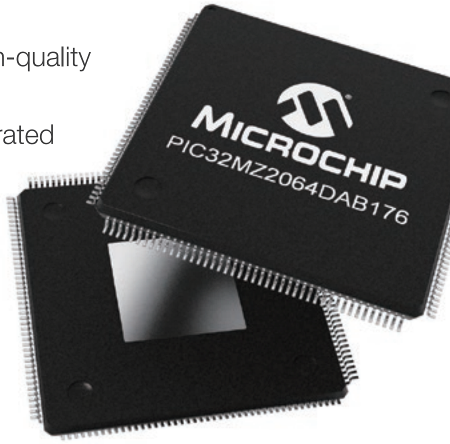
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for the water pump; power steering and air conditioning are fully electric.

In 2018, I ordered a new version; until then, the model changes hardly seemed worth the bother. The new Camry has advanced safety features across the entire range (including lane-keeping assistance and radar cruise control) and comes close to its 4.2L/100km rating.

However, its fuel consumption is more dependent on conditions. Traffic and short trips are definitely worse, while highway driving at 60-100km/h can return figures as low as 3.2L/100km. The batteries are now under the rear seat (they're still NiMH types) and that results in a very large boot.

My only gripe is that the engine noise is harsher, possibly due to a direct-injection design, but it's not the sort of thing you would normally notice. The Toyota hybrid engines have about 20 years of experience and have weathered the years well over numerous variations.

Some people may be confused by the description of an electronic CVT. It has nothing to do with the dual cone CVTs common to many small cars these days; as described in the article, it is an electronically controlled planetary gear system. It works smoothly and without any noticeable gear changes. The latest model has even done away with a drive belt for the water pump.

I have no affiliation to Toyota, I've just been very impressed with the design. The price differential between the conventional automatic vehicles and hybrids has fallen considerably. So if you're tempted, I'd say go ahead and try one.

Graham P. Jackman,
Melbourne, Vic.

RCDs don't prevent fires

I found your article on bad quality electrical and electronic stuff in the December 2019 issue interesting (siliconchip.com.au/Article/12169). I have been repairing mains-powered valve radios since the sixties, although I have since diversified and am currently repairing the farm tractor (head gasket failure plus cumulative minor repairs).

I do a bit of tagging and testing of the radios. I am also a member of the local Men's Shed, and it is incredible how much of the stuff that is donated in 'good faith' is non-compliant (much of it has "been in dad's shed" for decades, before he fell off the perch). One cable with a three-pin plug and socket turned out to use two-wire recycled vacuum cleaner cable!

That article reminded me of something I mentioned to the local fire brigade; I have seen many power boards made of substandard material, where switches have burnt, and more than one that melted at around 8A when it was rated at 10A. I also have trepidation as to the true rating of many of the circuit breakers.

Perhaps there is scope for getting a few of these boards, loading them to their ratings and see which ones survive. On face value, we seem to have lost the plot when it comes to electrical quality and regulations with regards to goods coming into the country.

I had to return two LED floodlights to a large electronic supermarket, as they generated just as much non-compliant RFI as the (overseas-built) wireless NBN system here.

Something many people do not realise about fused and RCD protected circuits is that if there is virtually no protection against a fault on the load side of an isolating transformer (as opposed to an auto-transformer). Unless this fault also overloads the primary and blows the thermal/mains fuse, the transformer will continue to deliver power into the faulting circuit.

Even with an autotransformer delivering less than about 130V AC, a 30mA RCD will often not trip when the output is shorted. I have seen recently two radios melt the transformer to the point where it nearly caught fire. This happened because there was no primary overload thermal fuse or Earth leakage breaker.

Older transformers (eg, from the 30s) supposedly were designed not to support combustion. The worst offenders I've seen are from the late 80s and early 90s.

In two cases, the secondary windings on stick welders went to frame ground. This resulted in no primary overload or Earth leakage on the primary side, so this didn't trip the RCD. One welder fused the Earth wire in its cable, but the household RCDs and breakers held.

The other was a little more destructive, as its mains Earth was clearly substandard. It was Earthed via a vintage metal lamp mounted on a metal wall. As it was an 8A cable, it melted the light cable all the way from the fuse box and destroyed it as well.

The photo at left is of a Thorn RG106 Stereogram that I had to fix. Proving my previous point, it had a 5A fuse; the holder had to be replaced as hot metal damaged it, but the fuse was intact! I deliberately Earth leakage tested the primary, and there was no problem on that side.

This happened because an output tube shorted. That upset the notoriously unreliable metal rectifier, and then the smoke escaped. It was lucky that the owner was around when it did this; it could have easily started a fire.

I added small 100Ω resistors in series with the secondary of the replacement mains transformer. These reduce surge currents, drop a little voltage and should fuse if a similar fault happens.

I guess my point is that one should not blithely assume that safety devices like RCDs will protect you from fires in faulty equipment!

Marc Chick,
Wangaratta, Vic.

Response: You're right that an RCD will only trip when there is a path from Active or Neutral to Earth. Once the power has gone through a galvanic isolation device like a transformer, any amount of current can flow to Earth and it will not trip the RCD. After all, current flow in the transformer supporting this is between Active and Neutral (indistinguishable from normal current flow from the supply point of view).

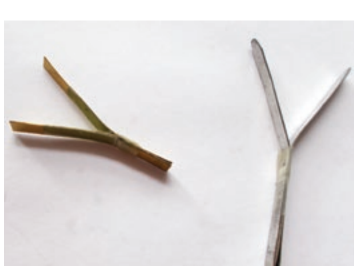
As you suggest, the only real protection against an electronic device starting a fire is a fuse (thermal or current limiting), but depending on how much current the device can draw and the size of the fuse, it may be able to generate enough heat to start a fire without blowing the fuse.

Toroidal transformers and capacitor input power supplies make fuse selection especially tricky, since you usually have to select a much higher fuse value than you might expect to avoid nuisance tripping due to the high inrush current. It may therefore fail to blow in the case of a serious fault on the secondary side.

Simple battery connectors are useful

After reading the letter from Joe Edgecombe on page 7 of the January 2020 issue, it would appear that he and I had similar ideas. The photo below shows a pair of battery/cell Y-adaptors I made in the late 70s. I made the first pair from brass, then misplaced them (that really brassed me off!), so I made a replacement pair from tin-plate.

They were insulated using sticky tape and held together with another piece of tape. I used alligator clip leads to connect these inexpensive and most useful tools to my multimeter leads.



Ray Smith,
Hoppers Crossing, Vic.

An Arduino

The Arduino microcontroller platform has been widely embraced by both young and old as an easy way to prototype digital electronics. The Arduino ecosystem has grown to be both extraordinarily popular and incredibly diverse. Tim Blythman explains where Arduino came from and where it is headed.

While strictly the name of a company which owns the 'Arduino' name and trademark, in practice, the term Arduino is used to describe the open-source hardware and software for which Arduino is known. There is a vast community of people spread around the world who have helped make Arduino what it is today.

Believe it or not, the name "Arduino" actually comes from a bar in the Italian town of Ivrea; the bar, in turn, appears to be named after an Italian king, Arduin, from over 1000 years ago!

The official Arduino website is at www.arduino.cc/

Before reading further, you might like to glance at our Arduino Jargon Guide panel.

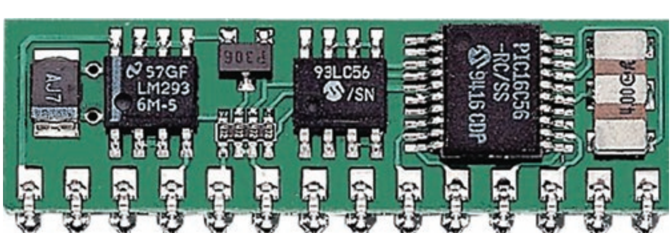
History

The first inklings of what we now know as Arduino began around 2003, at the IDII (Interaction Design Institute Ivrea) in Italy, under a project called Wiring. Wiring was intended to allow design students at the Institute to create digital electronics projects, despite not having an engineering background.

Part of the goal of the Wiring project was to find a cheaper alternative to the BASIC Stamp microcontroller.

We published an article on the BASIC Stamp back in January 1999 – see siliconchip.com.au/Article/4630 It is a small PCB fitted with a microcontroller and EEPROM. It has a SIL (single in-line) header and can be plugged into a breadboard. Back then, it cost around $80 and required an extra $20 programming cable.

The town of Ivrea is crossed by the Via Arduino. It is not far from Turin, where the early Arduino boards were manufactured. In 2018, Ivrea was declared a UNESCO World Heritage Site and an Industrial City of the 20th Century.



The BASIC Stamp was remarkable for its time, but it required a separate programming cable. The compiler and bootloader are proprietary, meaning it was difficult for third parties to create and develop tools for it. It has now been genuinely eclipsed by systems like the Arduino and Micromite.

PC software was needed to compile and upload a BASIC program (up to 100 lines long) via the programming cable. A separate editor program was needed to write the code.

The Wiring concept consisted of a microcontroller board and an IDE (integrated development environment) based on the Processing language. The IDE would combine the editor, compiler and uploader into one program.

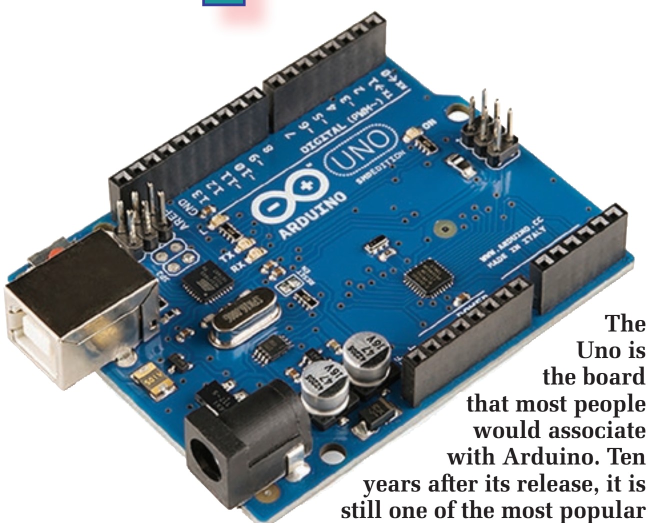
The Processing language is intended to allow people who are not familiar with programming to create graphi-

Retrospective

cal software. We used the Processing language to create patterns for our Stackable Christmas Tree in December 2018 (siliconchip.com.au/Article/11333).

One vital element which set Wiring apart from other platforms was to be open-source from the start. This allowed people to take the original idea, develop it further and put their own twist on it.

The Arduino platform is thus a 'fork' of Wiring. In fact, Wiring still exists and can even be used to program an Arduino Uno. The software and hardware designs can be downloaded from http://wiring.org.co/download/



The Uno is the board that most people would associate with Arduino. Ten years after its release, it is still one of the most popular boards, along with its numerous clones and variants. Its ubiquity is no doubt enhanced by the fact that it is an open-source hardware design. Source: Sparkfun Electronics.

The clear advantages of the Arduino platform over the BASIC Stamp, apart from cost, include:

- not requiring an external programming cable or separate editor software;
- allowing considerably more complex programs to be created;
- better performance; and
- more features.

Hardware evolution

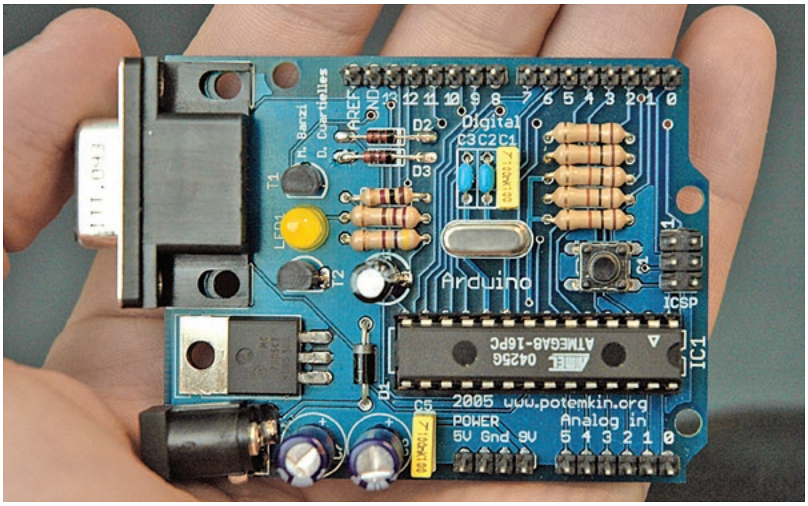
When the name Arduino comes up, most people would immediately think of the Uno board. A board which looked a little like the Uno first appeared around 2005.

A few years after that, a board called the "Arduino Serial" appeared. Practically all of the familiar Arduino pins are present in that layout, although PC communication is via a DE-9 multi-pin serial connector instead of the later USB port. Interestingly, the order of the ADC-capable pins is reversed, compared to current boards.

The DE-9 serial connector is not capable of supplying any useful amount of power, so an external power supply feeding the DC jack (or other pins on the board) was needed.

These earlier variants used an ATmega8 microcontroller. This is pin-compatible with the ATmega328 used in the Uno, although features such as PWM are missing from some pins. The ATMega8 also has less flash memory, EEPROM and RAM than its successor.

The design files for that version of the Arduino Serial are still available, so it can be made at home, if you have the facilities to make a single-sided PCB. The files are available at: siliconchip.com.au/link/aaxq

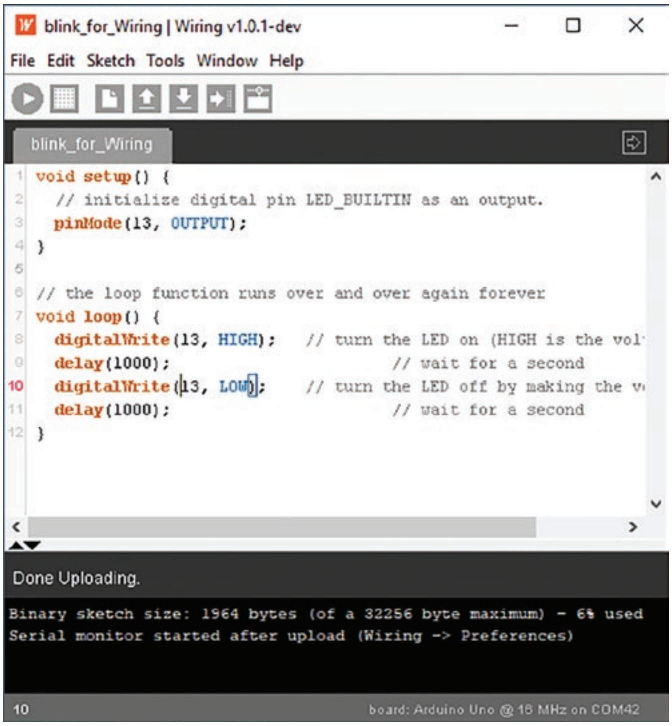


The Arduino Serial looks a lot like an Uno board but lacks the USB socket. The processor is an 8KB ATmega8 rather than the 32KB ATmega328. Curiously, its analog pins are in a different order from the Uno.

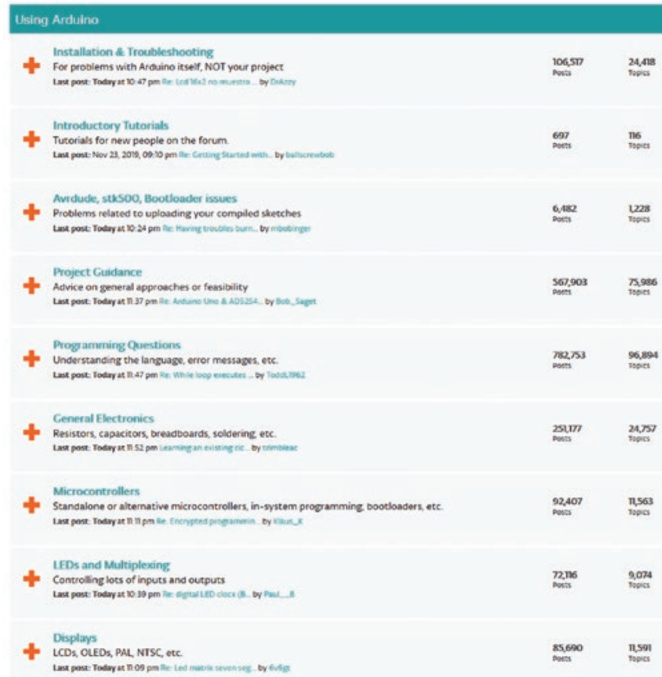
The Duemilanove (Italian for "2009") came not long after. It looks very much like the Uno. In fact, it is practically interchangeable with the Uno in most cases, having the familiar USB connector and the now-standard ATmega328 processor, although variants with an ATmega168 also exist.

As this board could be programmed and powered over USB, it was now possible for a beginner to program a microcontroller with no extra parts.

The following year saw the release of the



The Wiring IDE is almost but not quite the same as that for the Arduino IDE. Both can program the Uno; the Wiring IDE also supports a variety of other boards.



The Arduino forum has had over one million posts on over 200,000 topics dating back nearly ten years. Many of the people who have contributed to the Arduino software and IDE are on the forum answering questions. See: https://forum.arduino.cc/

Uno board and subsequently, in 2011, the first official release (version 1.0) of the Arduino IDE.

Nearly ten years later, the Uno (and its clones) are still among the most popular boards to be used with the Arduino IDE.

Software support

The code used to program an original Wiring board would probably be indistinguishable from that used to program any other Arduino board nowadays. It is the development of the IDE that has spurred the Arduino phenomenon the most.

The IDE hides a lot of the 'difficult' side of microcontroller programming. Features such as port and pin allocations and device-specific quirks are hidden away, so that inexperienced users do not have to worry about them.

This also means that boards with different processors (such as the Uno and Leonardo) can be used almost interchangeably. It is probably the areas in which they differ which are the greatest source of frustration for beginners!

Some people might complain that this abstraction hides a lot of what really goes on behind the scenes, and also reduces performance. But these are probably not the people that would get the most from using the Arduino IDE.

In any case, the features which are available through the IDE are fairly broad and suit a great many applications.

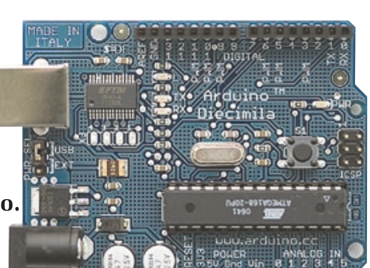
We'll get into more detail about this shortly, but Arduino has grown well beyond its original hardware and is no longer restricted to Atmel AVR-based microcontrollers. Hence, newer versions of the IDE have a Boards Manager and a Library Manager, making it much easier to target diverse hardware and accessories.

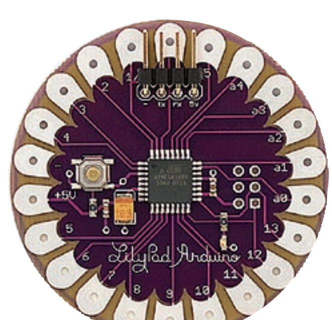
The open-source community

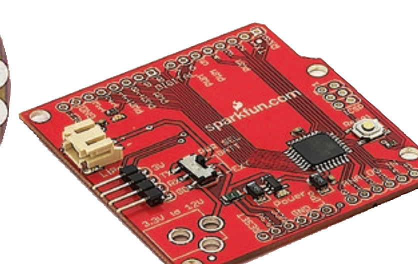
While the software and hardware behind Arduino are very tangible, there are some intangibles which have boosted its success. A large part of this is the massive community which does all sorts of things, from developing libraries to answering questions on the forums and more.

The Arduino forum is a great example of this. A web search relating to a specific Arduino problem will most often locate a forum post about someone else having the same problem many years ago (and hopefully, a solution!).

In 2008, Ocean Controls introduced the Diecimila USB, Skinny Board and Lilypad. This was probably the first time that many SILICON CHIP readers became aware of the Arduino. Ocean Controls continues to stock many SparkFun-branded Arduino-compatible products, plus some genuine Arduino boards.







Arduino jargon dictionary

Much of the language used when describing Arduino designs comes from the electronics community and C/C++ programming. Still, there are some other terms which are unique to the Arduino world. Here is an explanation of some of those.

analogWrite(): A function which configures a pin to deliver a PWM waveform. While not a true analog output on most boards, it has a similar outcome when applied to a motor or LED. PWM signals can be fed through a low-pass filter to more closely approximate an analog output. Some later boards have true analog (DAC) outputs.

Board: Usually used to describe a PCB fitted with a specific microcontroller and support components, plus a well-defined I/O pinout matching some reference design. Sometimes may refer to a bare microcontroller on a breadboard.

Core: A core is the set of files needed to support a family of Boards (see above), and can be added to the Arduino IDE via the Boards Manager. It usually includes a compiler, I/O pin profiles and a tool to upload to those Boards.

digitalRead(): This function returns the logic level on a digital input pin.

digitalWrite(): A function which sets a given digital pin to a logic value (0=LOW, 1=HIGH).

Library: A collection of files which provide extra functions to a sketch, by defining functions and other features. Often they are written to work with a Board's specific features and may form part of the Core.

MKR: The MKR series of Arduino boards have a standard form factor that is well-suited to breadboards. Most of these use 3.3V I/O signalling levels and have an ARM processor, which helps to differentiate them from the older 5V R3 AVR-based boards. Several MKR form-factor shields also exist.

Nano: A smaller, more breadboard-friendly form factor than the Uno. This includes the original Nano, the Nano Every and the Nano 33 series.

R3: The R3 form factor describes the most common Uno boards. This includes 32 pin sockets, of which 20 provide I/O functions. The most significant change since the R2 is that the hardware I^2C pins are duplicated at a fixed location, independent of the I/O pins to which they map. Many clone shields do not follow the R3 form factor and may not work as intended with boards other than the Uno. Mega R3 and Leonardo R3 boards are generally compatible.

Serial Monitor: A basic serial terminal utility built into the Arduino IDE, which can be used for debugging, displaying program output or sending data to the attached device.

Serial Plotter: The Serial Plotter in the IDE receives serial data from the Arduino as numeric values separated by commas (as though it were CSV data), and displays it as a plotted graph with coloured traces.

Sketch: The Arduino name for what many people would term a program. It derives from the Processing language's graphic design background and its use among artists and designers, similar to the notion of a drawn sketch.

Uno: The Italian word for "One" and the name of one of the most popular Arduino based boards; you may even hear the word "Arduino" used to refer to the Uno. It has an ATmega328 IC with 20 I/O pins.

Upload: This describes the process of transferring a program from a computer to the target board after compiling. This is typically done via a USB-serial device, although some boards support Bluetooth or WiFi.

Verify: Unlike other microcontroller platforms, where this term usually means to check that the program uploaded to the target board matches that stored on the host computer, the verification process under Arduino simply checks that the sketch compiles correctly.

The forum can be found at: https://forum.arduino.cc/

There are any number of tutorials and how-to guides on it. There's a good chance that, if you have an idea, somebody has already attempted it and posted about it on the forums.

The Arduino hardware and software is not so different from that of the BASIC Stamp, PICAXE or even the Micromite. But one major distinction is the open-source nature of Arduino. See our panel for more about how open-source works and why it has had such a large effect.

Arduino and Silicon Chip

We first made mention of an Arduino-compatible board in 2008, when a Diecimila ("10,000" in Italian) board appeared in Product Showcase, courtesy of Ocean Controls. Not long after this, readers started reporting their experiences with Arduino via letters in the Mailbag section.

The January 2012 issue saw a detailed review of the Arduino platform and its associated hardware (siliconchip.com.au/Article/806).

We now have over 600 articles that mention Arduino in some form or another, including dozens of projects that either use an Arduino board, or are designed to work with one.

There is still a continuous stream of new Arduino hardware rolling out. Last year, we reviewed three new Arduino main boards. We covered the MKR Vidor 4000 in March (siliconchip.com.au/Article/11448) and two Nano variants in October (siliconchip.com.au/Article/12015). The IDE software is also continually being updated.

Those boards are 'official' Arduino releases, but many other shields and modules are also being released, and a great many third party boards are being created, too. There is even work going on to allow other microcontroller boards to be used with the Arduino IDE, as well as several different IDE variants to cater for different users.

The Boards Manager

As mentioned above, the original Arduino boards were based on Atmel AVR microcontrollers. The Due changed this, bringing a 32-bit ARM processor to the Arduino world. This required changes to the IDE, to support different compilers and uploaders.

Incidentally, Due means "two'" in Italian; a clear indication that this was something different to the Uno ("one").

While the open-source nature of the IDE allows people

The Altronics K9660 TFT Touchscreen Maker Plate uses the same 32-bit SAM3X8E ARM CPU as used in the Arduino Due to drive a TFT display. It fits in a standard electrical wallplate, changing it from a development platform into practically a finished product.

The Altronics Z6360 is practically identical to the first ESP8266-based boards that began to appear around five years ago, labelled "ESP-01". We reviewed these and used one for the "Clayton's GPS" project in April 2018. Many variants have appeared, and most of them can now be programmed using the Arduino IDE.

to modify the Arduino IDE to suit other boards, this is not a straightforward process, and it was evident that another solution was needed.

This was solved when the IDE version 1.5 was introduced, which added the Boards Manager. Now, different architectures could be easily supported, and the multitude of board and processor types became possible.

Version 1.5 also brought streamlined installing of libraries. Finding a library to work with a new module is now simple, as you just need to run a search in the Library Manager.

This has access to a well-maintained and comprehensive list of libraries; the necessary files are downloaded and installed with a click, often including example sketches.

Hardware evolution

The software evolution of the Arduino IDE has been predictable. Steady improvements to the IDE have continued to make programming easier for a widening audience, while maintaining continuity and uniformity for existing users and software.

However, the hardware evolution has been rapid. There is now a vast array of hardware that can be programmed using the IDE. Even experienced microcontroller aficionados such as ourselves are amazed by the convenience and features that are on offer.

This makes it easy to see what can be done with new hardware without having to re-learn anything on the software or coding side. We think that this is a great feature that suits even very advanced users.

The ESP8266

One processor family that has seen a lot of use by being accessible under the Arduino IDE is the Espressif ESP8266, and subsequently its successor, the ESP32. Their 'killer feature' is integrated WiFi and, for the ESP32, Bluetooth, at a very low cost.

We saw the first examples of this hardware just over five years ago. Now they are used even in many consumer goods (which keen Arduino users are pulling apart and reprogramming).

The first of these ESP8266 modules went on sale with little to no documentation, except as WiFi modules controlled by AT commands over a serial port. At about USD $5 each, many people snapped them up just to try them out. At the time, even an Ethernet shield cost many times more than that.

Soon enough, projects involving LEDs being controlled through basic web-pages abounded. DIY home automation using WiFi seemed achievable.

While the AT interface worked, the serial port limited the speed. It wasn't long before a small community popped up with the intention of getting the open-source GCC compiler to program the microcontroller on this module.

This microcontroller is a 32-bit Tensilica Xtensa LX3 running at 80MHz; the program is typically stored on an external flash chip of at least 512kB. This had the potential to be much faster than the Uno at a lower cost; never mind that it had onboard WiFi!

Espressif noticed the popularity of their modules and released some tools to allow code to be compiled for the ESP8266; no doubt, this helped the Arduino community.

So less than the year after the ESP8266 appeared, it became possible to program it with the Arduino IDE, although a lot of manual file manipulation was necessary back then to enable it.

This was resolved with the Arduino IDE v1.6.2 with the simplified installation of new boards and libraries. This support was tweaked in v1.6.4, which we now consider the oldest version suitable for new projects.

In response to the above, a flurry of new Arduino-compatible boards appeared using the ESP8266 chip. These borrowed many of the features that made the original Uno so popular. Probably the best-known example is the WeMos D1 R2, which was subsequently cloned due to its popularity.

This is sold in our Online Shop (Cat SC4414), and we've used it in a few of our projects.

Typical features include a USB connector that allows the unit to be powered easily, while a USB-serial IC provides a channel for communicating, debugging and uploading code. Some clever circuitry on the board automatically detects when code needs to be uploaded, so the entire process is as seamless as it would be for an Uno.

Nowadays, the ESP8266 is one of the most popular Arduino IDE addons. We even use it when we want to quickly test out a 3.3V part or module, since we're so familiar with it.

What is open sourcing?

While open-source software and free software are not quite the same, they often coincide. One could argue that the Arduino IDE is popular because it is free, but it has continued to develop because it is open-source. In fact, the first mention of open source in SILICON CHIP was when Ocean Controls introduced the Diecimila.

The notion of open sourcing is fairly new (around twenty years old). Although it may appear at first to be a strange business model, it has been successful for several companies and individuals.

The simplest definition of open-source software is that it is software where third parties can legally download the source code. Usually, the tools to turn the source code into a working program are also freely obtainable.

In a sense, the movement was a reaction to the very 'closed' models of early software companies. This often led to computer users being saddled with glitchy software, where the originating company wasn't interested in fixing it, and the users couldn't.

Another important element in the development of the open-source model is the observation that digital objects such as code can be copied without requiring material resources; they simply exist as bits and bytes on a storage medium such as a hard drive.

So open-source software was devised as a way to release software so that others (including users) could assist in its development, and bug-fixing, but (in some cases) still allowing the authors to make money or otherwise benefit from their hard work.

Open-source hardware exists, but is nowhere near as common as open-source software. Maybe this is because it's unusual to get hardware for free! In any case, open-source hardware usually just refers to the design; in other words, 'some assembly required'.

Because of the nature of copyright, you are not automatically permitted to make copies of software. Thus, numerous open-source licenses exist. The simplest of these is to simply declare the code to be 'public domain', which means that there are basically no restrictions placed on its use.

But it's more common to see source code released under either the GPL (GNU Public License) or with a BSD-style license. The BSD-style license is only slightly more restrictive than public domain, while GPL places more strict restrictions on how the software may be redistributed. You might even see the term 'copyleft' applied to some of these licenses, to highlight the contrast with copyright.

The smart part of many open-source licenses is that there is a condition that any derivative works must be released under a similar license to the original software. This keeps the open-source software open.

How does Arduino fit in?

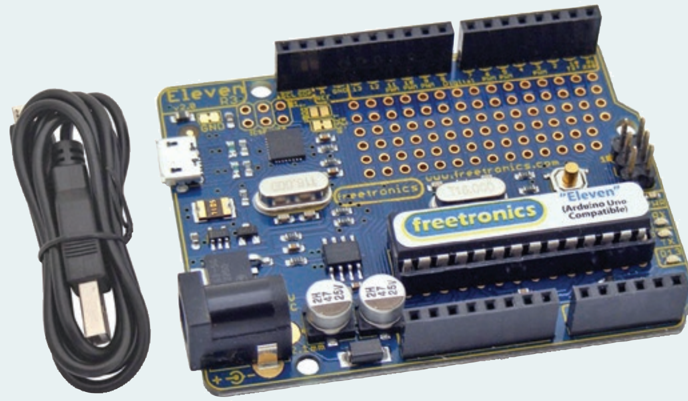
The Arduino IDE code is available under a GPL open-source license. Also, it depends on several open-source tools to work.

This includes the "avr-gcc" compiler (AVR GNU Compiler Collection), which takes the C/C++ code in the Arduino sketch and turns it into machine code to run on the microcontroller. Then there's "avrdude" (short for AVR uploader/downloader), which loads the compiled machine code into the target processor.

Arduino open hardware

Many official Arduino boards are also fully open-sourced hardware. For example, the Uno circuit and PCB layout are available under a Creative Commons Attribution Share-Alike license.

This has had a two-fold effect. The first is that it allows (generally lower-cost) clones to be sold. For the most part, these are practi-



cally identical and thus utterly interchangeable with the 'genuine' Arduino boards. This makes for a very low barrier to entry to the Arduino system.

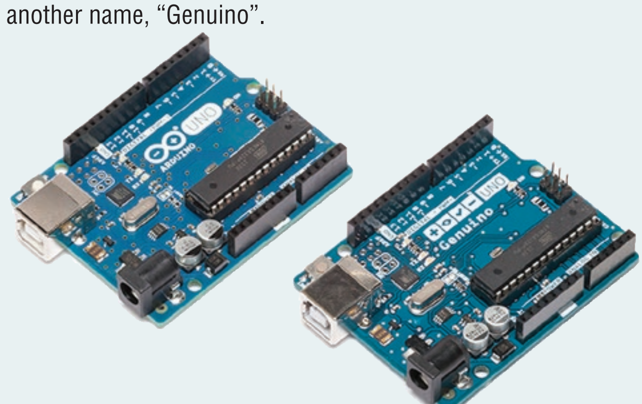
Secondly, improved versions of the original hardware have appeared too. Firms such as FreeTronics have created boards like the Eleven, which is an improved but still compatible version of the Uno.

Having downloaded the design files for the Uno or Eleven, you could build your own copies, or even improved versions.

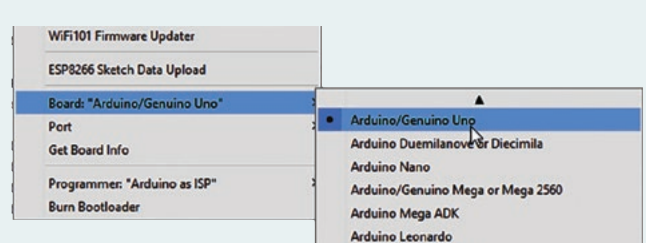
Trademarks and disputes

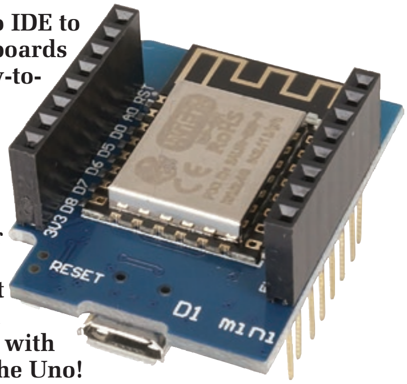
While Arduino software and hardware are open-sourced, the Arduino name itself is a trademark, and this has been the focus of at least one controversy.

The short version is that different people registered the Arduino trademark in different parts of the world. So some people trying to sell genuine Arduino boards could not use the Arduino name in some parts of the world. Therefore, they had to come up with another name, "Genuino".

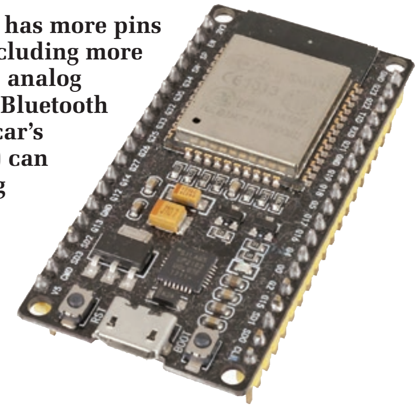


Eventually, the two groups merged, and for the most part, the Genuino is now part of history. In any case, the Arduino trademark and name appear to be valuable. This is why so many of the clones have other different names ending in -duino; simply because, legally, the Arduino name is otherwise off-limits. Instead, we have the term 'Arduino-compatible' to describe anything else.





The ability of the Arduino IDE to program ESP8266-based boards spurred the design of easy-to-use hardware. Jaycar's XC3802 WiFi Mini combines an ESP8266 module with a USB-serial converter, a voltage regulator and some clever hardware to allow firmware to be loaded without user intervention. Thus, a very capable 32-bit micro with WiFi is as easy to use as the Uno!



The ESP32 processor has more pins than the ESP8266, including more which can be used as analog inputs, and supports Bluetooth along with WiFi. Jaycar's XC3800 (shown here) can be programmed using the Arduino ESP32 Boards Manager add-on.

The ESP32

Noticing the popularity of the ESP8266, Espressif addressed several shortcomings that had been noted by the Arduino community when they created the dual-core ESP32.

One core can be dedicated to radio functions while the other core is free for functions needing a real-time response. The 2.4GHz radio of the ESP32 can even be used to implement Bluetooth, another compelling feature. Arduino support for the ESP32 came quickly.

The ESP8266/ESP32 Arduino support is a fantastic example of what an open-source community can achieve when allowed to put WiFi support into the hands of the masses.

And the rest

The support for other micros doesn't end there. Our ChipKIT Lenny review in last month's issue describes how a Microchip PIC32-based board can be programmed under the Arduino IDE. It compares favourably with other official Arduino branded 32-bit boards in performance, although some functions and features don't quite work the same.

There is a good list of third-party processor boards which can be added to the Arduino IDE at: https://github.com/arduino/Arduino/wiki/Unofficial-list-of-3rd-party-boards-support-urls

Some of the so-called 'boards' added by the Boards Manager are sometimes no more than a bare microcontroller, relaxing the requirement to use Arduino-compatible hardware. It isn't even that hard to add support for custom hardware.

Note that not all of the 'core' libraries may be fully implemented for each board, as it is up to the board designer to write those libraries. This includes support for serial protocols like I^2C and SPI.

From small...

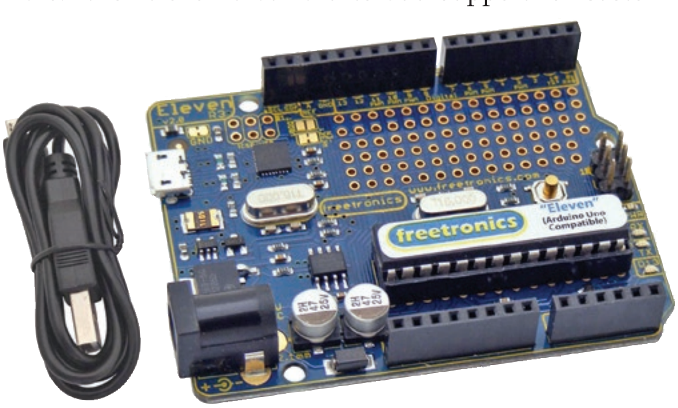
Newer boards such as the Nano Every (reviewed in October 2019; see: siliconchip.com.au/Article/12015) use the recent megaAVR series ATmega4809, which incorporates features from some Microchip microcontrollers since their takeover of Atmel.

There are a good number of other Atmel microcontrollers which have been made to work with the Arduino IDE, and they have been fitted to a surprising number of development boards.

For example, there is the ATtiny series; the ATtiny85 is an eight-pin device that can be had in a DIP, SOIC or even QFN package. Because of their similarity to the ATmega processors, adding full support for these micros to the Arduino IDE is not all that difficult.

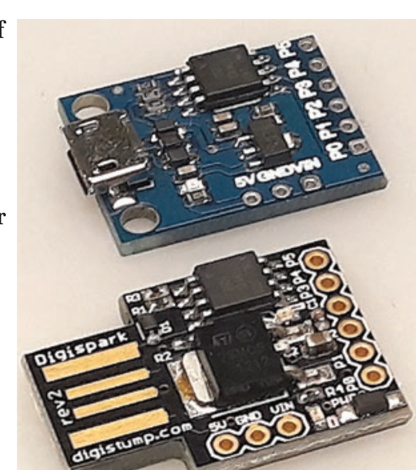
One of the more interesting ATtiny boards is the Digispark (http://digistump.com/products/1), which looks like a small USB drive. It fits an SOIC-package ATtiny85 alongside a 5V regulator and breaks out six I/O pins.

The ATtiny85 does not have a native serial UART, let alone USB support, but the Digispark is loaded with a cleverly-written USB bootloader which operates entirely in software. The bootloader uses the HID protocol normally used by keyboards and mouses. This is enough to allow sketches to be uploaded with minimal effort via a conveni-



The Freetronics Eleven is a great example of the benefits of open-source hardware. It is an improved version of the Uno, adding a prototyping area and replacing the full-size USB socket with a smaller micro-USB socket. Thus, there is less chance of the socket shorting out against a shield. Its design files are available on similar open-source terms to the Uno's.

The Digispark is one of the smallest Arduino-compatible boards. With an ATtiny85 microcontroller, it's the size of a small thumb drive and has six I/O pins, enough for many small projects. Its design files are open source, and clones have naturally appeared. The black board at right is the original Digispark; the blue board above it is a clone.



What's a bootloader?

One of the reasons Arduinos are so easy to program is the bootloader. This is a small program on a microcontroller which allows larger programs to be uploaded. Note that this is not unique to the Arduino world.

The "boot" part comes from the term 'bootstrapping', which refers to the notion of lifting oneself up by one's own bootlaces or, less figuratively, without outside help. Nowadays, the term 'booting' is used to describe a piece of electronic equipment starting up.

Practically all computers go through a similar process. A PC has a small program in a ROM chip on its motherboard, which in turn loads another program from its hard drive into RAM (which may, in turn, load another program). Without this small program in ROM, a computer would not be able to start up.

But since microcontrollers typically have non-volatile memory onboard, unlike a PC, this process does not need to occur every time a microcontroller starts up.

Every time an Uno is powered up or reset, the bootloader runs for the first second. It monitors the serial port, and unless it sees the correct sequence of data, it runs the program already stored in its flash memory.

If it detects a sequence which indicates that programming needs to occur, the bootloader continues to run, accepting data from the host computer and writing it to the internal flash memory. When programming is complete, the bootloader runs the freshly uploaded program code.

To program an early Arduino board, it had to be manually reset with a pushbutton. But now there is another microcontroller which detects when the host computer initiates a serial connection, and this triggers a reset automatically. This means that no action is required to load the sketch, apart from running the upload program on the PC. That is one factor which makes Arduino so easy to use.

Another clever point is that the bootloader resides in a protected part of flash memory, so it cannot overwrite itself or the configuration fuses. So it is tough to 'brick' an Uno through the normal upload process; another upload is usually sufficient to correct a faulty upload attempt, as the bootloader survives and runs at reset.

The bootloader used on the Uno is called "Optiboot", which is a development of other open-source projects which sprung up independently of Arduino.

For more information, see: siliconchip.com.au/link/aaxo

ent USB interface.

The designer of the Digispark has also released his design files as open source. Unsurprisingly, it is now possible to buy clones of these handy little boards.

... to large and varied

In terms of the 32-bit boards which can be programmed by the Arduino IDE, we've mentioned the Microchip-based ChipKITs, the ESP8266 and ESP32 boards and Arduino's own Atmel SAMD21-based MKR series boards. But there are others, many of which use the ARM (Advanced RISC Machine) Cortex-M0 architecture.

Some also use processors from Gecko and Infineon, or other ARM architectures. This includes the STMF103-based development boards with ARM Cortex-M3 cores, and Cortex-M4 based boards with chips from Maxim Integrated and Nordic Semiconductor.

Nordic is known for their radio ICs and modules, such as the 2.4GHz nRF24L01 modules we covered in January 2018 (siliconchip.com.au/Article/10940). Some Nordic ICs have BLE (Bluetooth Low Energy) radios.

There are even several Arduino-compatible boards with Intel processors. An example is the Galileo, which has a 400MHz processor, 512kB of SRAM, 8MB of flash and a standard R3 pinout. It actually runs Linux to handle communications with a custom version of the IDE for managing sketches.

With the rise of open-source tools for FPGA development, people are even creating boards based on 'softcores'.

A softcore is an implementation of a processor via programmable logic, most commonly an FPGA. While this may seem wasteful, it does give the ability to easily reprogram the device to add new features, or even to emulate a different processor.

If you are not familiar with FPGAs, refer to our introduction to the iCEstick FPGA development board in April 2019 (siliconchip.com.au/Article/11521).

Chips implemented as soft cores include the ATmega328, for example, as used in the Alorium XLR8 (www.aloriumtech.com/xlr8/) and the Lattuino (http://fpgalibre.sourceforge.net/Lattuino_en/index.html).

Many of these boards are used for education. So it's

The Arduino CLI is a command-line version of the Arduino IDE. Compiling and uploading a sketch is as simple as running the two commands shown here. It seems slightly quicker than the IDE, but we think its big advantage is its ability to use scripts to automate processes.

useful that one board can be used to teach both microcontroller and FPGA development, including concepts such as processor and ISA (instruction set architecture) design.

… and the new

We haven't seen many new main boards coming out with the classic Uno footprint. Apart from the Uno WiFi Rev2, most new Arduino boards use the MKR (pronounced 'maker') designation and footprint.

You can still buy the Uno from the Arduino online store (store.arduino.cc), but only third-party manufacturers are really developing the 'classic' footprint. Still, we don't expect it will go away any time soon.

Last year, four new Nano boards and several MKR-format shields were announced by the Arduino company on Arduino Day (March 16th). We expect to see more major hardware announcements from them on Arduino Day this year.

In contrast to the classic Uno and derivatives, the MKR boards are all 32-bit SAMD boards with 3.3V I/Os. There are several shields available with the MKR footprint, which is more breadboard-friendly than the Uno footprint.

Many of the new MKR boards have some form of wireless communication, including WiFi (Arduino MKR WiFi 1010), GSM (Arduino MKR GSM 1400), LoRa (Arduino MKR WAN 1300) and NB-IoT (Arduino MKR NB 1500). Interestingly, WiFi support on the MKR WiFi 1010 is an ESP32-based module, which has its firmware compiled under the Arduino IDE.

As we mentioned in our review of the MKR 4000 Vidor, a cryptographic chip is also fitted to these boards, allowing for secure communications over these wireless networks. Many of these boards also have a header for a rechargeable lithium battery, and support charging the battery from USB power. Thus, they are well suited to remote or untethered deployment.

These boards have been around for a few years now, but we are not yet aware of any clones of them, although we imagine they would be popular if they were available.

Software for advanced users

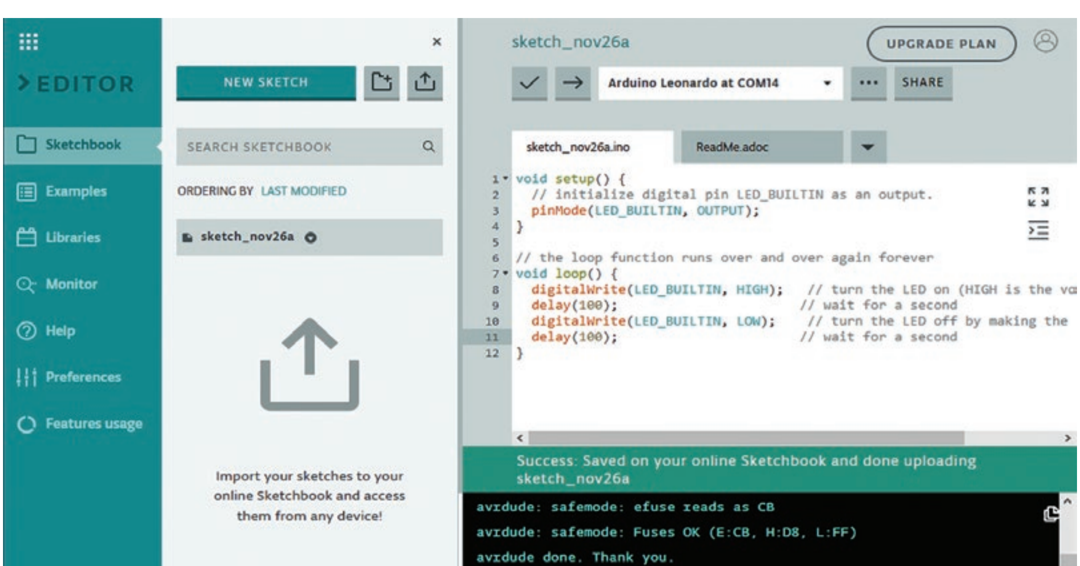
We noted above that some people who are experienced with microcontrollers might complain that the Arduino IDE hides too much. It's no doubt that the resulting simplicity is helpful for beginners, or even experts who are trying a new type of micro. But there are times when you need to know what is going on 'behind the curtain'.

There are two Arduino software tools which give users more control and power, and they are as follows.

Arduino CLI

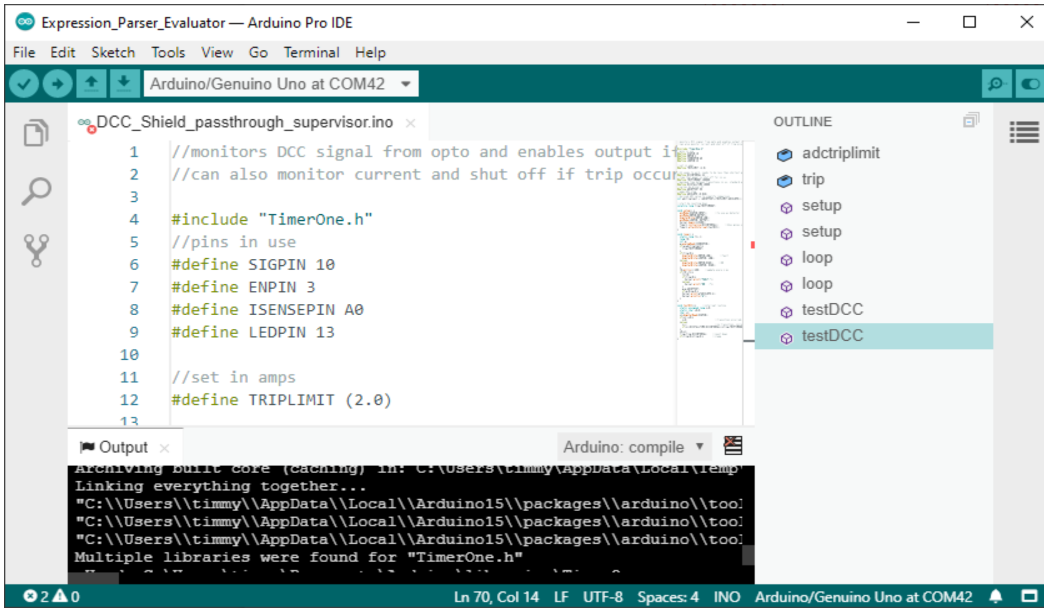
The Arduino CLI, released in 2018, is the first of these. CLI stands for Command Line Interface. As the name suggests, it allows the compilation and uploading processes to be controlled using a command line. You can write a sketch in a simple text editor, then use a CLI command to compile and upload it.

Many of these commands perform the same function as IDE menu options, but the lack of a GUI (graphical user



The Arduino Web Editor looks quite different from the desktop IDE, but many of the same features are present, and the process is much the same. Being accessible from a browser means that sketches can be viewed and edited from mobile devices, although uploading is not yet possible.

While only in the early stages of development, the Arduino Pro IDE has some promising features. The overview and outline at right allow easier navigation of large projects, and there are many more settings available in the Preferences menu.



interface) makes them run faster on slower computers. On our Windows 10 PC, the CLI is a 5MB executable file. It naturally needs the board cores and other files to work, but is certainly smaller than the full IDE.

Because it can be controlled from a command line, it lends itself well to scripting and automation. It could also be the basis of a custom IDE. See https://github.com/arduino/arduino-cli for more information.

Arduino Pro IDE

At the other end of the scale of complexity is the Arduino Pro IDE. This is currently only at the 'alpha' (pre-beta-testing) stage, but it appears to offer a lot more features than the standard IDE. In fact, it is a fully-featured development environment.

The Pro IDE gets new, experimental features which would only add confusion to beginners if they were added to the regular IDE. Some of the proposed features include live debugging, and the ability to use third-party plugins and different languages for programming. Eventually, some of these features may migrate to the basic IDE.

The Pro IDE relies on the Arduino CLI for core functionality. It can be downloaded from: https://github.com/arduino/arduino-pro-ide/releases

Note that it is still at a very early stage of development, so it is likely to have bugs and undergo significant changes as it evolves.

The 'cloud'

You probably won't be surprised to hear of a cloud-based version of the Arduino IDE. This lets you program an Arduino board without having the IDE installed.

A small program called the "Create Agent" needs to be installed, to communicate with the boards (since a web browser does not have access to serial ports). All sketches are saved online.

The Arduino Create website is at: https://create.arduino.cc/ You need to set up an Arduino account to access it. This gives you 100MB of space to store up to 100 projects and allows 200 sketch compilations per day. There is also a paid plan which offers more features.

We tried it out and found the online sketch editor easy to work with, and were able to upload a simple sketch within minutes. Apart from the online editor, there are tools for getting started and a project hub where other Arduino projects can be viewed and shared.

There is also an IoT Cloud, which allows devices to be connected to the Internet; this is limited to a small number of Arduino boards from the MKR series, plus the Nano 33 IoT.

Perhaps this is a gentle nudge away from the older, cloned boards towards the newer devices.

One advantage of the online version is that less capable devices such as Chromebooks can be used to work with Arduino. For schools and other institutions that use Chromebooks, this means that they can teach Arduino without worrying about software downloads and installations.

Of course, we all know 'the cloud' is just another term for 'someone else's computer', and some people might object to having their programs stored there. But it could certainly be handy for working on your sketches while you aren't at your desk.

You can even access Arduino Create from a mobile device like a smartphone, although it doesn't yet appear to allow sketch uploads from these yet.

What next?

There is no doubt that Arduino has come a long way in the last ten years. And we don't expect it to disappear any time soon. The new developments in the Arduino CLI and Pro IDE show that the Arduino folks are willing to broaden their audience.

New Arduino-compatible hardware is announced regularly. The Arduino community around the worldwide will no doubt ensure that the Arduino phenomenon will continue, regardless of what happens with the Arduino company.

Arduino Day is coming soon, on March 21st (http://siliconchip.com.au/link/aaxt), so look out for new announcements. If it is anything like the last few years, you can expect to see some new hardware if nothing else. We will find out soon what the future holds. SC

Nutube Guitar OVERDRIVE and DISTORTION Pedal

by John Clarke

Do you long for that true "valve sound" in a guitar and distortion pedal? How about this one – it uses a unique low-voltage twin triode valve, so you know it's the real deal!

Electric guitars are almost always played (at least professionally) with some sort of effects in the loop. Acoustic guitars with electric pickup can also take advantage of an effects pedal.

Among the many effects pedals available, overdrive and distortion are probably the most popular. Some produce a harsh distortion (as in 'fuzz boxes'), while others provide a more gentle form of distortion.

Effects boxes commonly use circuitry with semiconductors such as JFETs for providing these effects, and sometimes silicon diodes for distortion.

But the 'Holy Grail' overdrive effect is produced by valves. While some solid-state overdrive pedals attempt to emulate the distortion effect produced by valves when overdriven, there is no substitute for the real thing.

To date, it has been difficult to incorporate valves into a small effect pedal. But that has all changed now that a compact low-voltage 6P1 dual triode is available from music instrument manufacturer Korg.

We introduced it only last January in our Valve Preamplifier (siliconchip.com.au/Article/12217)

This new project can be used as a distortion pedal, an overdrive pedal or a mixture of both. Two stages of distortion and/or overdrive are included, and the first stage can be used on its own or in conjunction with the second stage that's switched in by the boost pedal.

Overdrive versus distortion

The main difference between overdrive and distortion is in the type of distortion produced.

Overdrive is when an amplifier is driven with a high signal level, causing the output to be rounded off and eventually, limited or clipped. So at low signal levels, there is no or little distortion. The distortion rises as the signal level increases.

Once the signal becomes limited, the volume remains constant and does not increase significantly as the input signal level increases.

A side effect of excessive overdrive is that it tends to also act as a sustain effect, where the volume level remains constant for some time after the string is struck. The sustain effect continues until the signal from the guitar drops below the level required for limiting.

The type of overdrive distortion depends on how the signal is limited. With valves, the limiting is usually asymmetric, with one polarity of signal excursion more sharply clamped than the other.

A **distortion** effect is different, in that there is a deliberate attempt to distort the signal even at low levels, and the output level is not restricted as much as for overdrive. In other words, there is generally some distortion at all signal levels. We have provided some oscilloscope traces that show the differences between overdrive and distortion (Scope1-Scope8), later in the article.

Our Guitar Overdrive and Distortion Pedal can be set up for overdrive or distortion via its control knobs.

If the distortion controls are set for minimum distortion and the gain increased, the pedal acts as an overdrive, rounding off the higher signal levels. If the distortion controls are adjusted for more distortion, then it acts as a dis-

The Valve Guitar Overdrive and Distortion Pedal is housed in a sturdy diecast case, not only for hum minimisation but to ensure heavy-footed axemen (or women!) don't do any damage in the heat of the moment! It operates from 9-12V DC (yes, it is a genuine valve!) so you can use it with a plugpack supply or even a battery.

tortion pedal, with the gain level determining whether it is also producing an overdrive effect.

The distortion control in each stage can be set at the mid position for minimum distortion, or closer to either end for more distortion. When wound anti-clockwise, the negative half of the waveform is distorted, but the positive half is not as affected. Conversely, in a more clockwise position, the positive half of the waveform is distorted, but the negative portion of the waveform isn't as affected.

The Overdrive and Distortion Pedal has two stages that provide distortion, with both used when boost is selected. So if the first stage is set for positive distortion and the second stage set for negative distortion, both halves of the waveform will be distorted with boost activated. With the boost off, only the distortion provided by the first stage is in effect.

This difference is more noticeable if the signal level applied to the second stage is reduced in level to match that applied to the first stage. This can be achieved by adjusting a trimpot inside the Pedal.

A tone control is included that provides treble cut. The cut-off frequency is adjustable between about 2kHz and 23kHz. A lower cut-off frequency reduces the distortion harmonics to get the desired sound.

The output levels for when boost is in and out are also adjustable. How you set these depends on the effect you want. The level when boost is switched out is typically set to provide the same output level when bypass is enabled.

When the pedal is in bypass, the input signal is directly connected to the output. When not in bypass, the signal passes through the distortion and overdrive circuitry.

You could set the output level when boost is selected for a higher level, or at the same level as when boost is off. In general, the boosted output sounds louder anyway, due to the more squared waveform and added harmonics.

Features

- Two distortion stages
- High input impedance suits most pickups
- Gain, output level, distortion and tone controls
- True bypass and boost switches with LED indicators
- Housed in a rugged diecast enclosure
- No high voltages
- Uses a Nutube dual triode with no transformers
- Nutube plate glow is visible
- 30,000-hour Nutube life
- Low power consumption
- Battery or DC plugpack power
- Signal phase preserved from input to output
- Automatic and silent on/off switching
- Power supply reverse polarity protection

Presentation

The Pedal is housed in a rugged diecast aluminium case. It has two foot switches, six rotary controls and three indicator LEDs. Clear bezels are located over the two dual triode plates so that the grid bias setting can be

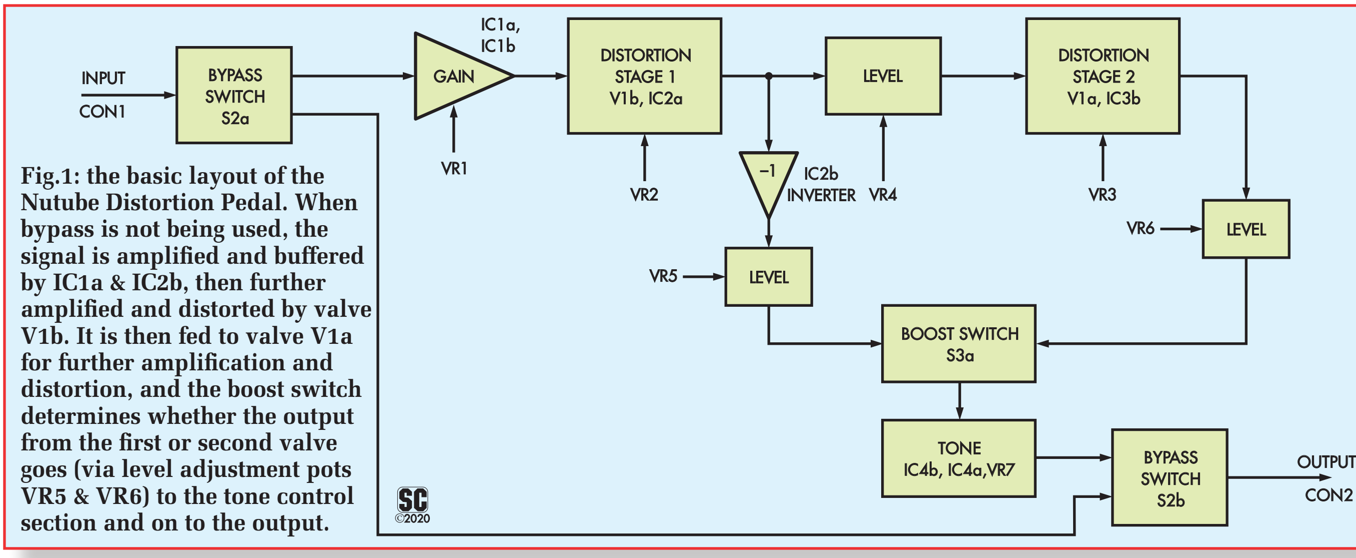


Fig.1: the basic layout of the Nutube Distortion Pedal. When bypass is not being used, the signal is amplified and buffered by IC1a & IC2b, then further amplified and distorted by valve V1b. It is then fed to valve V1a for further amplification and distortion, and the boost switch determines whether the output from the first or second valve goes (via level adjustment pots VR5 & VR6) to the tone control section and on to the output.

observed (more about this later) and so that everyone can see your magnificent valves glowing.

Two 6.35mm (1/4”) jack sockets at the rear provide signal input and output connections, with a DC socket to supply power. The unit can also be powered from an internal 9V battery. Power is automatically switched on when a plug is inserted into the output socket

Operation

Fig.1 shows a simplified block diagram of the Guitar Overdrive and Distortion Pedal. The signal from the guitar at CON1 can pass directly to the output at CON2 via the bypass switch (S2b). When bypass is not selected, the signal passes to the first gain stage instead. This comprises a high input impedance buffer stage (IC1a), an attenuator (potentiometer VR1) and an 11 times amplifier (IC1b).

The first distortion stage uses one of the Nutube Triodes (V1b) to provide amplification and distortion. The amount of distortion produced by this stage is adjustable via potentiometer VR2.

The output of V1b is buffered by op amp IC2a. As V1b inverts the signal, the output of IC1a is fed to an inverter (IC2b), restoring its original polarity. The output level from the inverter is adjusted by VR5, and the signal then goes to one side of the boost switch, S3a.

The output from before inverter IC2b is also applied to a level-adjustment trimpot (VR4) and then fed to the second distortion stage. This allows the second distortion and overdrive block to have the same input signal level as the first block. In that case, VR4 is adjusted to reduce the signal level from the first stage by about 15dB.

Alternatively, VR4 can be set to provide the full signal level to the second distortion block, to maximise limiting and overdrive.

The second distortion block circuitry is the same as the first, only it uses triode V1a and buffer IC3b. Potentiometer VR3 sets the distortion level while the output level is adjusted with potentiometer VR6. The resulting signal is applied to the other side of the boost switch, S3b.

So the boost can select between the signals from the first or second distortion stages. The selected signal goes to the tone control with adjustable high-frequency cut, as set by potentiometer VR7.

The output from the tone control then goes to one side of the bypass switch, S2b. The bypass switch selects between this signal or the input signal at CON1 (when in bypass).

The Nutube twin triode

One of the things that makes the Nutube so special is that it can run at a very low voltage. Traditional valves require a high anode voltage (above 100V). The Nutube 6P1 was developed by Korg and Noritake Itron of Japan. While it is a directly-heated triode with a filament, grid and plate, it is made in a way that more resembles a vacuum fluorescent display (VFD) than a traditional valve (or tube).

The Nutube has rectangular glass encapsulation, and each triode comprises a single-pixel VFD. Its internal construction has the heater filament as a fine-gauge wire running across the front, with the metal mesh grid located below that. Behind the grid is the plate (or anode), which is phosphor-coated and glows when the filament is heated.

The filament wire is held taut, so it can vibrate similarly to a guitar string. (The Nutube is, after all, sold by a musical instrument manufacturer). This vibration is not necessarily a wanted feature as it can be the source of microphonics, where an external sound can couple to the filament and alter (or modulate) the audio signal being amplified. As a result, this vibration is heard in the sound.

Careful construction methods can minimise microphonics. This includes protecting the Nutube from surrounding air vibrations, by using flexible wiring, and a vibration-damped mounting method.

In operation, the Nutube draws minimal current, with each filament requiring just 17mA. The grid and plate currents total around 38μA. The Nutube is best operated with a plate voltage of 5-30V. The load-line curves show that within this voltage range, the grid voltage needs to be above the cathode filament voltage.

This is different from the traditional triode, where plate voltages are much higher, and the grid voltage is usually negative with respect to the cathode. Nutube distortion can be adjusted by varying its grid bias voltage.

Circuit details

The circuit is shown in Fig.2. You can see the two halves of the Nutube near the upper middle, with both connected

Specifications

- *Supply: 9-12V DC @ 47mA with bypass and boost LEDs off (+6mA for each LED)*
- *Gain: 32dB maximum with boost off; up to 43dB with boost on*
- *Frequency response: -0.6dB at 20Hz. Upper frequency response is dependent on the tone setting.*
- *Tone control: 20dB/decade high-cut filter, -3db point varies from 2.12kHz to 23.4kHz with tone control*
- *Maximum input and output swing: 2.3V RMS for 9V supply; 3.3V RMS for 12V supply*
- *Minimum signal level for overdrive limiting: 55mV without boost, 15.5mV with boost*
- *Signal to noise ratio: 82dB with respect to 55mV in and 55mV out*

as common-cathode amplifiers; the cathode filaments are connected to ground at pin F3. Signals are applied to the grids (G2 & G1), and the resulting amplified signal appears at the anodes (or plates), A2 and A1. The anodes have resistive loads to the positive supply, Vaa.

The Nutube triodes have a relatively low grid input impedance and high output impedances at the anodes. Therefore, buffers are used; one to provide a low-impedance drive for the grid of each triode, and others to keep the anode load impedances high.

These op amps (OPA1662A) have very low noise and distortion, of around 0.00006% at 1kHz, 3V RMS and unity gain. So the op amps do not affect the sound of the signal in any way. Any noise or distortion they might introduce is dominated by that from the triodes.

The signal path is as follows. When the bypass switch (S2a) is in the non-bypass position, the signal passes through ferrite bead FB1 and a 100Ω stopper resistor. These, in conjunction with the 100pF capacitor, stop RF signals from entering the circuit, which may result in unwanted radio frequency detection and reception. The 100pF capacitor also provides loading for piezo guitar string pickups.

The signal is AC-coupled to pin 3 of op amp IC1a and biased to half supply (Vaa/2) via a 1MΩ resistor. The Pedal's input impedance is therefore high at 1MΩ, making it suitable for a piezo guitar pickup.

The half-supply rail (Vaa/2) is derived by two 10kΩ resistors in series across the Vaa supply. It is bypassed with a 100µF capacitor to remove supply noise, and buffered by unity gain amplifier IC3a.

The output of IC1a is AC-coupled to the level control, VR1, which then feeds IC1b. IC1b provides 11 times gain. So when VR1 is at maximum, the output signal from IC1a is directly applied to the IC1b amplifier for an overall gain of 11.

With reduced settings for VR1, there is less overall gain from input to the output of IC1b.

The signal from the output of IC1b drives the grid (G2) of Nutube V1b via a 10µF coupling capacitor. This grid is DC-biased via a 33kΩ resistor connected to the wiper of potentiometer VR2. VR2 is adjusted to set the operating point and hence, distortion produced by V1b.

VR2's wiper voltage range is restricted to 1.27-3.3V by 8.2kΩ and 6.2kΩ padder resistors. This provides a good range of distortion variation. The resistor values were chosen so that the centre position for VR2 provides the lowest distortion for V1b.

The amplified signal appears at the plate of V1b (A2). This has a 330kΩ load to Vaa via a 150Ω decoupling resistor. The supply is bypassed using a 100µF capacitor to remove supply ripple.

The high-impedance anode signal is again AC-coupled to another op amp buffer (IC2a) via a 100nF capacitor, biased to half supply with a 1MΩ resistor. This resistor loads the anode and so reduces the signal swing by about 25%. This is unavoidable in such a high-impedance circuit.

The output signal from IC2a goes to IC2b, a unity-gain inverter, which inverts the signal to compensate for the inversion by V1b. It also goes to the grid of V1a via trimpot VR4. The trimpot allows the signal to be attenuated (if desired) before being applied to the grid. V1a's grid bias is adjusted by potentiometer VR3 from 1.96-3.48V. These voltages are higher than for V1b for reasons explained below.

The output signal from the anode (A1) of V1a is buffered by IC3b, similarly to how IC2a buffers the output of V1b. The signals from both IC2b and IC3b drive level adjustment potentiometers VR5 and VR6, respectively. The wipers of these potentiometers connect to either side of the boost switch, S3a. S3a therefore selects between the outputs of the first and second distortion stages.

Note that in the second stage, triode V1a inverts the signal in the same way that op amp IC2b does. So both signals applied to S3a have the same phase. The signal selected by the boost switch is applied to buffer IC4b, ensuring that neither VR5 nor VR6 is unduly loaded. This buffer also provides a low impedance drive for the following tone control circuitry.

This comprises a simple low-pass filter with a corner frequency controlled by potentiometer VR7. The tone control provides a 20dB per decade (6dB/octave) roll-off of high frequencies. The roll-off (-3dB point) starts at about 23kHz when VR7 is fully anti-clockwise, so the tone control essentially does nothing.

The roll-off frequency drops to about 2kHz when VR7 is wound fully clockwise. The resistance of VR7 and the 1kΩ fixed series resistor sets the RC time constant of the filter. The -3dB point can be calculated as $1/(2\pi RC)$, where C is 6.8nF, and R varies from 1-11kΩ.

IC4a buffers the output of the tone control RC network. The signal from IC4a is then AC-coupled with a 100µF capacitor to remove the DC bias and fed to bypass switch S2b, then through RLY1 and to output connector CON2. The output signal goes through a 100Ω isolation resistor to stop IC4a from oscillating should long (capacitive) leads be connected.

When S2 is set to the bypass position, the input signal at CON1 bypasses the distortion/overdrive circuitry, and the input to IC1a is tied to ground. This prevents switching noise when not bypassing, by keeping the 100nF capacitor at IC1a's input charged.

To prevent any audio noise when power is switched on and off, the output signal passes through the contact of relay RLY1, which is open when power is off. At power-on, the relay contact only closes after a delay, to allow time for the voltages in the circuit to stabilise. More on this later.

Filament current

Like most thermionic valves, the Nutube has heater filaments. There is one for each triode, between the pins labelled F1 and F2 for V1a and between F2 and F3 for V1b. These filaments are connected in series, with F2 being the junction.

There are two ways of driving these filaments. Current can be supplied to F1 and F3 via separate resistors with F2 tied to ground. In this case, 17mA flows through each filament for a total of 34mA. Or, like in our circuit, F1 or F3 can be connected to ground and current is supplied to the opposite end of the pair of filaments, so the same 17mA flows through both, halving the total current requirement.

The latter method is more efficient and enhances battery life. In our circuit, F3 is tied to ground, F2 is effectively open (with just a bypass capacitor connected) and current supplied via a 200Ω resistor from 5V to F1. F1 is also bypassed with 10µF capacitor, which forms an RC low-pass filter with the 200Ω resistor. These two capacitors reduce noise in the circuit.

The disadvantage of connecting the filaments in series is that, due to the voltage drop across the filaments, the cathode of one triode will sit at 0.7V rather than 0V. This means that the two triodes need 0.7V different grid bias voltages to operate in the same manner. This is the reason for the different grid voltage adjustment ranges for potentiometers VR2 and VR3, due to their different padder resistors.

Indicators LED1-LED3 are powered from the 5V supply via 510Ω resistors. LED1 is the power indicator, and it runs off the 5V rail. The bypass (LED2) and boost (LED3) LEDs are only powered when the bypass and boost switches are on.

Power supply

The circuit powers up when microswitch S1 is activated by a jack plug being inserted into CON2. The plug pushes on the ground pin in CON2, and this lifts the microswitch actuator to power the circuit. This is a slightly unconventional method of switching power, but it works reliably.

We decided to do it this way, rather than using a PCB-

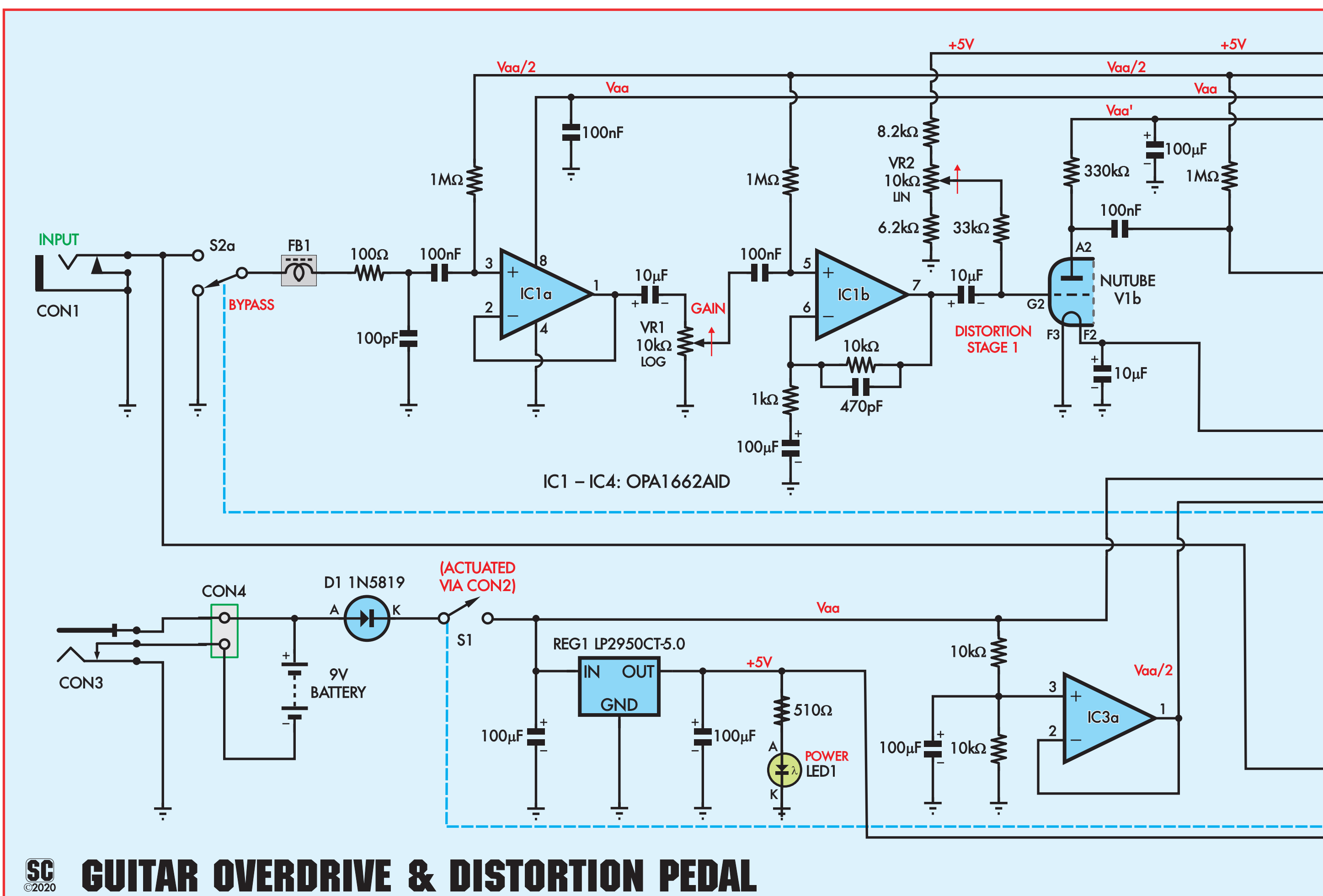


Fig.2: the circuit diagram of the Distortion Pedal. Potentiometers VR2 and VR3 set the grid bias voltages for valves V1b and V1a, and in doing so, determine the amount and nature of distortion that they introduce. The signal from the output of V1b to the input of V1a (via buffer IC2a and attenuator VR4) also goes to pin 6 of IC2b, which acts as an inverter, so that the non-boosted and boosted signals on either side of switch S3a are in-phase.

mount jack socket with an isolated internal switch or a panel-mount wired socket, mainly because those socket types are not universally available, while the type we are using is.

When there is no DC plug inserted, the DC socket (CON3) connects the negative end of the battery to ground, so the circuit will be powered from the battery when S1 is closed. When a power plug is inserted, the battery negative is disconnected, and the unit runs from the DC power supplied to CON3. In either case, schottky diode D1 prevents damage if the battery or DC power plug polarity is incorrect.

REG1 is a low-dropout, low quiescent current 5V linear regulator. Its main purpose is to maintain a constant grid voltage for the Nutube triodes and a constant voltage for the filaments. It also supplies power to 5V relay RLY1. A 100µF capacitor bypasses the input supply to REG1, and its output voltage is filtered similarly.

Relay delay

As mentioned, RLY1 switches on after a delay when power is first applied. IC5, a CMOS version of the 555 timer, provides this delay. When power is first applied, the 10µF capacitor at its trigger input (pin 2) and threshold input (pin 6) is discharged. The pin 3 output is at 5V, which drives the bottom end of the relay. There is no voltage across the relay coil, so it is off.

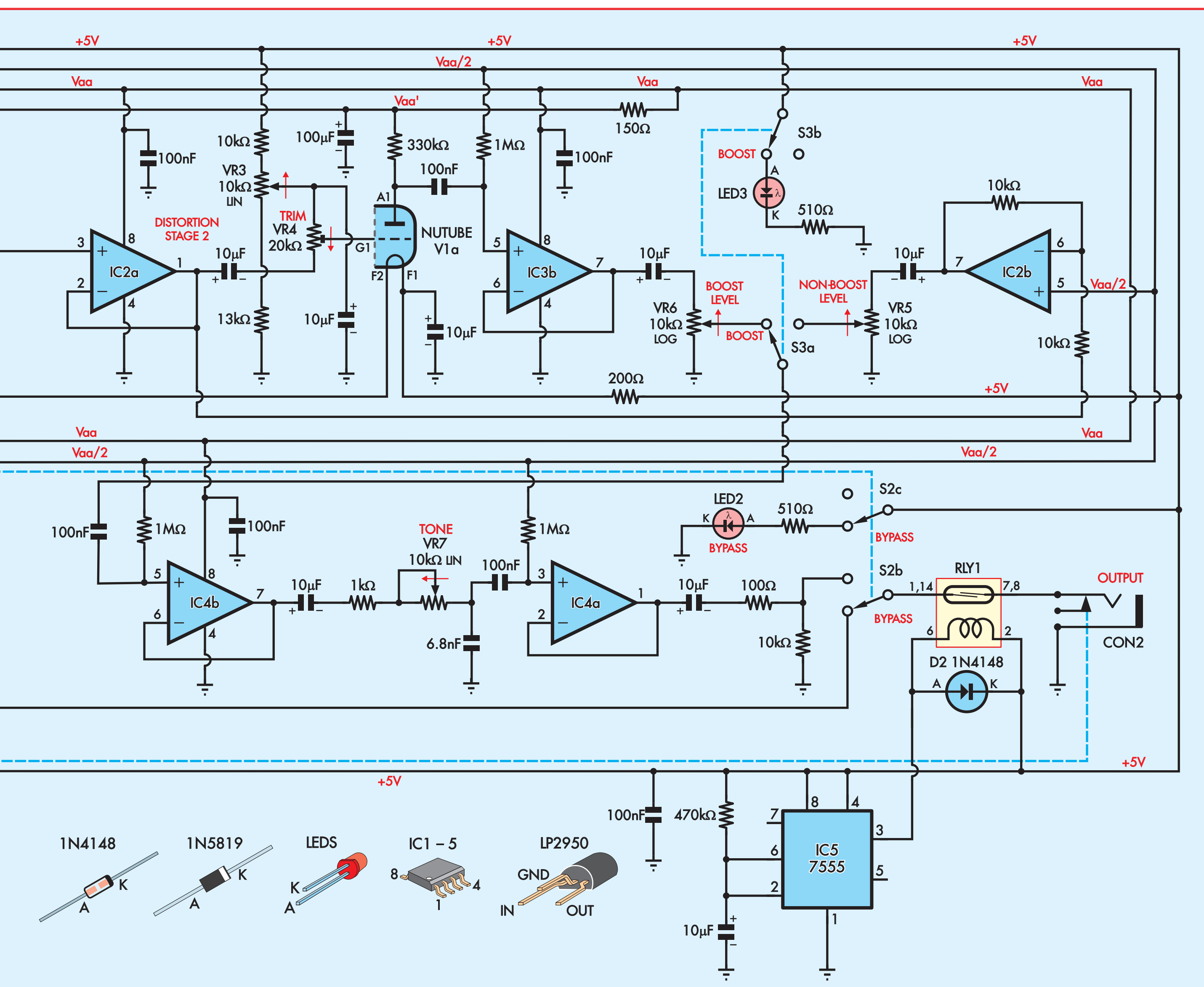
When the 10µF capacitor charges to 66% of the 5V supply (3.33V), the threshold voltage is reached and the pin 3 output goes low, energising the relay coil.

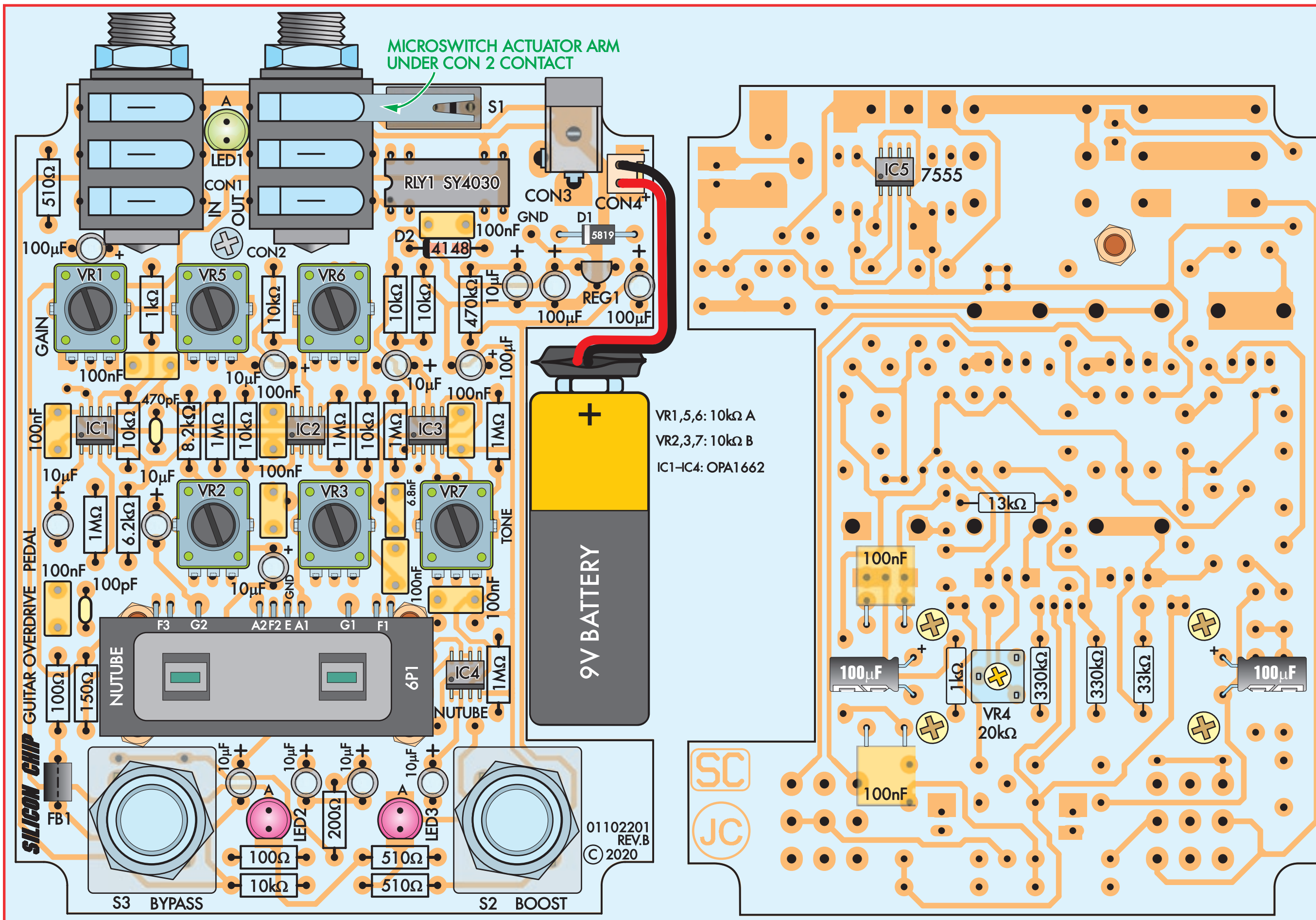
RLY1 is a reed relay with a meagre 10mA coil current requirement, so IC5 can drive the coil directly. Diode D2 shunts the back-EMF voltage from the coil when RLY1 is switched off.

Note that RLY1 prevents a bypass signal from getting to the output when the Pedal is powered off. But since power is switched on automatically when a plug is inserted into output connector CON2, and you can't get a signal from the unit without anything plugged into CON2, this is not a major problem.

Construction

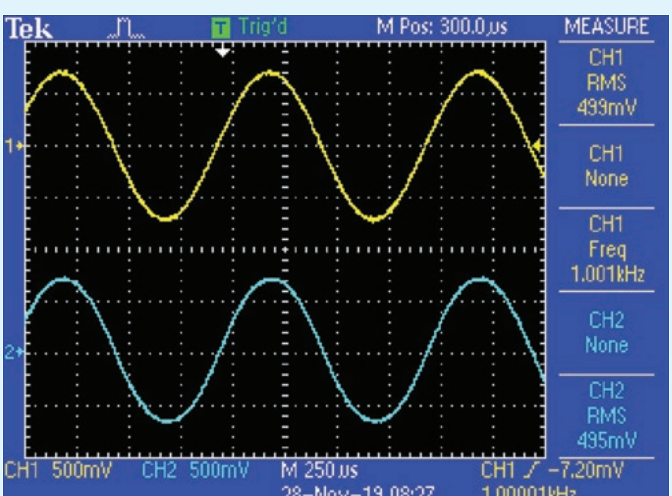
The Guitar Overdrive and Distortion Pedal is built using a double-sided PCB coded 01102201 and measuring 86 x 112mm. It is housed in a diecast enclosure measuring 119



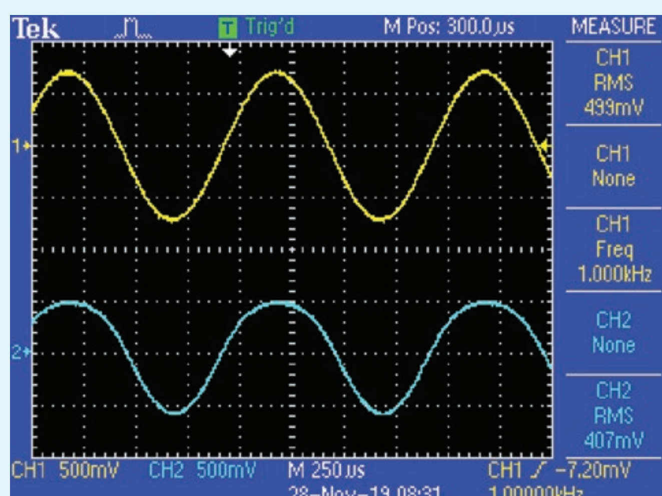


(TOP OF PCB) (UNDERSIDE OF PCB)

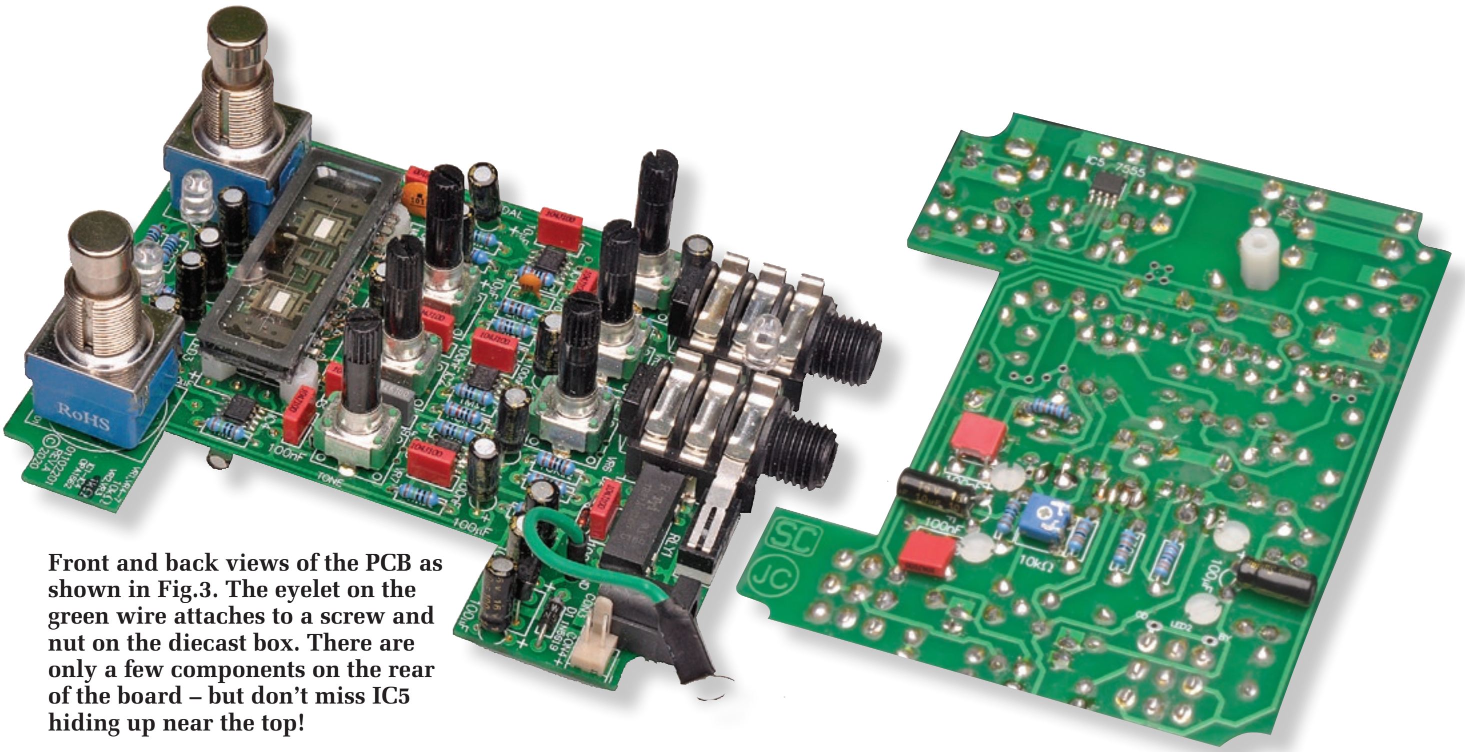
Fig.3: these PCB overlay diagrams show where all the parts go on both sides of the board. Note how the lever of microswitch S1 is touching jack socket CON2 (also see photos). And while potentiometers VR1-VR3 and VR5-VR7 look identical, and are all 10kΩ pots, some are linear and some are logarithmic, as described adjacent to the board. Be sure to orientate the ICs, diodes, LEDs, electrolytic capacitors and RLY1 as shown here.



Scope1: the input signal is shown at the top and the output signal at the bottom. Here the first distortion control is set for minimum distortion (mid-position), with the gain control set so that there is no overdrive. Therefore, the output waveform is similar to the input.



Scope2: using the same settings as in Scope1, except that the first distortion control is rotated fully clockwise. The lower trace shows flat-topping of the sinewave for the positive portion of the waveform, giving significant distortion.



Front and back views of the PCB as shown in Fig.3. The eyelet on the green wire attaches to a screw and nut on the diecast box. There are only a few components on the rear of the board – but don't miss IC5 hiding up near the top!

x 94 x 34mm. Fig.3 shows the PCB assembly details.

Begin by fitting the surface-mounting parts on the top side of the PCB, ie, IC1-IC4, followed by IC5 on the underside. These are not difficult to solder using a fine-tipped soldering iron.

Good close-up vision is necessary; you may need to use a magnifying lens or glasses to see well enough.

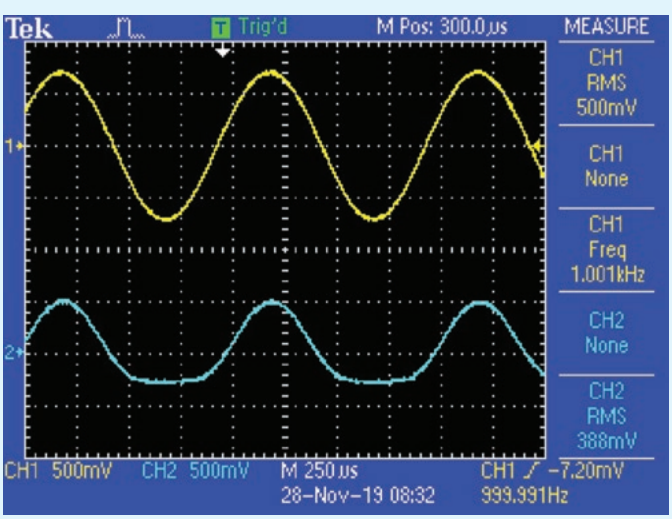
Make sure that these components are oriented correctly before soldering in place. Also, check that IC5 is the 7555 timer. For each device, solder one pad first and check its alignment.

Adjust the component position by reheating the solder joint if necessary before soldering the remaining pins. If any of the pins are bridged by solder, use solder wick to remove it.

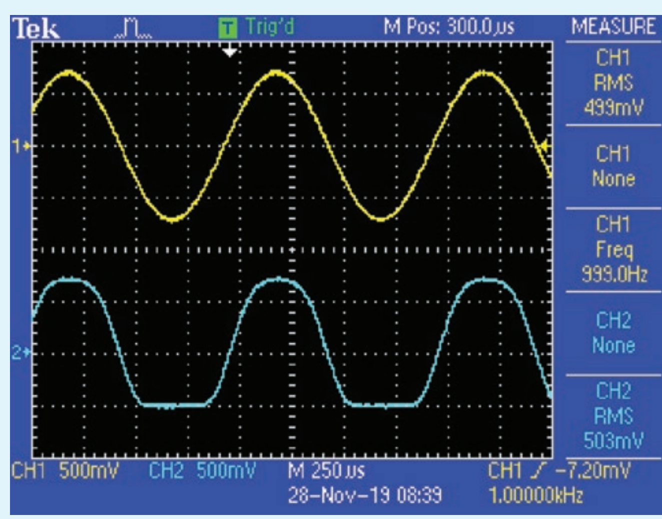
Note that adjacent pins 1 & 2 of IC1, IC2, and IC4 and pins 6 & 7 of both IC3 and IC4 connect together on the PCB, so a solder bridge between these pins is acceptable.

Continue construction by mounting the resistors on the top side of the PCB (use your DMM to check the values), followed by the ferrite bead (FB1). Feed a resistor lead off-cut through the bead and bend the lead to fit the PCB pads. Push the bead lead down so that it sits flush against the PCB before soldering its leads.

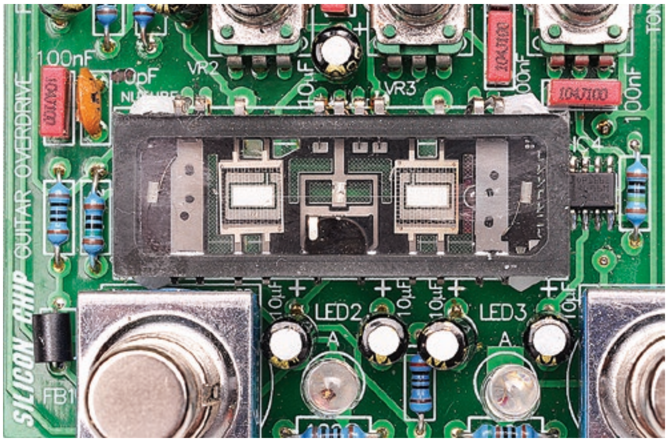
The resistors that mount on the underside of the PCB can be installed now. Solder these from the top side of the

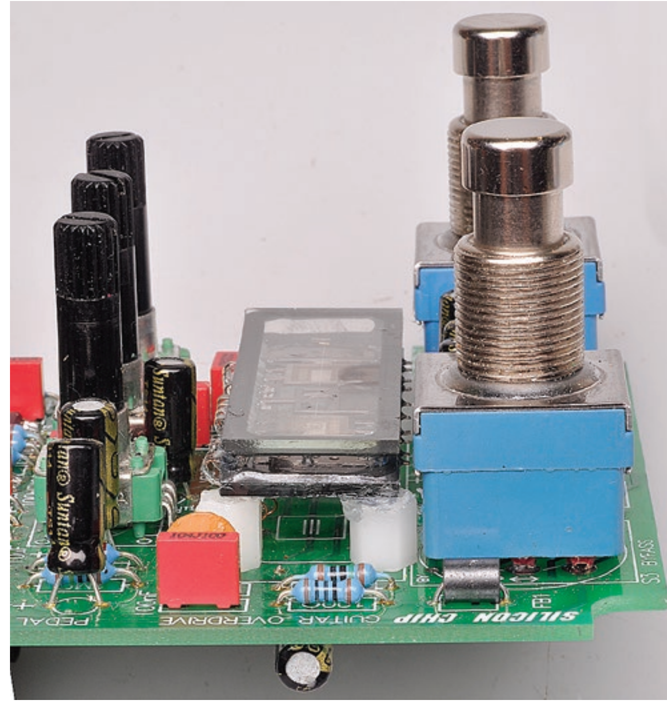


Scope3: the first stage distortion control is now set fully-anticlockwise. The top trace is the input signal, while the lower trace shows the flat topping (or is that bottoming?) of the sinewave on negative excursions.



Scope4: the gain is increased to set up an overdrive situation with the first distortion control set for minimum distortion (mid-way). The output level control is adjusted down to reduce the output signal level, compensating for the high gain at the input. Note how flat the negative portion of the waveform is; more signal would increase this and also begin to flatten the positive portion.





The 6P1 valve mounts on four 6.3mm Nylon standoffs, as shown in these photos. This helps minimise microphonics which could otherwise be a problem.

PCB and trim the leads close to the PCB. Diodes D1 and D2 can then be mounted – note they are different types. Take care to orientate them correctly.

Now fit the MKT and two ceramic capacitors, followed by the electrolytic capacitors, which are polarised. Their longer leads go to the pads marked with a + on the PCB. The two 100nF and two 100µF capacitors that mount on the underside of the PCB need to lie on their sides.

Next, install trimpot VR4 on the underside, soldering its pads on the top side. VR4 might be marked as 203 rather than 20kΩ.

Follow with potentiometers VR1-VR3 and VR5-VR7, noting that VR1, VR5, and VR6 are logarithmic types (marked A) and VR2, VR3 and VR7 are linear types (marked B). These pots may be labelled as 103 instead of 10kΩ.

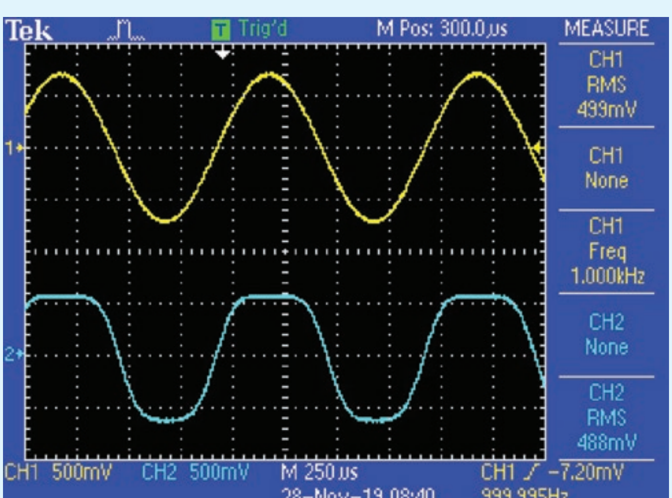
The next step is to fit REG1 by splaying its leads slightly to fit the hole arrangement on the PCB. Also, install the PC stake at the GND test point. The locking header for the battery lead can be fitted now, then RLY1, the two jack sockets and the DC socket.

Switch S1 is mounted so that the lever is captured under the front sleeve contact of the CON2 jack socket. We have provided slotted holes so the switch can be inserted and slid, so the lever enters under the contact.

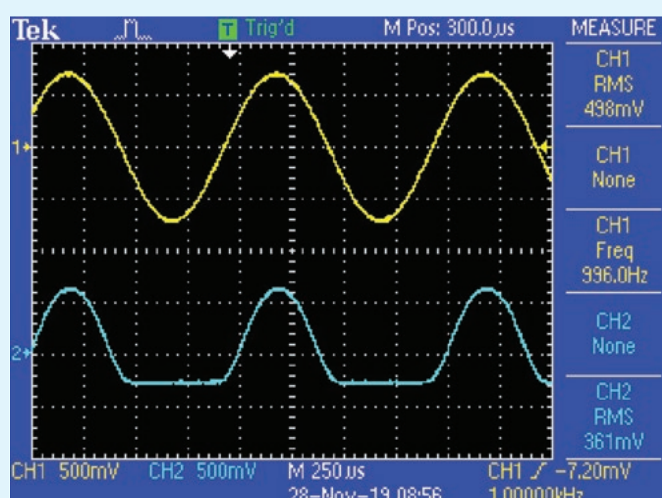
Check that the switch is open circuit, between the two outside pins, when there is no jack plug inserted. There must be continuity between the two outside pins when a jack plug is inserted.

You may need to bend S1's lever a little so that the switch works reliably.

Mount foot switches S2 and S3 now. Make sure these are perfectly vertical before soldering their pins. The LEDs

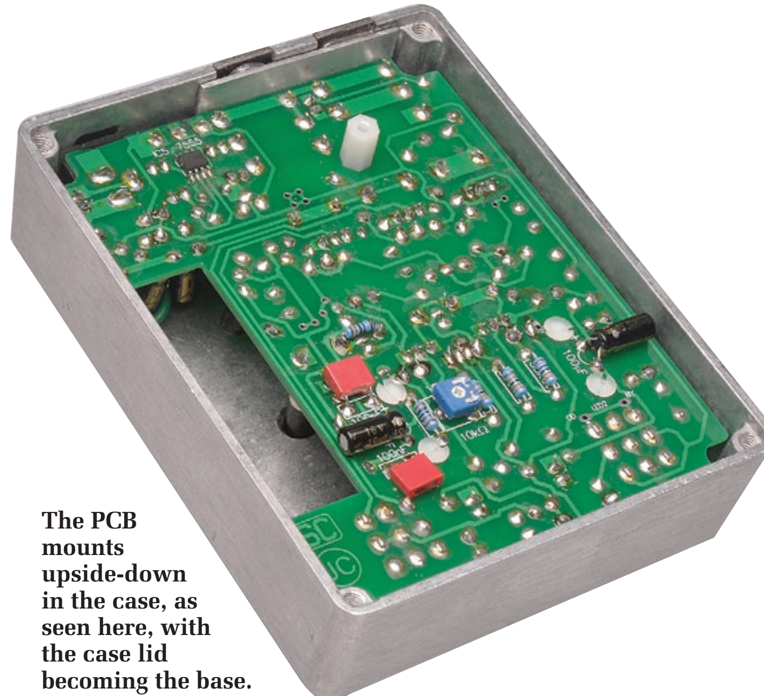


Scope5: the settings as the same as in Scope4, but with the Stage1 distortion control set fully clockwise. This produces a more square form of overdrive; the incoming sinewave is being converted into a sort of rounded square wave.



Scope6: the same settings as in Scope4 and Scope5, but with the first distortion stage control set fully anticlockwise. The output waveform is now very flat on negative excursions but mostly undistorted on positive excursions.

14 holes and two slots are drilled/cut in the diecast case. Note these holes are in the bottom and end of the case. (See dimensioned drilling diagram on page 36).



The PCB mounts upside-down in the case, as seen here, with the case lid becoming the base. All controls emerge through what was the base – which is now the front panel! Five bezels in the panel show the status of the LEDs and 6P1 Twin Triode.

are mounted later when the PCB is installed in its case.

Wiring

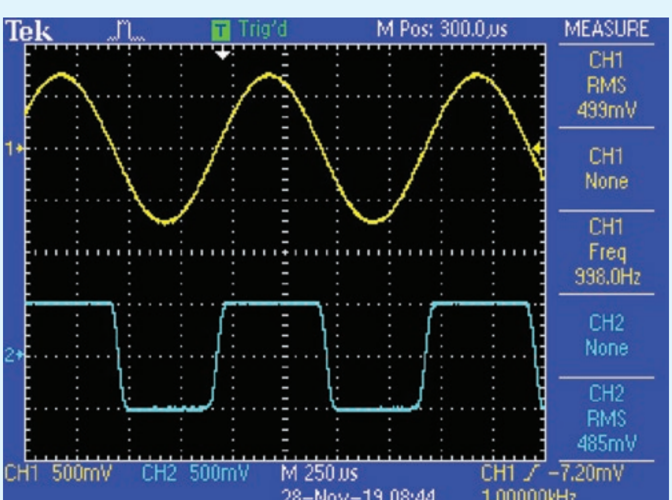
The Nutube is mounted with its envelope parallel to the PCB. Its leads are soldered to the pads on top of the PCB using short lengths of enamelled copper wire. This wire helps prevent microphonics in the Nutube, by giving a flexible connection.

Bend the Nutube leads back under the body and solder 20mm lengths of the 0.25mm enamelled copper wire to each Nutube lead. Molten solder held over the end of the wire will burn off the enamel so that the wire can be soldered.

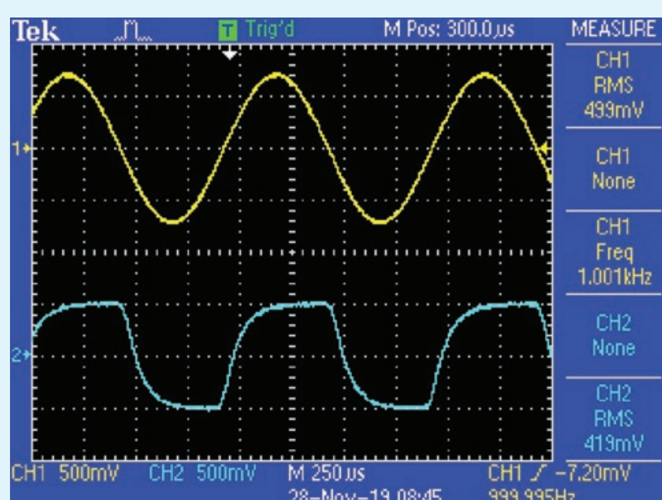
There are two leads for F1 and two leads for F3 at each end of the Nutube. The two leads are connected together, so only one wire is needed to connect each pair to the PCB.

Secure the four 6.3mm Nylon spacers to the PCB under where the Nutube mounts, using Nylon or polycarbonate screws.

Place small dobs of neutral-cure silicone sealant on top of each spacer, then sit the Nutube on top. There should



Scope7: with boost on, the waveform is now so overdriven and limited that the output waveform is almost square.



Scope8: this shows the effect of the tone control when set for maximum high-cut. The settings are the same as in Scope7, except for the tone control. Note the difference between the squared waveform in Scope7 and the rounded off surf-wave like effect here, due to the operation of the tone control.

Parts list – Nutube Guitar Effects Pedal

1 double-sided PCB coded 01102201, measuring 86 x 112mm
1 panel label
1 119 x 94 x 34mm diecast enclosure [Jaycar HB5067]
1 Korg Nutube 6P1 double triode thermionic valve (V1) [RS Components 144-9016]
2 6.35mm PCB jack sockets (CON1,CON2) [Jaycar PS0195]
1 2-pin PCB-mount header with 2.54mm spacing (CON4) [Jaycar HM3412, Altronics P5492]
1 PCB-mount DC power socket (CON3) [Jaycar PS0520, Altronics P0621A]
1 2-pin polarised header plug [Jaycar HM3402, Altronics P5472 + 2 x P5470A]
1 C&K ZMA03A150L30PC microswitch or equivalent (S1) [eg, Jaycar SM1036]
2 3PDT footswitches (S2,S3) [Jaycar SP0766, Altronics S1155]
1 5V DIL reed relay (RLY1) [Jaycar SY4030, Altronics S4100]
6 11.5mm diameter 6mm tall 18-tooth spline knobs [RS Components 299-4783] (see text)
1 4mm OD, 5mm-long ferrite bead (FB1) [Altronics L5250A, Jaycar LF1250]
5 5mm clear LED bezels [RS Components 171-1931]
1 6.3mm mono jack plug or jack plug lead (to test power switching)
1 9V battery
1 9V battery clip lead
1 9 x 45mm piece of 1-1.5mm thick aluminium sheet
1 PC stake (GND)
1 solder lug (for grounding enclosure)
4 stick-on rubber feet OR
4 M4 x 10mm Nylon screws – see text
4 6.3mm-long M3 tapped Nylon spacers (to go under Nutube)
4 M3 x 6mm Nylon or polycarbonate screws (for Nutube spacers)
1 9mm-long M3 tapped Nylon spacer (support for PCB)
2 M3 x 6mm screws (for solder lug and 9mm spacer)
1 M3 nut and star washer (for solder lug)
1 160mm length of 0.25mm diameter enamel copper wire
1 50mm length of green medium duty hookup wire
2 100mm cable ties

Semiconductors
4 OPA1662AID dual op amps, SOIC-8 (IC1-IC4) [RS Components 825-8424]
1 ICM7555CBA CMOS timer, SOIC-8 (IC5)
1 1N5819 1A schottky diode (D1)
1 1N4148 small signal diode (D2)
1 LP2950CT-5.0 5V LDO regulator (REG1)
3 5mm high-intensity LEDs (one green and two red recommended)

Capacitors
6 100µF 16V PC electrolytic
10 10µF 16V PC electrolytic
11 100nF MKT polyester
1 6.8nF MKT polyester
1 470pF ceramic
1 100pF ceramic

Resistors (all 0.25W, 1% metal film)

6 1MΩ	1 470kΩ	2 330kΩ	1 33kΩ	1 13kΩ	7 10kΩ	
1 8.2kΩ	1 6.2kΩ	1 1kΩ	3 510Ω	1 200Ω	1 150Ω	2 100Ω

1 20kΩ miniature horizontal trimpot (VR4) [Altronics R2481B, Jaycar RT4362]
3 10kΩ vertical 9mm log (A) pots (VR1,VR5 & VR6) [Altronics R1958]
3 10kΩ vertical 9mm linear (B) pots (VR2,VR3 & VR7) [Altronics R1946]

Miscellaneous
Solder, solder wick, clear neutral-cure silicone sealant (eg, roof and gutter silicone)

The infill piece we made to cover the slots (as seen opposite). Fig.4 (below) shows the dimensions.

be a 1mm silicone bead between each spacer and the underside of the Nutube envelope. Ensure the Nutube is correctly positioned and wait for the silicone to cure.

The next step is to cut the battery wires to 60mm long, then crimp or solder them to the polarised plug pins. Insert these terminals into the plug shell, making sure you get the red and black wires in the correct position for polarity: + to red and – to black.

A grounding wire is required to connect the case to the GND terminal on the PCB. This prevents hum injection to the circuit via the enclosure. Solder the wire to the lug at one end and the GND terminal at the other.

Heatshrink tubing can be used over the lug terminal and the GND PC stake. When assembled, the solder lug is secured to the case using M3 x 6mm screw, star washer and M3 nut.

Powering up and testing

If you are planning to use a battery, connect it now. Alternatively, plug in a 9-12V DC supply to CON3. Insert a jack plug into CON2 to switch on the power.

Set your multimeter to read DC volts, connect the negative probe to the GND terminal and measure the regulator input and output voltages. The input should be about 0.3V below the DC supply. The regulator output should be between 4.95V and 5.05V.

Also, check that RLY1 switches on

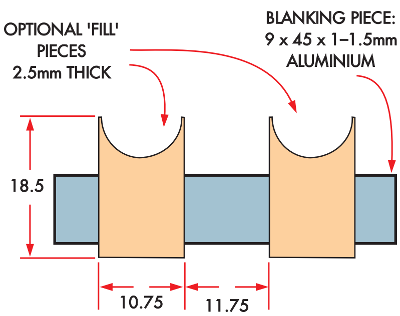


Fig.4: cut a piece of aluminium as shown to partially cover the slots, with the two optional plastic pieces glued to it to fully cover those spaces.

The 6.35mm input/output sockets need to be slid into place which necessitates slots, rather than holes (as can be seen in the drilling photo on page 33). We fashioned an infill piece from scrap aluminium (seen opposite) the same size as the slots, held in place by the sockets themselves and their washers/nuts.

(Right): rather than glue feet on the lid of the case (which becomes the base!) we used four M4 Nylon pan-head screws which act as pretty robust feet, their heads being slightly proud of the surface. We reasoned that glue-on feet probably wouldn't last long in use but the screws should last.

after about five seconds. You should hear a quiet click.

Centre VR2 so that the left-hand plate of the Nutube lights up at its brightest. Similarly, adjust VR3 so the right-hand plate of the Nutube glows brightest. Note that when the signal passes through the unit, the plate glow will dim a bit. Set VR4 fully clockwise for now.

Housing it

We use the lid of the diecast enclosure as the base, and the main body becomes the top. The drilling diagram (Fig.5) shows where holes are made in the base and side of the case, and can also be used as a template. Holes are required for the potentiometer shafts, LED bezels, Nutube viewing holes and the footswitches on the main panel area.

Cut-out slots are also required for the two jack sockets and DC power inlet, at the end of the box. Slots, rather than holes, are required so that the jack sockets can be manoeuvered into place.

To stop dirt and other gunk from entering the case we made a 45mm x 9mm blanking piece from a sheet of 1-1.5mm thick aluminium. This covers the slots from the inside, after the jack sockets have been inserted. We also added some shaped plastic pieces to fill the slots to the same level as the outside of the enclosure.

This is optional; the fill pieces can be glued to the backing piece, as shown in the drawing and photograph.

It's a good idea to add rubber feet so it won't move during use. While you could apply stick-on rubber feet to the lid, we weren't convinced they would stay stuck on during the rough and tumble of use.

So we replaced the original lid securing screws with Nylon M4 panhead screws instead. The heads are proud of

Resistor Colour Codes

	Qty.	Value	4-Band Code (1%)	5-Band Code (1%)
❑	6	1MΩ	brown black green brown	brown black black yellow brown
❑	1	470kΩ	yellow violet yellow brown	yellow violet black orange brown
❑	2	330kΩ	orange orange yellow brown	orange orange black orange brown
❑	1	33kΩ	orange orange orange brown	orange orange black red brown
❑	1	13kΩ	brown orange orange brown	brown orange black red brown
❑	7	10kΩ	brown black orange brown	brown black black red brown
❑	1	8.2kΩ	grey red red brown	grey red black brown brown
❑	1	6.2kΩ	blue red red brown	blue red black brown brown
❑	1	1kΩ	brown black red brown	brown black black brown brown
❑	3	510Ω	green brown brown brown	green brown black black brown
❑	1	200Ω	red black brown brown	red black black black brown
❑	1	150Ω	brown green brown brown	brown green black black brown
❑	2	100Ω	brown black brown brown	brown black black black brown

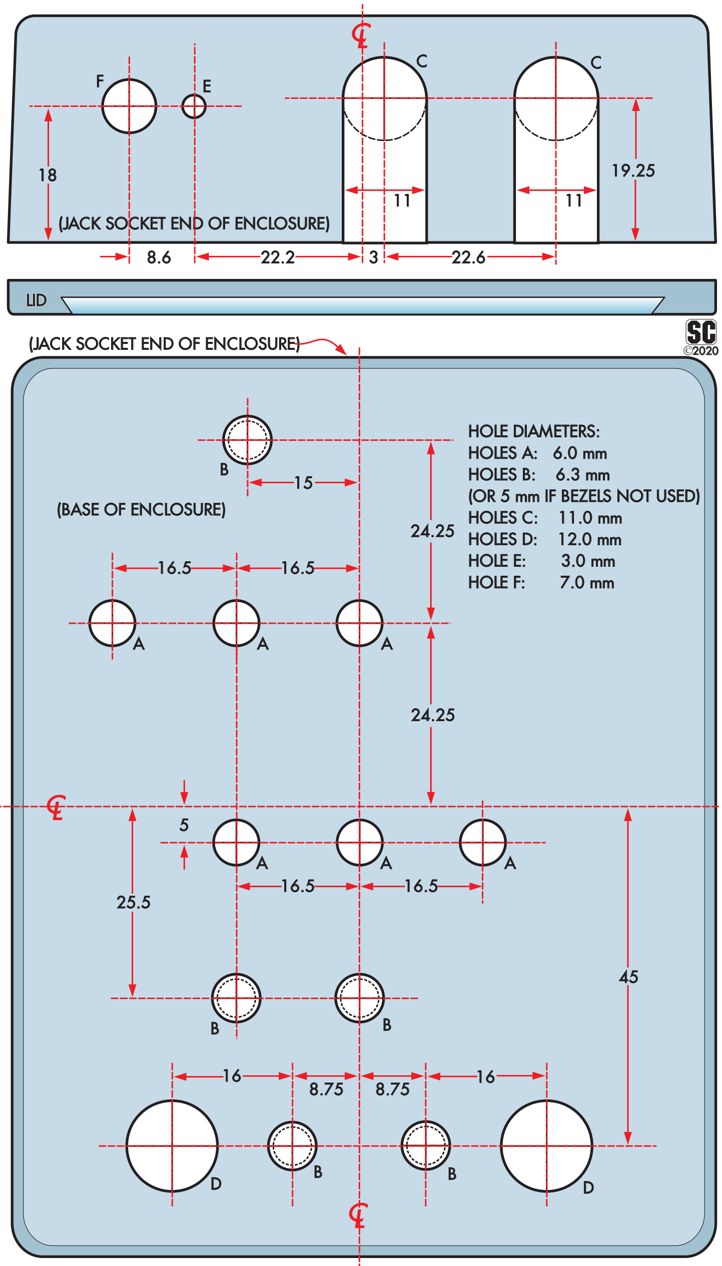


Fig.5: drill the holes in the enclosure base and side as shown. Two of the holes in the side need to be slotted so that the sockets can slide down into place. The only hole required in the lid is optional, to access VR4; use the PCB to locate this hole if you've decided to drill it.

the surface by a couple of millimetres and hence act as the feet. However, to allow this, the holes in the enclosure for the original mounting screws had to be drilled out to 3.5mm then tapped using an M4 tap.

Fig.6 shows the lid panel artwork we have prepared for the Pedal. It can be copied from this diagram, or downloaded from the SILICON CHIP website and printed out (the download also includes the drilling templates).

To help protect it, you can print the label onto overhead projector film as a mirror image, so the ink will be between the enclosure and film when affixed. Use projector film that is suitable for your printer (either inkjet or laser) and affix using clear neutral-cure silicone sealant. Squeegee out the lumps and air bubbles before the silicone cures. Once cured, cut out the holes through the film with a hobby or craft knife.

For more detail on making labels see www.siliconchip.com.au/Help/FrontPanels

Mounting the PCB

Attach the 9mm M3 tapped spacer to the rear of the PCB using an M3 screw through the top. The hole is located between CON1 and CON2. This spacer keeps the PCB in place by resting on the lid when the case is assembled.

If you haven't already done so, solder the ground to the GND PC stake on the top of the PCB and shrink a short length of heatshrink tubing over the stake. The ground lug mounting position is adjacent to the DC socket. Secure this using an M3 screw, star washer and nut before the PCB is inserted into the case.

Orientate the solder lug so that the wire is closest to the base of the enclosure, so it does not foul any components on the PCB.

Insert the LED bezels from the outside of the case. The Nutube viewing holes also require bezels to stop dirt and dust from getting in. They can be held in place with small cables ties, pressing them against the inside of the enclosure, then glued in place with silicone sealant.

Before putting the PCB into the enclosure, insert the LEDs into the PCB holes. The longer anode leads must go into the holes marked "A" on the PCB. Place the Nylon washers for the footswitches onto each switch shaft, then fit the PCB into the enclosure. Push the LEDs into position in their bezels to capture them, then solder the LED leads from the rear of the PCB.

The battery compartment is made from a rectangular cut-out on the PCB. The battery can be prevented from moving by packing some of the foam packaging supplied with the Nutube around it.

Insert this between the end of the battery and the edge of the PCB. If you are not using a battery, unplug the battery clip from CON3 and remove it to prevent the contacts from shorting against the board.

Knobs

Since the potentiometer shafts do not protrude much more than 9mm above the lid, you can't use standard knobs with a skirt. The skirts are intended to cover the potentiometer securing nut but there is no nut here, resulting in insufficient internal fluting to secure the knobs to the shafts.

There are two ways around this; either use knobs without a skirt, or cut the skirts off. The knobs mentioned in the parts list don't have skirts.

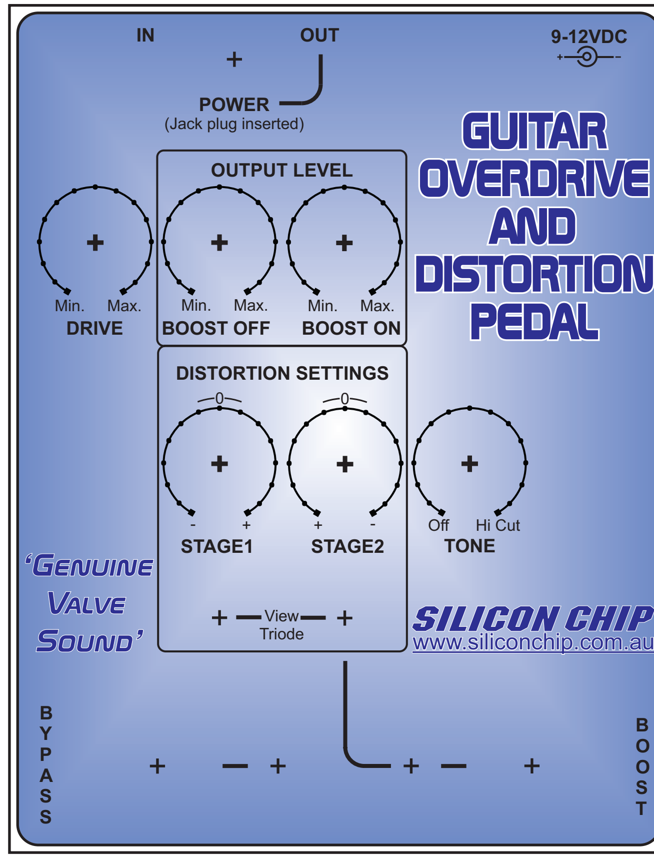
If you can't get those for some reason, you can purchase Jaycar knobs in the HK7730-7734 range (we recommend Cat HK7733 blue) and cut the lower skirt flange off with a hacksaw.

Finally, secure the lid in place using either the original screws or Nylon M4 screws, as mentioned previously. Attach the rubber feet to the base using their sticky-back adhesive if you are not using the Nylon screws as feet.

Removing the knobs

The knobs may be difficult to remove by pulling; you may need to lever them off. Insert a sheet of thin plastic between the lever (eg, a flat-bladed screwdriver) and the case to prevent damage to the panel.

Fig.6 (right): same-size front panel artwork which fits on the bottom of the diecast case (which of course becomes the top!) It's easiest to cut the holes once the panel has been glued in position. Note our comments re longevity of this panel – it's likely to suffer some pretty rough treatment!



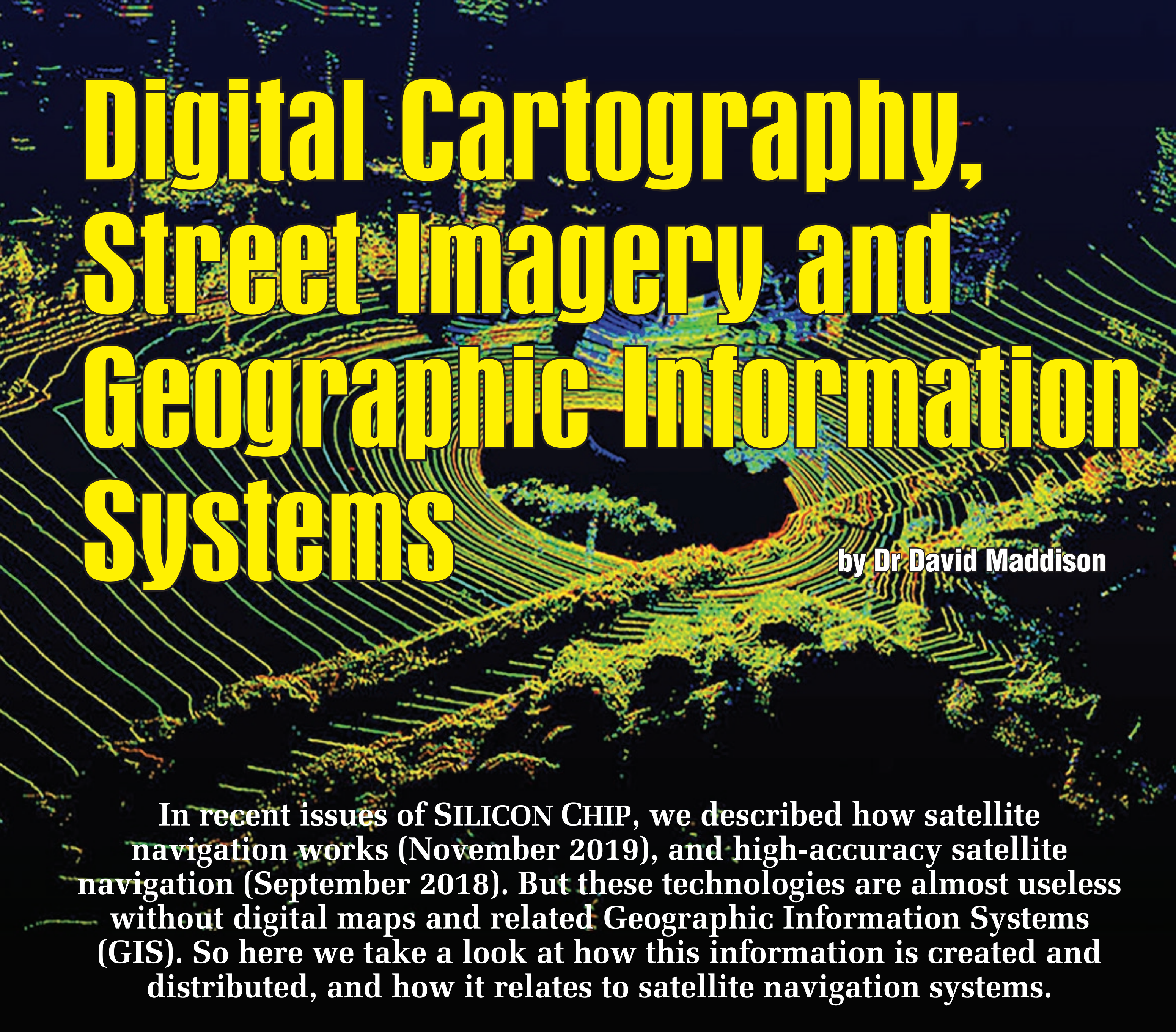
Using it

It's basically just a matter of twiddling the controls until you get the sound you want. The only control which is not externally accessible is trimpot VR4, so it's a good idea to figure out what you want to do with this before you close the case. But note that the Pedal is designed so that you can drill a hole in the base to externally adjust VR4 with a screwdriver.

We prefer to leave VR4 fully clockwise so that there is a substantial limiting action when in boost. But you might want to adjust VR4 so that the second distortion stage has a similar effect to the first, and they combine more evenly with the distortion control adjustments. It is a matter of personal preference.

Many amplifiers for musical instruments have an Earth loop switch which allows the common shield connection of the jack lead to either be Earthed or floating. When used with a guitar that has piezo pickups, you should get less hum when it is connected to Earth.

Oscilloscope screen grabs Scope1-Scope8 show how the output waveform varies with a range of different control settings. See those screen grabs for more details. SC



Digital Cartography, Street Imagery and Geographic Information Systems

by Dr David Maddison

In recent issues of SILICON CHIP, we described how satellite navigation works (November 2019), and high-accuracy satellite navigation (September 2018). But these technologies are almost useless without digital maps and related Geographic Information Systems (GIS). So here we take a look at how this information is created and distributed, and how it relates to satellite navigation systems.

Digital cartography, also known as digital mapping, is the process by which information is collected, compiled and formatted to produce maps in an electronic form. These can be used in a variety of applications, but most commonly they are used for everyday navigation tasks via smartphones or in-car navigation systems.

Digital maps can also be used to represent a variety of other information such as income levels, voting patterns, sales figures, disease outbreaks, pollution levels, agricultural productivity, soil types, rainfall or any of thousands of other metrics.

Technologies used to analyse, manipulate and acquire such data are referred to as Geographic Information Systems or GIS.

The history of modern mapping

In the past, such information was represented on paper maps, but those took a long time to produce, and could not be easily updated. It was also more difficult to overlay other data on paper maps compared to electronic systems.

One of the earliest attempts at using maps for spatial analysis was by physician John Snow in 1854, with his famous cholera map of the Broad Street area of London (Figs.1 & 2). This lead to the determination that one cholera outbreak was due to a contaminated public hand water pump. Removing the handle of the pump, rendering it inoperative, stopped the outbreak.

This followed on from French geographer Charles Picquet, who published a map in 1832 showing cholera death rates.

The data from the John Snow cholera map is sometimes used today in digital mapping training exercises.

Modern digital cartography has its origins in the late 1960s to 1970s (with certain applications as early as the 1950s), when computers were starting to become available with the large amount of memory and processing speed needed to produce digital maps.

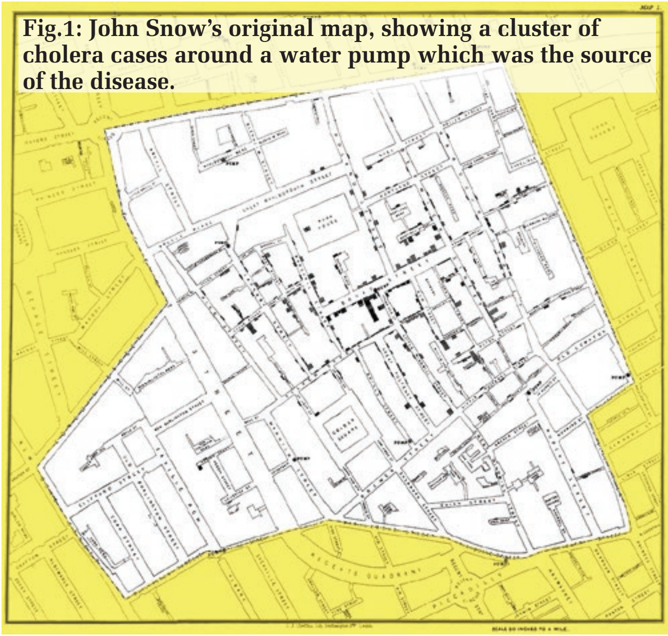


Fig.1: John Snow's original map, showing a cluster of cholera cases around a water pump which was the source of the disease.

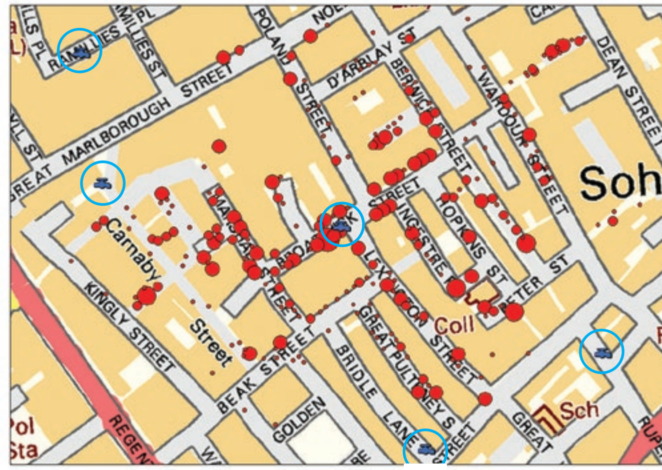


Fig.2: a portion of John Snow's data replotted on modern digital maps of the area by Dr Robin Wilson, clearly showing the position of the pumps (blue icons). The size of the red dots represents the number of cholera cases at a particular location. There are five pumps visible, but the disease outbreak is clustered around one.

Digital cartography was initially known as computer-assisted cartography. It preceded the speciality of Geographic Information Systems (GIS) involving the storage, retrieval, analysis and display of spatial data on a cartographic background, such as the modern version of John Snow's map shown in Fig.2.

Different types of map projections require the evaluation of complex mathematical formulae on a repeated basis, and this was an early advantage for the use of computers in cartography.

As early as the late 1950s, alphanumeric character line printers were used to make crude maps, with an approximate resolution of ten columns per inch across the page and six or eight rows per inch down the page.

Output quality continued to improve with the development of more advanced plotters through the 1960s and 1970s. Eventually, regular printers could produce high-resolution images and plotters became unnecessary. It also helped that monitors became capable of displaying high-resolution images.

Early digitisation of maps and aerial photos

Before the availability of GPS, digital cameras and computers were used to copy features from aerial photographs into digital maps. With the advent of computers, it became possible to digitise such maps or to directly digitise features from a photograph. Aerial and satellite photography is still used today in the production of maps.

An early example of such a digitising unit is the Kern ER34 (Fig.3), combined with the Kern PG2 photogrammetric stereo plotter (Figs.4 & 5). The stereo plotter was used to perform an analog transfer of data from stereo aerial photos to other materials, such as paper or to a computer, when fitted with an appropriate interface.

Thus it could produce mapping data by either analog or digital methods. The machine corrects for distortion in the photograph and plots the data onto a map, or sends digital data to a computer. Because of the stereo nature of the photos, elevation contours could be produced. This elevation data was also used to create a Digital Elevation Model (DEM) of the terrain in the digital age.

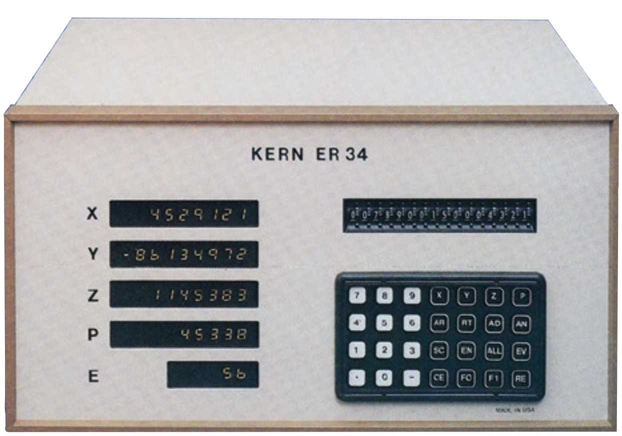


Fig.3: the Kern ER34 digitising unit from 1979 which used a Zilog Z80 microprocessor. It displayed coordinates on numerical LED displays and data was acquired from a digitising device like a Kern PG2 stereo plotter, connected via a TTL interface. Data could also be recorded to an external computer via RS-232.

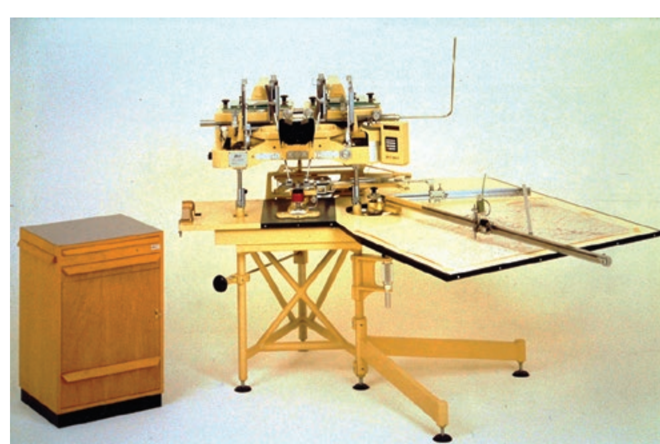


Fig.4: a Kern PG2 stereo plotting instrument. When fitted with rotary encoders, it could send data to the Kern ER34 digitising unit. Otherwise, it acted as a conventional stereo plotting device, thus straddling the old and new ways of mapping.

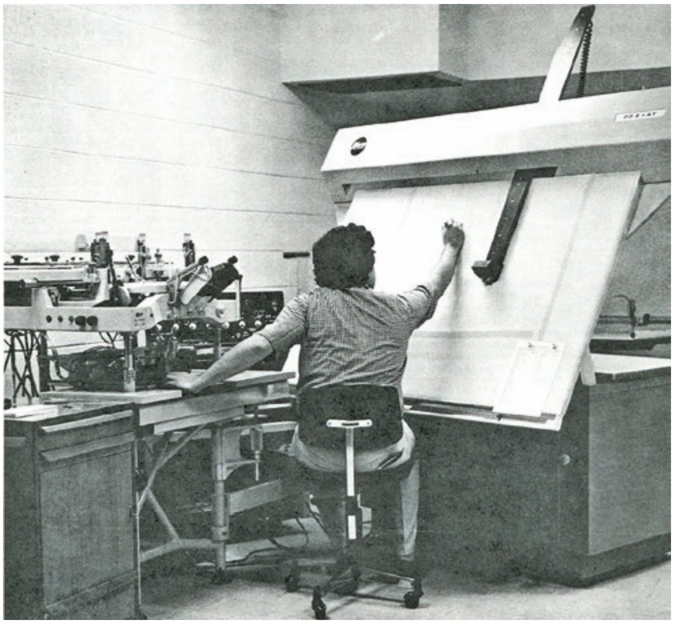


Fig.5: a photo from the "The Ontario Land Surveyor" of Winter 1979, showing the Kern PG2 stereo plotter connected to a Kern DC2-B Digitiser-Graphics Computer and an "automatic drafting table". Aspects of feature extraction from stereo photos were automated or semi-automated.

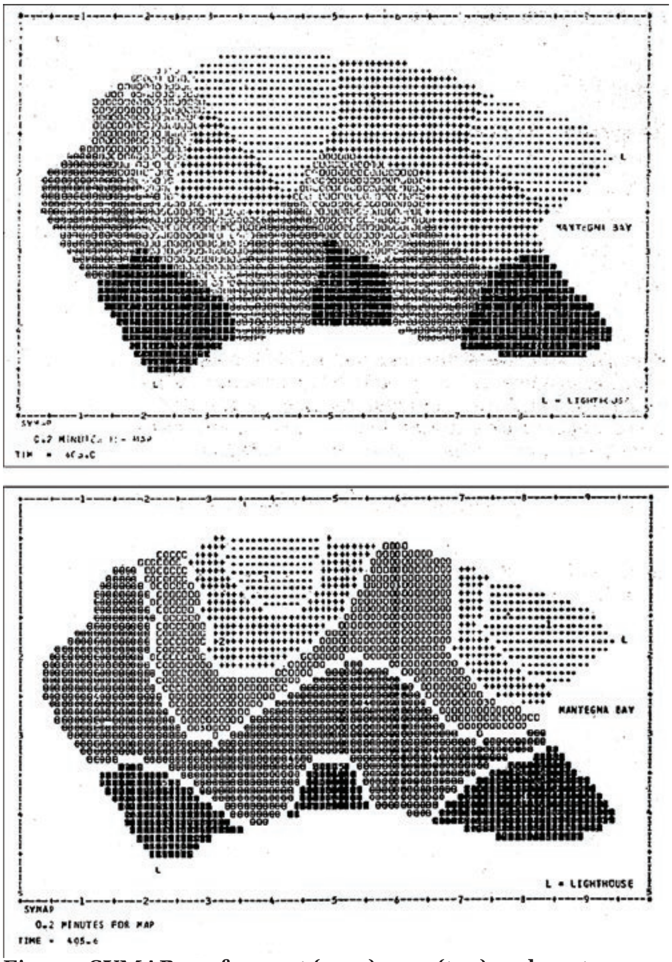


Fig.7: a SYMAP conformant (area) map (top) and contour map (bottom) from 1963. There are no true graphics involved; this map is made of characters printed on a line printer, some of which are overprinted to produce greyscales.

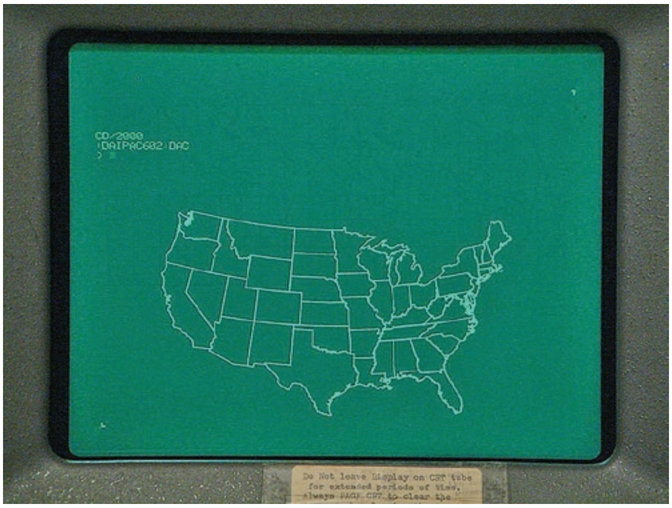


Fig.6: vector map data displayed on a Tektronics 4014 storage tube graphics terminal, released in 1972. Memory was expensive in early computers, so only the endpoints of the straight lines representing the vector elements are stored in computer memory. The lines drawn between them exist only as persistent images in the phosphor of the display. Source: David Gesswein of PDP8Online.

Before Google Maps, most of the world was mapped using stereo plotter machines such as these.

Digital map data could also be plotted or displayed on a video display unit such as a Tektronics graphics terminal (Fig.6), instead of plotting it on paper.

Map-making today

Today, maps are usually made straight from digital images such as aerial or satellite photos, or from remote sensing images, or other digital data such as GPS plots or LIDAR/radar data. These allow elevation to be fed directly into a

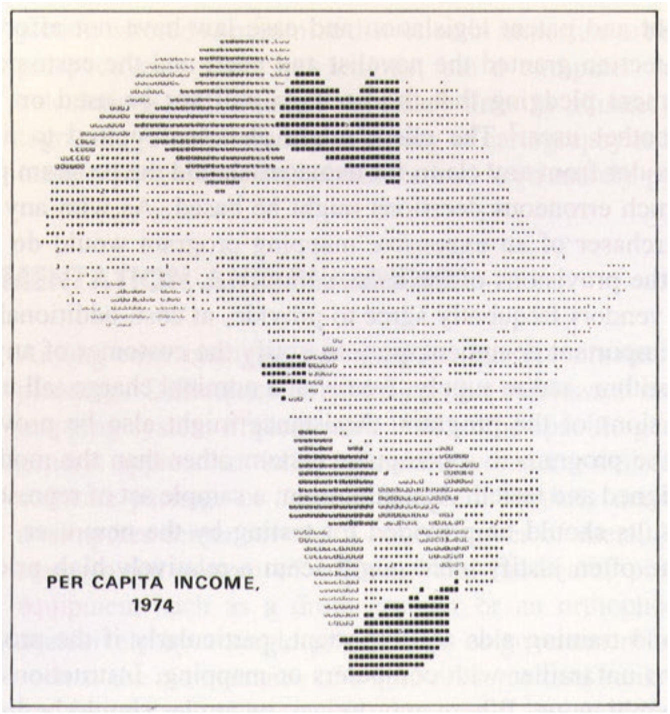


Fig.8: a map from 1974 showing income levels printed using alphanumeric characters on a line printer.

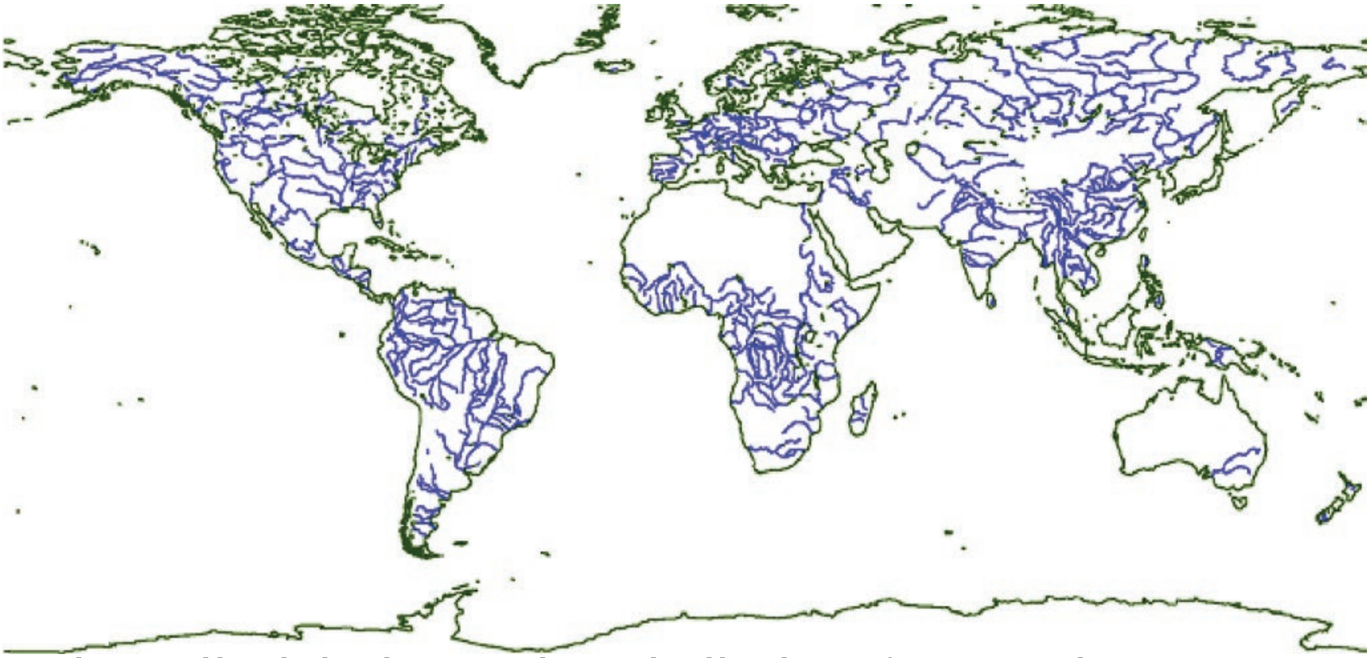


Fig.9: the CIA World Databank II, showing rivers but not political boundaries. Reference Gorny and Carter, 1987.

computer, avoiding numerous intermediate steps like manually "walking the land", as used to be done before aerial photography.

These days, the focus is very much on adding layers of information as in Geographic Information Systems (GIS), ie, building GIS databases.

SYMAP software

Howard Fisher invented the SYMAP (Synergistic Mapping) system in 1963. It was the first computer mapping system that could be used to analyse and produce maps of spatially distributed data (Figs.7 & 8). With the aid of grants and other individuals, he established the Harvard Laboratory for Computer Graphics and Spatial Analysis and developed SYMAP for release in 1966, along with other mapping systems.

The laboratory existed at Harvard University (in Cambridge, USA) from 1965 to 1991, and it pioneered early digital cartographic and geographical information systems (GIS). SYMAP became popular in the late 1960s because it

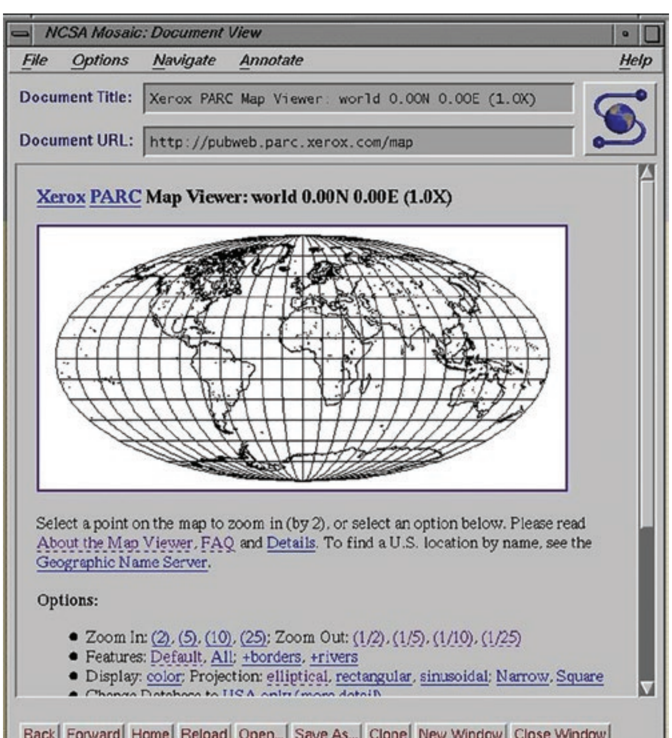


Fig.10: a Xerox PARC map view, as shown in the 1993 Mosiac browser.

The "godfather" of digital mapping

One of the little-known but important figures of digital mapping is Jack Dangermond. He founded the Environmental Systems Research Institute (Esri; www.esri.com/en-us/home) in California in 1969, which in 2014 had a 43% worldwide market share of Geographic Information System products, with ArcGIS Desktop being the main one.

The company has seen the transition from minicomputers to workstations, PCs, the internet, cloud computing and mobile devices. The company remains privately held by the Dangermond family.

It has survived despite popular mapping applications like Google because Google Maps is mostly consumer-oriented and Esri focuses on government, business and professional organisations and the highly specialised geospatial information they require. One of the recent major developments of Esri was the establishment of the Los Angeles GeoHub, as described in this article.

Their popular programs include ArcScan as an extension to ArcGIS Desktop, for raster to vector data conversion; ArcView, ArcEditor and ArcInfo are often mention in literature and have been renamed as Basic, Standard, and Advanced versions of ArcGIS Desktop.

Fig.11 (above): an early version of MapQuest from 1996, as displayed in the Netscape browser. Source: Computer History Museum.

could produce inexpensive maps with the standard technology of the time, which were useful although of relatively low quality.

The output was produced on a line printer which drew character-based "graphics" by techniques such as overprinting multiple characters to produce dark areas, or with less overprinting to produce light areas, thus creating a crude type of greyscale.

CIA World Databanks I and II

The CIA World Databank I was first discussed in 1966. You can view the original memo online at siliconchip.com.au/link/aay6

The original proposal was for a map of the world which would require 50,000 data points.

The CIA World Databank II was released in 1985, and was a vector map of land outlines, rivers and political boundaries of the world (see Fig.9). The maps comprise five million data points and are simple black and white images. They have been typically used as a basis for composing other maps. This map data can be downloaded from siliconchip.com.au/link/aay7

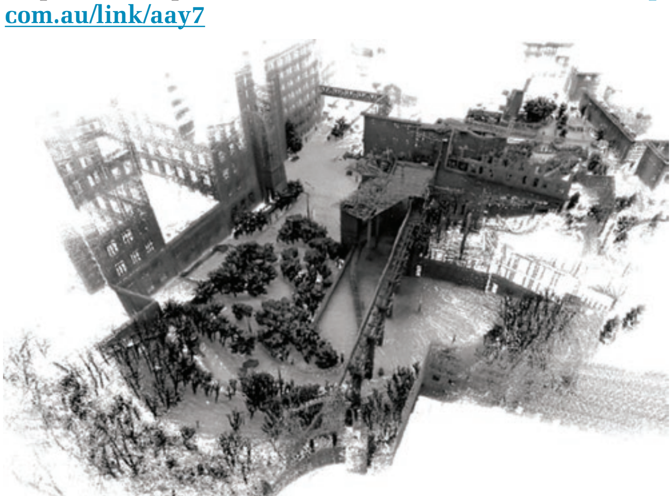


Fig.13: a typical image as produced by the company "Real Earth" using a Velodyne LIDAR "Puck LITE", the same type said to be used on Google Street View cars. This 3D imagery can be used for guidance by autonomous vehicles such as cars and drones. Google also produces photographic imagery and other data.

Fig.12: a Google Street View car in Australia. Note the cameras on top of the mast and the two LIDAR devices beneath the blue camera housing.

If you want to see some beautiful examples of CIA Cartography, visit the following links: siliconchip.com.au/link/aay8 and siliconchip.com.au/link/aay9

The Xerox PARC map viewer

The Xerox PARC (Palo Alto Research Center) Map Viewer was the first online map released via the then-young World Wide Web in 1993. It was the first map database to be shared online (see Fig.10).

This was mainly an experiment in interactive information retrieval, rather than a product that could be used for serious navigation. The maps were static images and could not be zoomed or panned, as we are now used to with products like Google Maps.

MapQuest

MapQuest followed on from the Xerox PARC Map Viewer and was established as an online commercial web service in 1996 (Fig.11). Unlike the Xerox Map Viewer, the maps could be zoomed and panned. The company and its predecessors had been in business since the 1960s, and these early web maps were based on digital maps and codes they produced in the 1980s.

Google Earth

Google Earth provides a continuous view of the whole Earth based on satellite and aerial imagery. It has its origins in the 1990s with a computer gaming company called Intrinsic Graphics. It was used as a demonstration platform

Fig.14: a Velodyne VLP-16 LIDAR device, as used on Google cars.

Fig.15: an Apple Maps vehicle near Philadephia, USA. There are thought to be 12 cameras plus LIDAR sensors in the pod on the roof. Source: David Levy.

Fig.16: the Mapillary coverage of Australia.

for 3D gaming software libraries, but the company board wanted to focus on games and not mapping, so created a new company called Keyhole Inc.

They used the technology to stream map databases over the internet. The company was highly successful, and in 2004, Google found that one-quarter of its searches were geospatial in nature, so they acquired that company.

Google now acquires the imagery from several sources, and the maps are available at various resolutions, depending on the area of the Earth covered, at pixel resolutions from 15cm to 15m. Depending on the location, Google Earth can also provide 3D views of certain buildings and also historical imagery.

Google Street View (see below) is now integrated into Google Earth. It also now incorporates 3D imagery of the ocean floor.

Google Maps

Google Maps is the digital mapping service with which most people are likely to be familiar. It is installed on most smartphones and also accessible via the web on desktop and notebook PCs. It shows street maps, aerial/satellite imagery or a hybrid view which combines both.

High-resolution imagery, where available, is taken from low-flying aircraft at an altitude of 240-640m (800-2100 feet). Other imagery is from satellites at slightly lower resolutions. The map data is mostly purchased or leased from aerial imagery producers or copyright holders.

What most people probably do not know is that Google Maps has its origins in a Sydney-based company, Where 2 Technologies. Their software program called Expedition was developed by Danish brothers Lars and Jens Rasmussen and Australians Noel Gordon and Stephen Ma. Google purchased the rights to this software in 2004.

There is an interesting video about Google Maps by an Australian student, Ruby Cogan, titled *"Google Maps - The Australian Co-Inventor, Noel Gordon"* at **https://youtu.be/Es19FvYYI_0**

Google Street View

Google Street View cars have been imaging and mapping Australian streets since 2008. The latest version of Google cars have seven cameras (previous versions had fifteen) – see Fig.12. The current cameras have a resolution of 20MP, and the images taken are mathematically stitched together to produce spherical images.

You can therefore click just about anywhere in Google Maps and see what the street looks like, at that location, from just about any angle.

In addition to those cameras used for general street imagery, the cars also have two high-definition cameras facing left and right, which read street numbers, business names and other written information to produce map metadata.

Apart from cameras, the cars are also said to have two Velodyne VLP-16 "Puck LITE" LIDAR sensors (Figs.13 & 14). LIDAR is akin to radar using lasers. These are presumably used to build a 3D model of the streetscape, perhaps for use by self driving-cars as well as mapping purposes. Naturally, the cars also carry GPS receivers so that they know where each set of images was taken.

For more information on those LIDAR units, see the video titled *"Velodyne Alpha Puck Sensor"* at **https://youtu.be/KxWrWPpSE8I**

Apple Maps and Look Around

Apple has a mapping product like Google Maps, and has also introduced a product similar to Google Steet View called Apple Look Around. They started imaging Australian cities

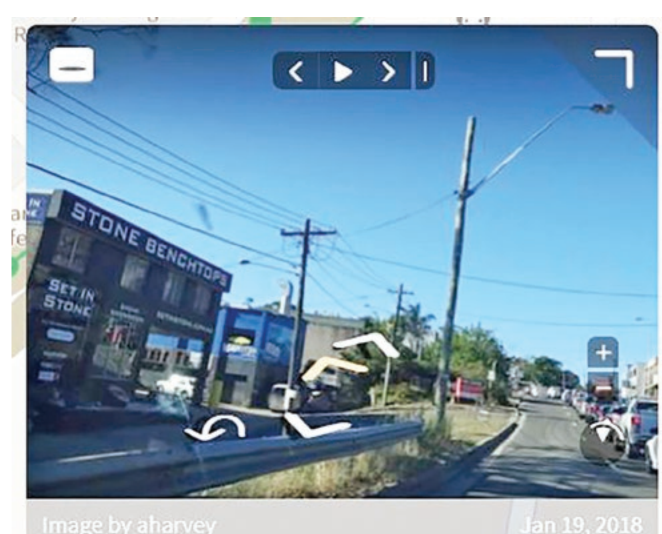


Fig.17: an example of imagery available from Mapillary.

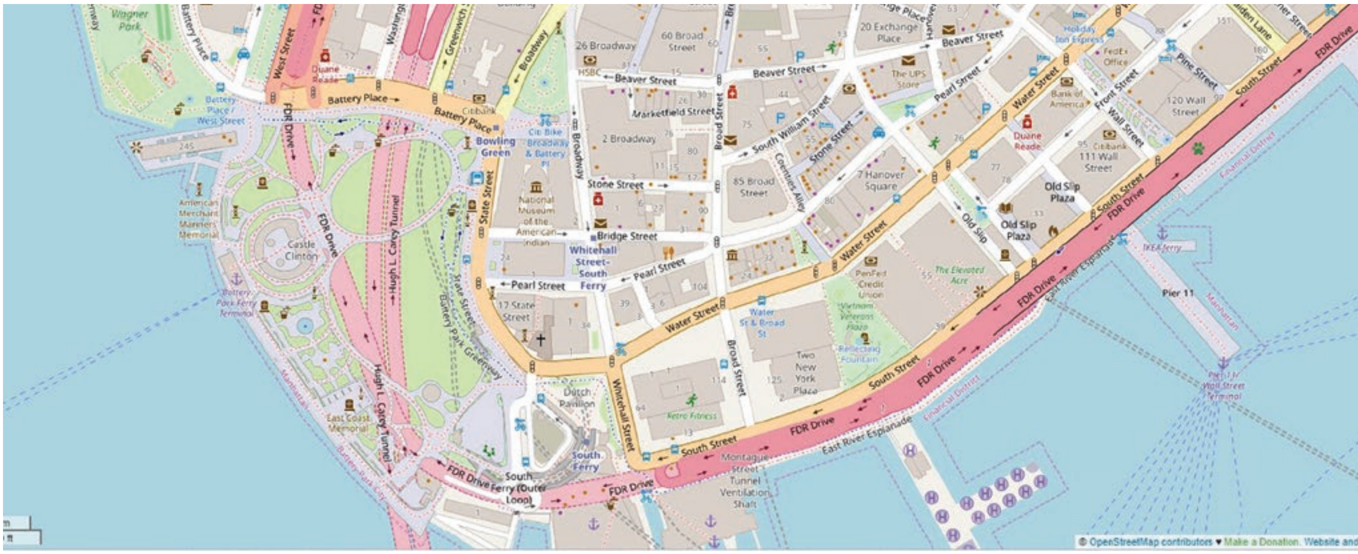


Fig.18: an OpenStreetMap view of lower Manhattan, USA, showing the detail available. These maps are made by ordinary people walking or driving around.

in November 2019 (Fig.15) and are expected to be finished by the end of 2020. A list and schedule for Australian image collection can be seen at siliconchip.com.au/link/aaya

OpenStreetMap

OpenStreetMap is a volunteer collaborative project to provide free maps of the whole world. You can participate in digital mapping yourself by contributing to the OpenStreetMap project at siliconchip.com.au/link/aayb

There are many ways of contributing, including walking or driving routes, geocoding information such as street numbers, and examining and entering data from out-of-copyright maps.

OpenStreetCam and Mapillary imagery

It is also possible to contribute street imagery through unrelated projects such as Mapillary (www.mapillary.com/ – see Figs.16 & 17) or OpenStreetCam (https://openstreetcam.org – see Fig.18). There are iOS and Android apps for both of these services.

Digitising old maps

There is a great deal of valuable information in old maps, such as the location of buildings, roads or property boundaries which might no longer exist. So there are efforts underway all over the world to digitise them.

At the most basic level, historical maps can be scanned just like a photograph. The resulting images can then be made available online for computers and smartphones.

Georeferencing is the process of associating a map image with a precise physical location, so that it can be used with a GPS enabled program (Figs.19 - 22). When georeferencing an old map, it is typically necessary to use four points and to know which projection system was used to draw the map. Of course, the original map also must be checked to ensure it is accurate.

Another way old maps can be used is to compare them with modern maps or satellite imagery once they have been georeferenced.

Suppose you had an old treasure map or a historical map of some town, or wartime battle. Assuming it was accurately drawn, it could be used as a raster map (more on raster maps later) in a GPS-enabled program or App once certain geographic features in the map were used to georeference it.

The British Library has a crowd-sourcing project that you can participate in to help georeference historical maps in its collection; see www.bl.uk/georeferencer/

An example of where an old map has been digitised and georeferenced for historical interest, and where that map can be compared with a new OpenStreetMap version interactively, can be seen at siliconchip.com.au/link/aayc

That site also includes a description by Koko Alberti of how the digitised map was produced, and a comparison with the modern map (see Fig.20). You can also view maps of numerous cities worldwide in this manner at the following website: siliconchip.com.au/link/aayd

Also see the related video titled *"HyperCities NewYork-Collection"* at https://youtu.be/-3J8uSRHwX8

The free smartphone App for Android and iPhone called "GPS on ski map" by Maprika can be used to georeference and view old scanned maps on your device. It is not just for ski maps as the name implies. See the video on how to do this titled *"Secrets of how we use GPS with old maps on your phone!"* at https://youtu.be/qvI71ihRV-o

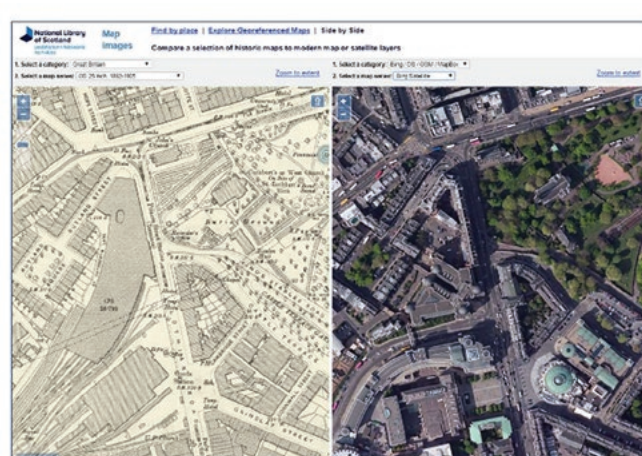


Fig.19: a comparison of a georeferenced historical map and modern satellite imagery, from the collection of the National Library of Scotland.

Fig.20: a 1775 map of New York and environs superimposed on Google Maps. The old map is adjusted and georeferenced, so it fits accurately on the modern map. The level of transparency of the old map can be adjusted.

Several maps are available for that App, including for Australia, or you can scan or acquire your own.

Another free App for viewing old maps is Old Maps Online (www.oldmapsonline.org/), available on the web or for iOS or Android. It indexes over 400,000 old maps including many old Australian maps. On the web interface, old maps can be overlaid with modern maps with varying transparency to best see the differences (Fig.21 & 22).

Apart from historical interest, it is also important to digitise old maps which contain property boundaries for government administration or the location of underground utilities (see our article on mapping utilities in the February 2019 issue – siliconchip.com.au/Article/12334).

This information can still be relevant even if it is one hundred or more years old. Such maps may be georeferenced and vectorised (see below) to bring them into conformity with modern map databases.

Raster vs vector map data

Map data may be represented as either raster data or vector data. Raster (or bitmap) graphics are like a photograph or other image, where the data is represented by a grid of individual pixels or picture elements.

In contrast, vector maps (which are the more typical representation for road maps) are shape-based, which means that the image elements are made up of points, lines and polygons (representing areas). Instead of pixels, the elements of vector data are known as vertices (coordinates) and paths (lines joining vertices). In other words, it's like "joining the dots" (see Fig.23).

With vector maps, it is only necessary to record data points where a change occurs. For example, a straight road between two points can be described with just two data points regardless of its length. The software fills in the straight line between the points, whereas a raster map would require hundreds of points.

Thus vector maps are much more memory-efficient than raster maps due to fewer data points, although raster maps require less computational power to render as they are displayed "as is" in their final form. With vector maps, the

Fig.21: an old wartime map of The Hague (left) compared with the modern OpenStreetMap form (right). In the interactive version of the map, the split between the two can be moved so changes between old and new maps can be readily seen. The old map is a digitised raster image while the OpenStreetMap version consists of vectors.

Fig.22: an old map of the Lane Cove area of Sydney overlaid onto a modern map, generated by www.oldmapsonline.org/

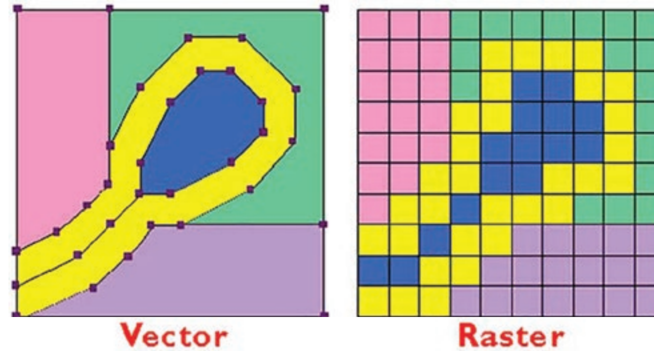


Fig.23: a comparison of vector and raster representation of map data. At higher zoom levels, raster graphics appear chunky, but vector graphics mostly maintain their appearance. Text is a common everyday type of vector graphics. In a modern word processor, the text remains smooth regardless of the font size selected, even though the data comes from the same font file.

map has to be regenerated from data points every time it is displayed.

To avoid a "pixelated" appearance, raster data must be of a sufficiently high resolution. In contrast, vector maps appear smooth at any resolution, assuming there is be a sufficient number of data points to represent whatever is being portrayed accurately.

Both raster and vector map data have specific advantages and disadvantages. Apart from the computational resources mentioned above, it is not practical to represent certain forms of data in vector form.

For example, satellite or other imagery is best represented in raster form.

For other forms of maps, especially when they involve lines, curves and shapes such as roads, borders, boundaries of various kinds, it is very efficient to represent them in vector form.

In some cases, raster and vector images might be combined, such as when a vector street map is overlaid on a satellite photo.

Once a map is vectorised, additional layers of information can be easily added. For example, where buildings are represented, the age or function of a building could be stored in the database and then it would be possible to only display on a map buildings only of a certain age or function.

Download free Australian government maps

Some government agencies offer free digital topographic maps. Australian topographic maps at 1:50 000, 1:100 000, 1:250 000 and 1:1 million scales can be downloaded for free from Geoscience Australia; see: siliconchip.com.au/link/aayg

Free digital maps are also available for NSW at resolutions as high as 1:25,000, see: siliconchip.com.au/link/aayh

Queensland maps can be obtained for free at: siliconchip.com.au/link/aayi

ACT maps can be procured at: siliconchip.com.au/link/aayj

Other states and territories appear not to offer free digital maps, but there are free maps for Victoria (soon to be expanded to other states) at: www.getlost.com.au/

Free topographic digital maps for New Zealand are available at: siliconchip.com.au/link/aayk

This is the basis of Geographic Information Systems (see below).

Geographic Information Systems (GIS)

A Geographical Information management System is intended to capture, analyse and present location-dependent information on a map (see Fig.25). This allows better decisions to be made, based on geography. Examples of where this can be useful are for retailers to figure out where to put a new store or for police forces can discover patterns in criminal activity.

When the data is presented on a map, it is much easier to understand and interpret than when presented as a list. Information is typically shown in the form of "layers" of map data (see Fig.27).

Examples of layers might include parcels of land, zoning, topography, demographics, location of houses, office

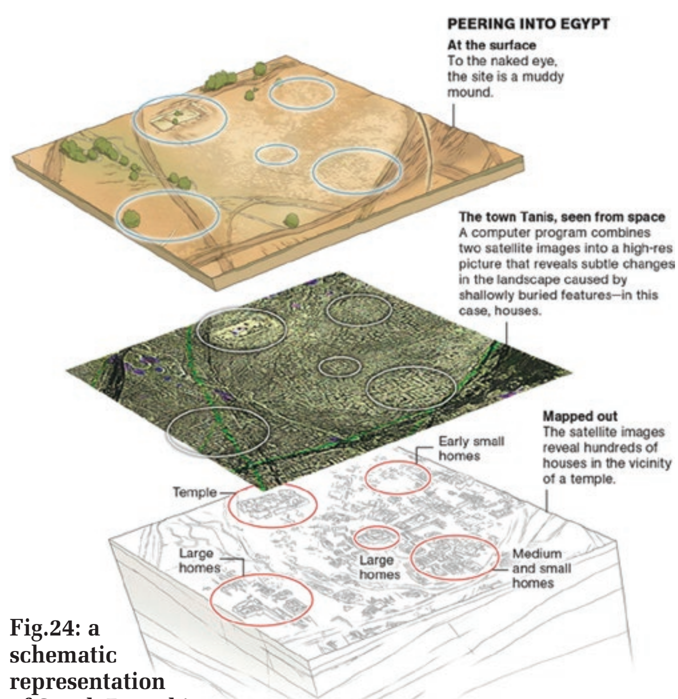


Fig.24: a schematic representation of Sarah Parcak's discovery of Tanis in Egypt, showing how faint surface features visible only from satellite revealed an ancient township.

Fig.25: a Google Maps view of the northern beaches area of Sydney, where the Silicon Chip office is located. This combines two different 'layers': a satellite view as a raster image, and a street map with names as a vector image. In geographic information systems, many different layers can be added.

buildings and shops etc.

Alone, individual items of information might be meaningless, but when combined, relationships can be seen to emerge.

Google Earth and satellite-based archaeology

A new area of archaeology has begun, with high-resolution Google Earth imagery being used to discover new archeological sites. This imagery is used by both amateurs and professionals, although sadly it is also being used by criminals to loot such sites.

One of the pioneers of using satellite imagery for archaeological purposes is Dr Sarah Parcak. (See Fig.24). She discusses her work in the following videos:

- *"The Future of Archaeology: Space-based Approaches"* (2001) at https://youtu.be/n_KZLsO3XYY
- On the looting of archeological sites, *"Culture Heroes: Sarah Parcak | Nat Geo Live"* at https://youtu.be/RP9nuUg0Hw0
- *"The Greatest Living Space Archaeologist - Sarah Parcak"* at https://youtu.be/p89DCFK6nH0

She has made numerous discoveries. More of her work and videos can be seen at: www.sarahparcak.com/

Moving to the archaeology of more recent structures, there is a video about using old scanned maps with Google Earth overlays to find the locations of old homes. It is titled *"Finding old homes using Google Earth overlays"* and can be viewed at https://youtu.be/6sjIbIpyPmM

This video is from the USA, but the techniques demonstrated are just as relevant for Australia.

Ocean floor composition

Digital maps are not just limited to land. They can also

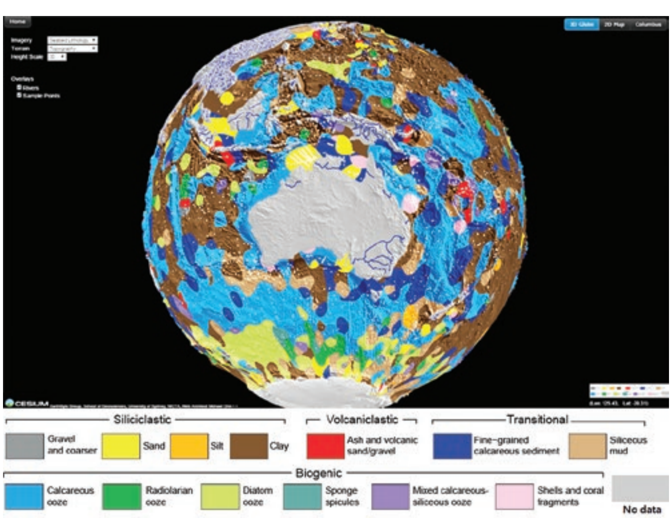


Fig.26: the first digital seafloor map, produced in 2015 by Dr Adriana Dutkiewicz and colleagues, showing the distribution of sediments based on 14,500 samples. Source: EarthByte Group, School of Geosciences, University of Sydney and National ICT Australia (NICTA), Australian Technology Park, NSW.

Free open-source mapping software

Apart from commercial offerings, you can use some free Geographic Information Systems as follows:

- QGIS: www.qgis.org/en/site/
- GDAL: https://gdal.org/
- gvSIG: www.gvsig.com/en
- Whitebox GAT: siliconchip.com.au/link/aayl
- SAGA: www.saga-gis.org/en/
- GRASS: https://grass.osgeo.org/
- MapWindow: www.mapwindow.org/
- ILWIS: siliconchip.com.au/link/aaym
- GeoDa: siliconchip.com.au/link/aayn
- uDig: http://udig.refractions.net/
- OpenJUMP: www.openjump.org/
- DIVA-GIS: www.diva-gis.org/
- OrbisGIS: http://orbisgis.org/

There is an online georeferencing tool called Georeferencer at: www.georeferencer.com/

Instructions on how to georeference in QGIS are at: siliconchip.com.au/link/aayo and also see siliconchip.com.au/link/aayp indicate seafloor composition. The first digital map showing seafloor composition was produced in Australia (see Fig.26). This revealed sediment distribution to be significantly different and more complex than indicated in earlier hand-drawn maps. You can view an interactive 3D version of this map at siliconchip.com.au/link/aaye

Digital maps of off-earth locations

Google has added digital maps and imagery for the Earth's moon and other planets and moons, as well as views of the interior of the International Space Station (ISS). The feature is hard to find so go to www.google.com.au/maps and select "Satellite View", then zoom out as far as possible using the "-" zoom control.

On the left, you will then see a panel enabling you to view digital maps and imagery of Mercury, Venus, Earth, the ISS, the Moon, Mars, Ceres (a dwarf planet), Io, Europa, Ganymede, Callisto (moons of Jupiter), Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Iapetus (moons of Saturn), Pluto and Charon (moon of Pluto).

You can also see images of the universe at Google Sky (www.google.com/sky/).

The China GPS offset problem

For reasons supposed linked to national security, mapping and other geographic data in China is under state control and many GPS equipped cameras won't geotag photos in China (as I experienced myself, with a Panasonic camera).

Crowd-sourced mapping such as Open Street Maps is illegal in China (but happens anyway) and there is a random offset between the position as determined by a GPS receiver and official Chinese street maps, of 100-700m (see below).

Street maps supplied under Chinese Government control use a unique coordinate (datum) system known as GCJ-02 that contains random offsets from real coordinates, with the English name of "Topographic map non-linear confidentiality algorithm". The rest of the world mostly uses WGS-84 or a similar real coordinate system.

To make GPS usable in China, GCJ-02 coordinates will work with GCJ-02 maps, but there is no direct correspondence with WGS-84 coordinates (the real position). Despite the secrecy of the algorithm behind GCJ-02, it has been reversed-engineered by various people, and there are open-source projects to convert between GCJ-02 and WGS-84.

Google Earth and Google Maps intended for use outside China will not display correctly in China due to this offset. Still, a version of Google Maps made in conformity with Chinese laws for use in China uses the GCJ-02 datum and works for both satellite imagery and maps.

A comparison of real satellite imagery and official Chinese maps (overlaid in yellow), showing the lack of correspondence of the map with reality. Source: https://geoawesomeness.com

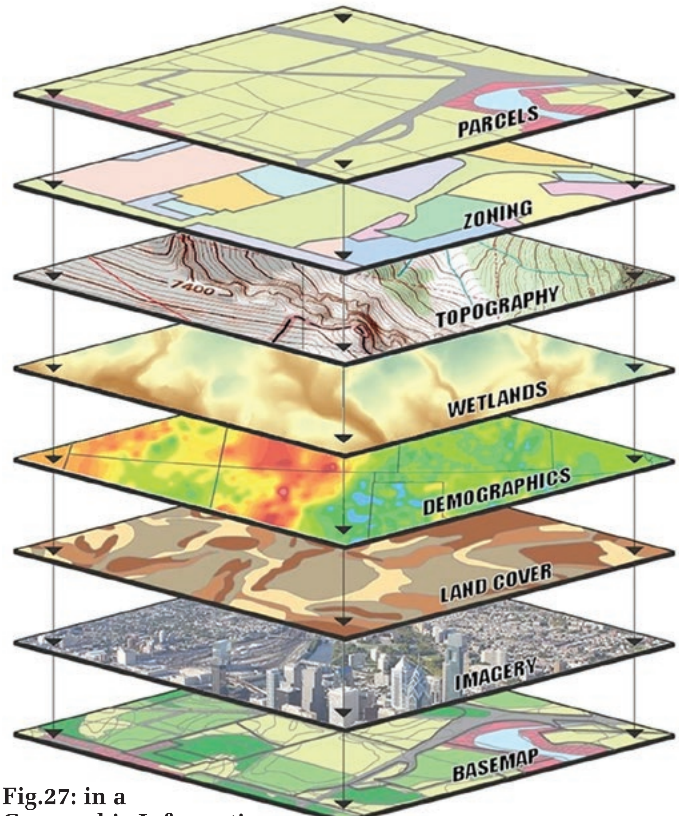


Fig.27: in a Geographic Information System (GIS), many different types of data can be combined to reveal spatial trends and to show how different types of features relate to each other.

SLAM (Simultaneous Localisation and Mapping)

SLAM is a method by which autonomous vehicles or other electronic mapping devices can map caves, mines or other planets. The vehicles which can use this technique include robot vacuum cleaners and lawnmowers, unmanned aerial vehicles (UAVs), unmanned underwater vehicles (UUVs), underground vehicles and space vehicles.

This technique can also be used with handheld 3D mobile mapping systems such as the ZEB devices or Hovermap (see below). In all cases, it is possible to simultaneously map a location and locate the device itself within that mapped area.

A SLAM device may use sensors such as ultrasonic rangefinders, LIDAR (light detection and ranging), radar and other technologies to map the surrounding environment.

SLAM provides 3D maps both indoors and outdoors in real-time by the use of sensors.

When a GPS signal is not available, a SLAM device can establish its position with the use of an inertial measurement unit, which contains three-axis accelerometers and gyroscopes (and possibly magnetometers), to provide data for a relative position fix.

To provide maximum accuracy with SLAM, it is desirable to "close the loop", ie. return to the starting point, so that the mapping algorithm can correct for any drift or slippage of the calculated position.

Fig.28: a drone with the Hovermap payload attached (the black box at the bottom with a white LIDAR device). Image courtesy CSIRO.

SLAM technology can be used for mapping underground structures including tunnels, caves, mines and more. This can be done using a handheld scanning device or with a similar device carried by an autonomous drone.

Australian CSIRO Zebedee Scanner

The Zebedee three dimensional handheld SLAM LIDAR mapping system was invented by the CSIRO and is now licensed to be manufactured by UK company GeoSLAM (https://geoslam.com/).

Commercial versions of the Zebedee include the ZEB Discovery, ZEB Pano, ZEB Revo and ZEB Horizon. Zebedee technology can also overlay historical data over newly captured data.

See the following videos on Zebedee:

- Early 2013 CSIRO video of the technology, *"Mobile mapping indoors and outdoors with Zebedee"* at https://youtu.be/jyt4-Wz3JC8
- *"CSIRO Zebedee 3D Mapping"* at https://youtu.be/gKPp2MYBYX0
- *"Zebedee 3D laser scanning in Val de Loire"* at https://youtu.be/k8q5xr_eLgk
- *"Real science from caves to the classroom"* at https://youtu.be/jt38pF_TJvY

The Australian CSIRO Hovermap

Hovermap was developed by CSIRO researchers and commercialised by Brisbane-based company Emersent (https://emesent.io). Hovermap uses SLAM technology and is the world's first 3D mapping payload for attachment to drones that works indoors or outdoors, and without the need for GPS (see Fig.28).

It can work underground, inside storage tanks, inside buildings or under bridges.

See the following videos:

- *"Hovermap - World's first autonomous LIDAR mapping payload"* at https://youtu.be/2zadTtCadeI
- *"Hovermap UAV LIDAR mapping payload"* at https://youtu.be/_Gu6Fx7Jt5A
- *"Autonomous underground drone flight beyond line-of-sight using Hovermap payload"* at https://youtu.be/S0HIeDxqevQ

SC

The Los Angeles city GeoHub

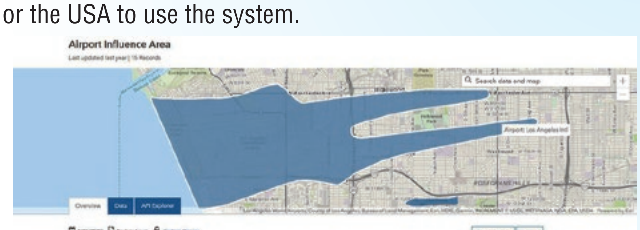
The Los Angeles GeoHub (http://geohub.lacity.org/) is an initiative of the City of Los Angeles and Jack Dangermond from Esri. It is a digital mapping portal capable of delivering immense amounts of information in real-time or near-real-time to a wide variety of people, including the general public.

It is probably one of the most advanced such systems in the world. When the portal was opened, the LA Mayor gave a few examples of how this system could be used. One was a firefighter who, after an earthquake, needs to know the location of fire hydrants, sewer lines, electrical equipment, building infrastructure and even the current location of other emergency workers.

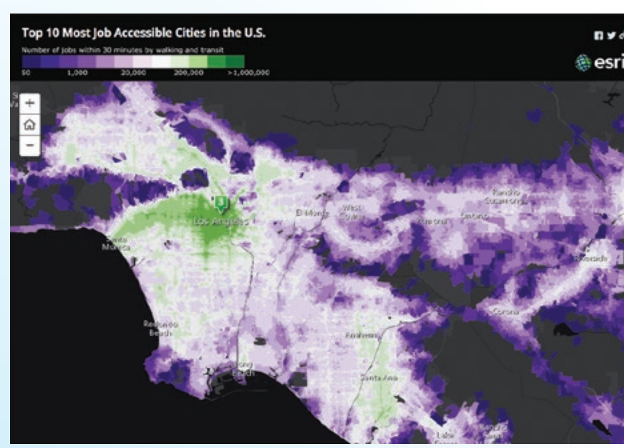
Or social workers might want to see if there is a correlation between the location of homeless encampments and liquor store locations and police patrol activities.

It has numerous possible uses in the areas of business; boundaries of various districts, fire zones etc; health; infrastructure; planning; recreation and parks; safety; schools; transportation and others.

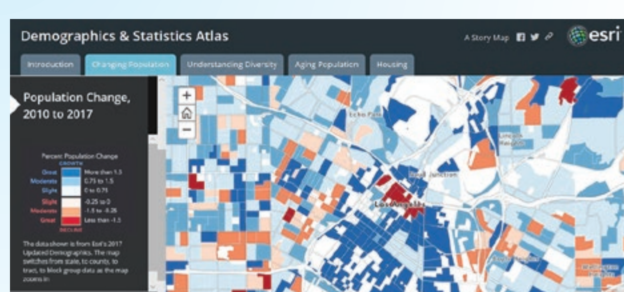
You don't need to have an account or even be a resident of LA or the USA to use the system.



An example map from the Los Angeles GeoHub, showing aircraft noise around Los Angeles International Airport.



An example of data visualisation from the Los Angeles GeoHub, showing the number of jobs within 30 minutes walking or transit distance from specified areas.



A map of the population change in areas of Los Angeles from 2010 to 2017.

CIRCUIT NOTEBOOK

Interesting circuit ideas which we have checked but not built and tested. Contributions will be paid for at standard rates. All submissions should include full name, address & phone number.

Low-noise split supply and switched gain signal amplifier

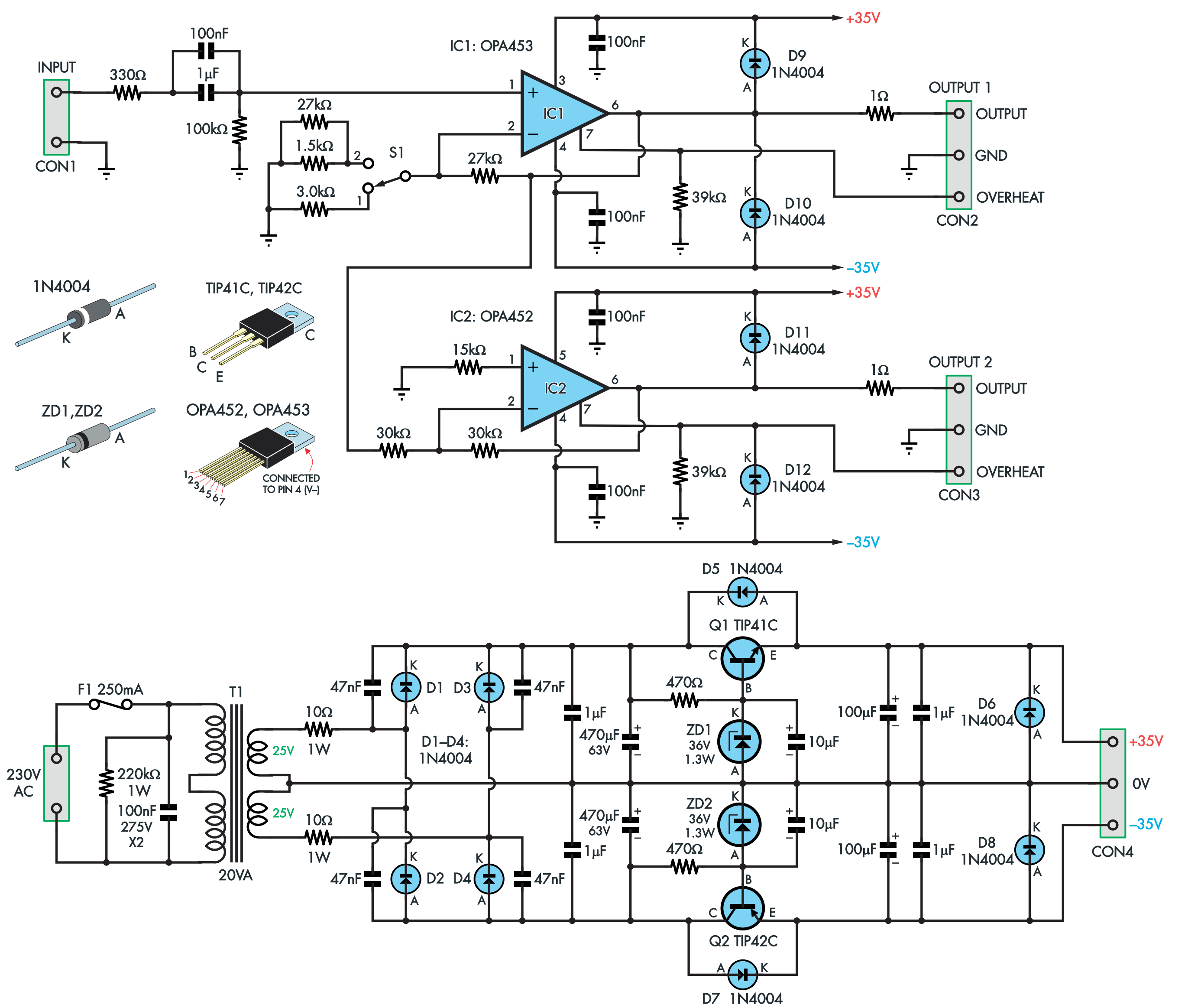
This signal amplifier provides two outputs which are 180° out of phase, with swings of more than 60V peak-to-peak (21V RMS) and the ability to deliver up to ±50mA. This is achieved using OPA452 and OPA453 high-voltage op amps (IC2 and IC1 respectively).

They are powered from well-filtered split supplies derived from a centre-tapped mains transformer, for best performance. Those approximately ±35V DC supply rails are also available for running external circuitry.

Starting with the signal amplifier section, the incoming signal (from a function generator, PC sound output, mobile phone etc) is fed into CON1 and then AC-coupled to non-inverting input pin 1 of IC1. This is an OPA453 which is stable with a gain of at least five times. The gain is set to either 10 times, with switch S1 in the lower position (1), or 20 times with switch S2 in the upper position (2).

The output from pin 6 of IC1 then goes to CON2 via a 1Ω protection resistor. Diodes D9 and D10 protect IC1 from externally applied voltages or spikes from inductive loads. The OVERHEAT pin of CON2 goes high if the internal temperature of IC1 is too hot, in which case IC1 shuts down to protect itself. This would normally only happen if the load current is high for an extended period.

The output from pin 6 of IC1 is also



fed to the inverting input of IC2 via a 30kΩ resistor. The gain of IC2 is set to -1 due to the use of two 30kΩ feedback resistors, with a 15kΩ resistor tying pin 1 to ground, so that the inputs have the same source impedance. As IC2's gain is below five, it is an OPA452, which is internally compensated for stability at a gain of 1 or higher.

The output and protection arrangement is the same for IC2 as for IC1, with the inverted signal going to CON3. Op amps IC1 and IC2 have a low distortion figure of around 0.0008% and high gain bandwidth and slew rate figures. So despite the high output signal swing capability, the circuit's bandwidth is still well over 20kHz (the -3dB point is around 40kHz).

Power comes from a ~20VA 25-0-25 mains transformer (T1) with a 100nF capacitor across its primary for EMI suppression. This has a 220kΩ high-voltage bleeder resistor across it.

The secondary windings of T1 are connected to a bridge rectifier formed from 1A diodes D1-D4, via a pair of 10Ω stopper resistors which help to filter the bridge output and reduce switching spikes. Switching spikes are also attenuated by having 47nF capacitors connected across each of D1-D4.

The DC voltages from the rectifier are filtered by 470µF capacitors with paralleled 1µF capacitors for lower ESR at higher frequencies. These unfiltered rails then go to 'capacitor multiplier' stages built around NPN transistor Q1 and PNP transistor Q2.

These provide effective ripple and noise filtering without many losses, as the gain of the transistors increases the effectiveness of the filter capacitors. Zener diodes between 0V and the bases of these transistors also limit the output voltages to around ±37V, protecting IC1 & IC2 and providing some limited regulation of these rails.

Ideally, IC1, IC2, Q1 and Q2 should be fitted with small flag heatsinks.

Petre Petrov,
Sofia, Bulgaria ($75).

Combining DDS and IF alignment circuits

After reading the article on Dead Simple Radio IF Alignment with DDS in the September 2017 issue (siliconchip.com.au/Article/10799), it occurred to me that it would be possible to build it and still retain all the functions of the DDS Signal Generator that it was based on (April 2017; siliconchip.com.au/Article/10616).

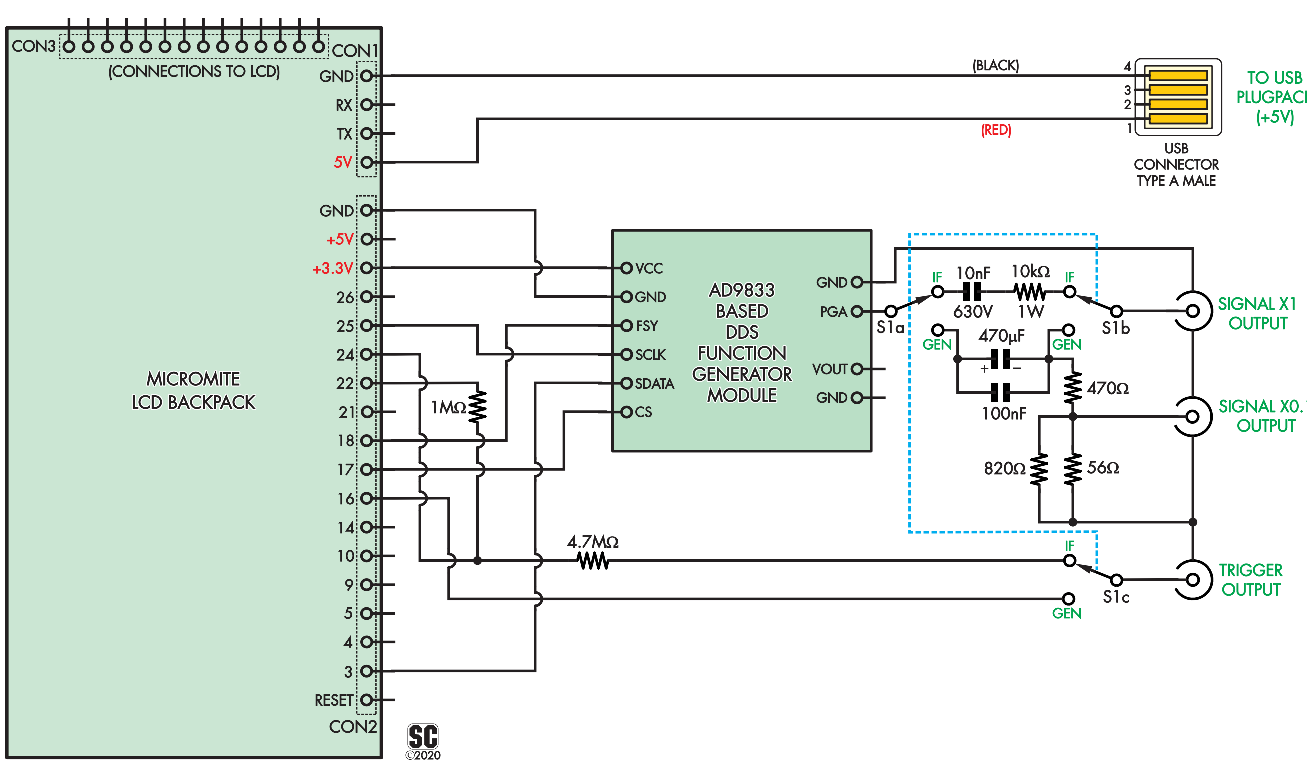
Essentially, the only differences between the two circuits are the way that the output of the DDS module is coupled to the output connector, and how the incoming signal is routed to the Micromite's pins.

So by adding a 3PDT or 4PDT switch, we can keep all the components needed for both functions and switch between them.

There isn't much more to it than that; in the positions marked "IF", the IF alignment components are in-circuit, including the 10kΩ series resistor to the signal output and the 4.7MΩ/1MΩ feedback divider. In the positions marked "GEN", those components are switched out, and the low-impedance generator output is connected instead, along with the direct feedback connection for triggering.

Note that the SIGNAL X0.1 output, which was only used in the DDS Signal Generator project, is always connected to the 10:1 output divider so it can be used the same way regardless of the position of switch S1.

Ross Herbert,
Carine, WA. ($65)



Resurrecting a turntable with a Micromite Explore 64

I had an urge to listen to my old vinyl records again, so I pulled out my Dual 1218 turntable. It was one of the better consumer-grade turntables of its day with a heavy platter, four-pole motor, idler drive, auto cueing and arm lift and return at the end of playback. The tonearm is gimbal-mounted, with anti-skating control and a usable tracking force down to about 2g.

All the above was implemented using the most astounding array of cogs, ratchets, pushrods, escapements and other mechanical wizardry that would impress Heath Robinson or, if you are American, Rube Goldberg. Unfortunately, such complex mechanics tend to seize up over time and troubleshooting can be very difficult.

So I was disappointed when I discovered that the tonearm would not position correctly, and the platter speed was wrong. I decided it was easier to remove the offending mechanics and replace them with an electronic solution.

I chose to base it around a Micromite Plus Explore 64 module (August 2016; siliconchip.com.au/Article/10040). It is overkill, but cheap enough and includes an integral USB interface for programming.

For stylus lift and tonearm control, I used basic model aircraft servos. The new circuitry is powered from a 5V switchmode supply, with a solid-state relay to activate the turntable motor under Micromite control.

The centre groove position is detected with a Hall Effect sensor and a small magnet on the tonearm drive assembly.

Its main tasks are:

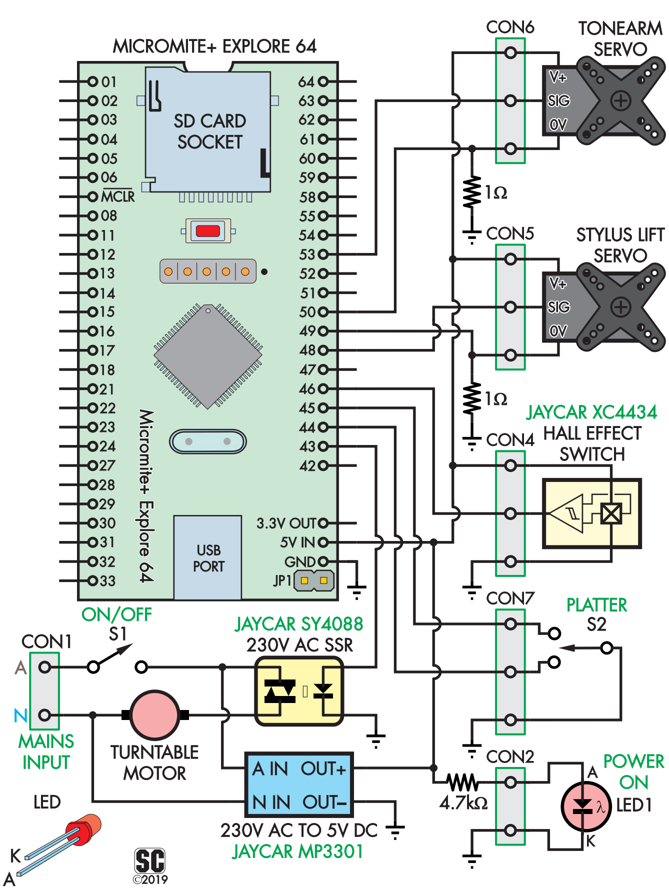
1. Ensure that the arm is in the home position (on the arm rest) at power-on.
2. Start the motor when the "platter on" switch is operated.
3. Raise the stylus and return the arm to the home position, then stop the platter when the "platter off" switch is operated.
4. Raise the stylus, return the arm to home and turn the platter off when the stylus reaches the centre groove.
5. After each lift or arm positioning action, position the servos so that manual operation of lift and cueing are possible.

The last task is enabled by designing the tonearm pushrods to drive in only one direction and by having a "dead spot" in the stylus lift pushrod.

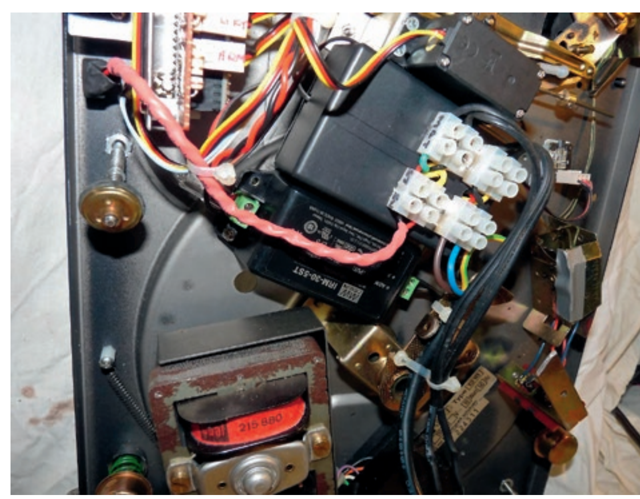
This description is not intended as a construction article, but will perhaps trigger ideas for others to resurrect old turntables.

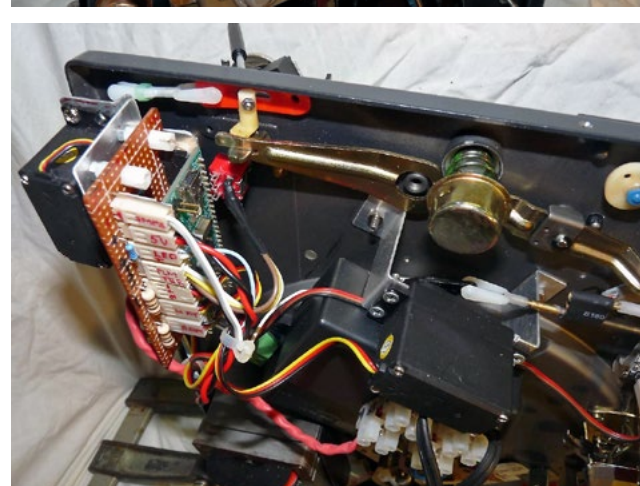
There isn't much to the circuit which hasn't already been mentioned; the servo motor currents are monitored via 1Ω shunts so that they can be shut down in case of an overload. Refer to my photos (shown below) for details of how I mounted the various components.

Peter Bennett,
Beacon Hill, NSW. ($80)



These photos show an example of how to mount the various components. Different turntables will have varying amounts of free space to work with.





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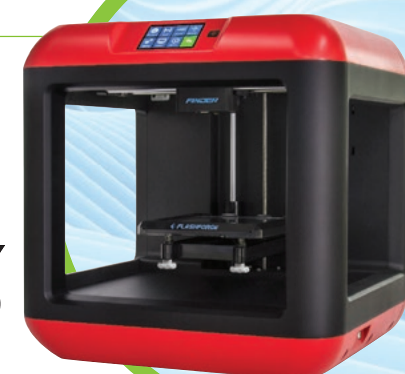

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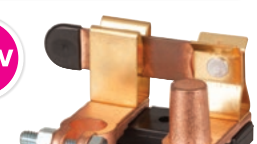

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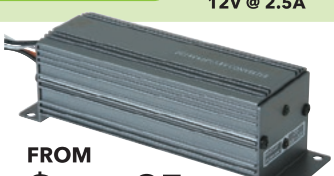

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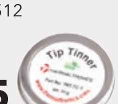

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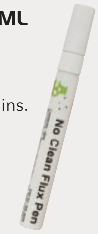

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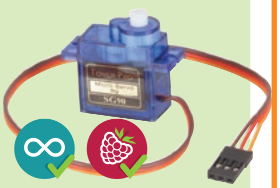

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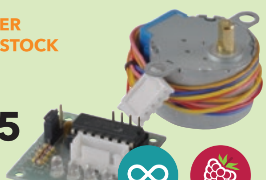

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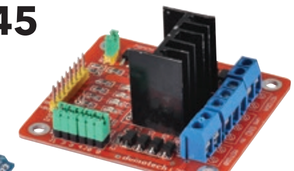

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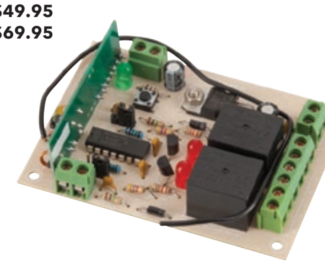

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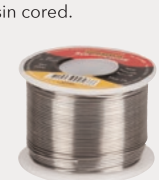

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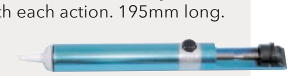

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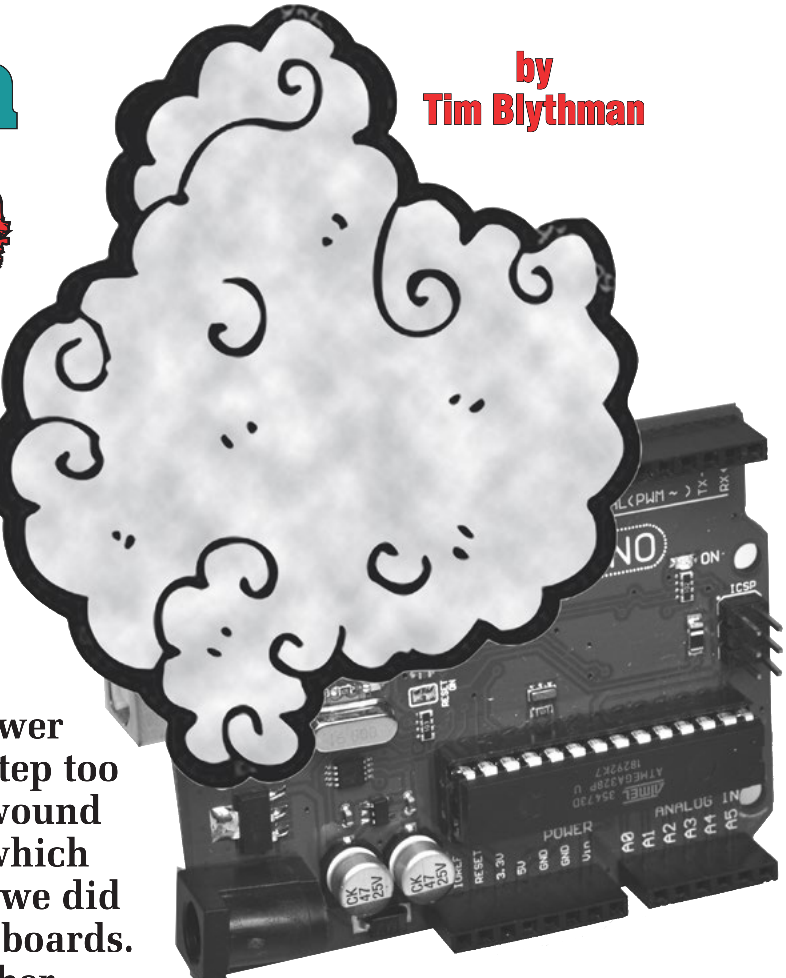
Fixing a BUSTED Arduino Uno

by
Tim Blythman



The Arduino Uno is a hardy beast, but occasionally we manage to let the magic smoke out. Perhaps our attempt to harness the power of lightning to run an Arduino was a step too far . . . who is to say? Regardless, we wound up with a few poor Arduino victims which needed to be resurrected. Here is how we did it, for less than the cost of buying new boards. These techniques should work with other Arduino boards, too.

The Arduino Uno (and its various clones) has been designed to be resilient in the face of poor treatment by both beginners and experienced users. The ruggedness of the ATmega328 microcontroller is a major factor in this.

Despite this, we managed to break a few Unos. Most of these have been due to excessive voltages being applied to the DC jack or VIN input.

Let's look at the damage caused and how we can fix it. If you have an Arduino to fix, we're assuming that you have some experience with Arduino boards and the Arduino integrated development environment (IDE) software.

While there is no doubt that some Arduino-compatible boards are very cheap, almost to the point of being disposable, it can still be worthwhile to repair them. Below, we discuss three components that are likely to fail and how to replace them.

Clones and DC regulators

Some Uno clones use a different 5V regulator from the original, and these cannot withstand as high an input voltage. This stung us twice before we figured out what was going on.

Genuine Arduino Uno boards have an NCP1117 regulator, capable of handling up to 18V, while some clones use the AMS1117 instead, which is only good up to 15V. If (like us) you apply more than 15V to a clone, this voltage can find its way to places it shouldn't, like the USB port of a connected laptop. This can also burn out the regulator.

Replacing that regulator can not only fix the board, but you can replace it with a proper NCP1117 or equivalent, giving you the full 18V input range.

Note also that the original Uno, and most clones, have an ATmega16u2 microcontroller as their USB-serial converter IC. This chip can also be damaged as it is connected to the 'outside world'.

Some clones use a CH340 instead, and this could potentially also be damaged.

We haven't managed to blow up any ATmega328s (yet!), but we did have one that appeared to have a damaged ADC pin and as a result, was giving erroneous (and frustrating!) readings. If it does fail, this IC is easy to replace, as it is usually socketed.

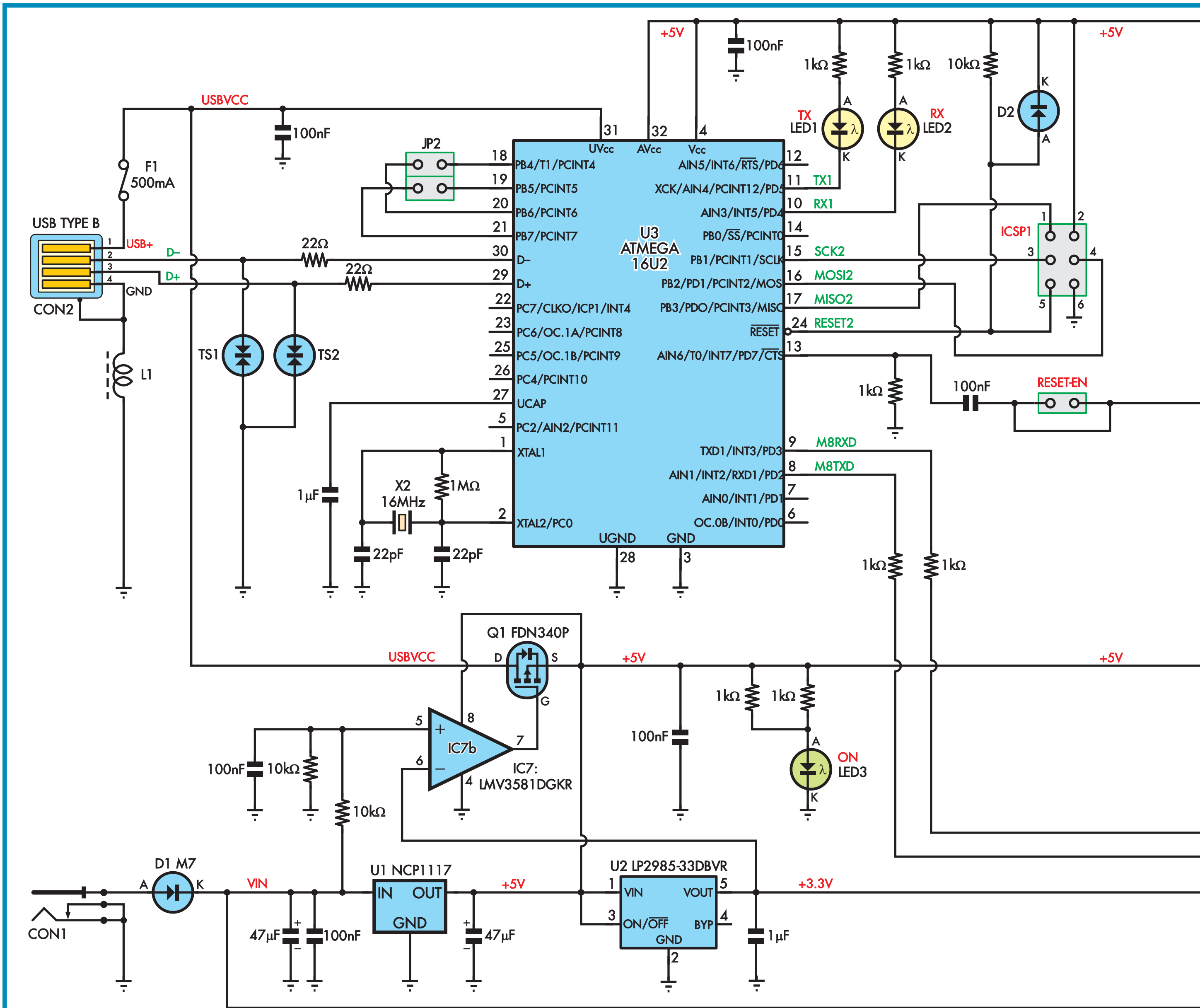
One way to quickly check that the ATmega328 is functional is by pressing the reset button and watching the onboard LED. It flashes twice when the Arduino bootloader starts up. If you don't see this flash, either the micro is not getting power, it hasn't been programmed, or it is faulty.

Clones of the Arduino Mega and Leonardo often feature similar parts to those described above, so the following advice is pertinent to these boards, if not relevant to all components.

Things that go pop

The most likely component to require replacement on a dead Uno board is the main voltage regulator.

Referring to the official schematic for the most common "R3" variant shown in Fig.1, this part is labelled



SC ©2020 **ARDUINO™ UNO REV3**

U1. It takes its input from the DC jack via diode D1, or from the VIN pin header directly. Its output provides the 5V rail.

Both the 18V-rated NCP1117 and 15V-rated AMS1117 come in the SOT-223 SMD package, and their specifications are very similar, apart from the maximum input voltage. If U1 is damaged, you will not be able to power the Uno from these inputs, but it may work when powered directly from 5V (eg, from USB).

While removing U1 may allow the board to operate, we found that it is usually not the only damaged component. On two of our boards, U1 was feeding its input voltage to its output, which is an expected but unpleasant failure mode. This lead to further failures on these boards.

In one case, we found that U2 was also getting quite hot when the board was powered from the USB socket or the DC jack. This is an LP2985 3.3V regulator which runs from the 5V rail.

On a typical Uno board, the 3.3V rail does not power anything. It is simply there for anything else that might need 3.3V, such as an attached shield or module. Thus, an overheating LP2985 on a bare Uno is a sure sign of regulator failure.

On another board with a failed regulator, we found that U3, the ATmega16u2 which provides the USB-serial function, was getting quite hot, even when connected via USB. Since it too runs from the 5V rail, it had probably been irreversibly damaged.

In both cases, the failure of U2 or U3 likely provided some protection to ZU4 (the ATmega328 microcontroller), by behaving like a very crude shunt regulator, as in both cases, the micro was still operational.

When we say that parts are getting hot, we mean too hot to touch. Sometimes you can smell that there is a problem or feel the general warmth of the board, but it is still entirely possible that some part of the board is hot enough to cause a small but painful burn if you start probing around with

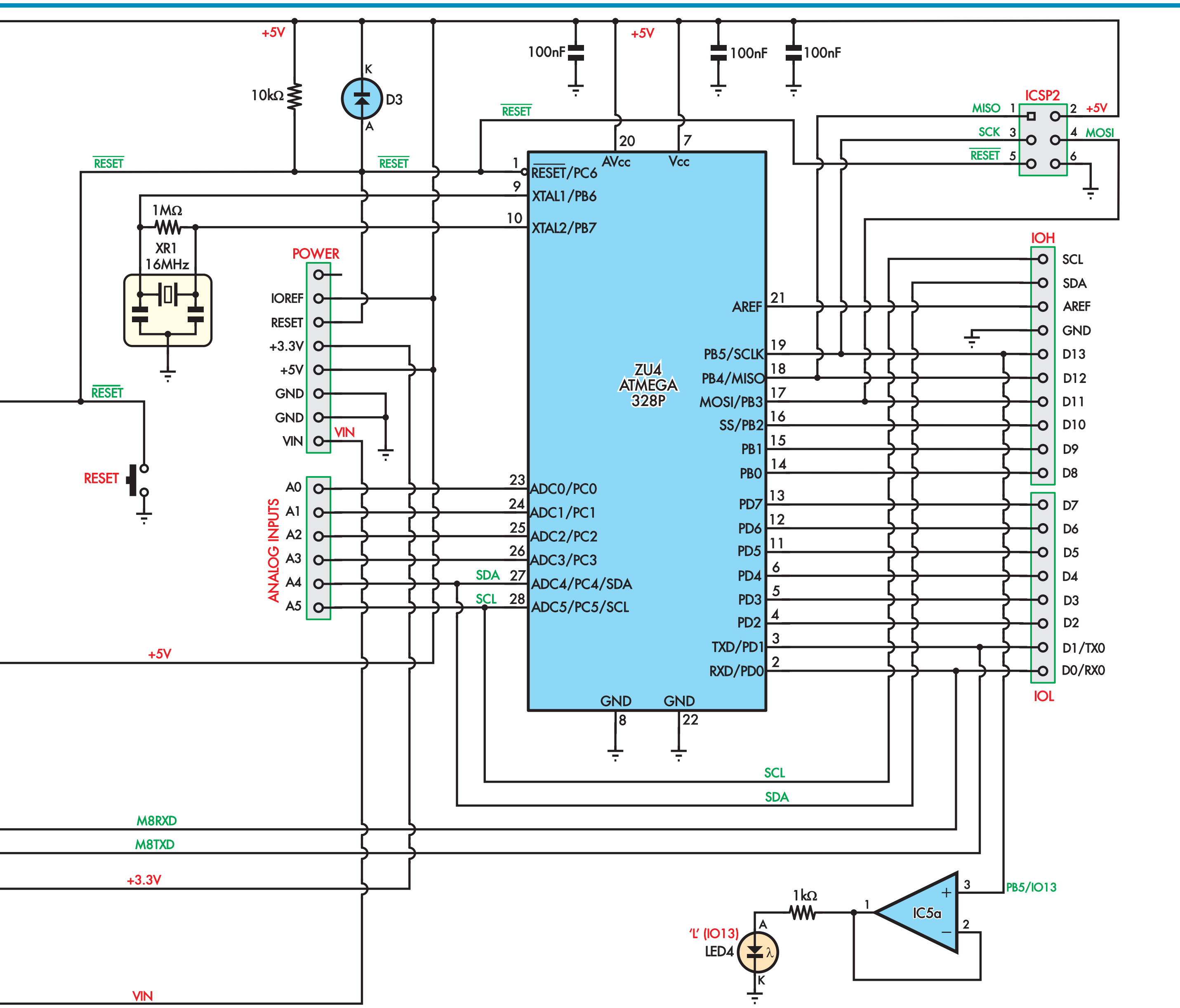


Fig.1: the circuit of the R3 Arduino Uno design. The R2 used an ATmega8u2 instead of an ATmega16u2 to provide the USB-serial interface, but was otherwise very similar.

your fingers, looking for a fault. So take care when inspecting damaged boards!

Also note that we suggest you do not plug any potentially faulty Uno board into your computer's USB port with external power applied, in case the board is back-feeding power into the USB pins.

If you must do this, use something like our USB Port Protector (May 2018; **siliconchip.com.au/Article/11065**) to provide a measure of protection. You have been warned!

The diagnosis

The first Uno we repaired was showing two main symptoms: its 3.3V regulator (U2) was getting hot when the board was powered, and it was not showing up on our computer when connected via USB, even though the power LED was on.

We didn't try powering it from the DC jack, to see if regulator U1 was working, as that would almost certainly make things worse. But we assume that U1 was indeed fried and had caused this other damage.

In retrospect, the damage to U2 may have caused the 5V rail to sag enough to prevent U3 from working correctly. Because the 3.3V rail is not critical to a bare Uno's operation, we suggest removing U2 first if it's getting hot, and seeing if that results in any change.

In our case, we jumped straight in and replaced U1, U2 and U3, and that fixed it.

The second Uno had just one symptom: the USB/serial chip, U3, was getting hot (and naturally enough, the computer wasn't detecting it). A quick test with a multimeter showed 4.4V on the 3.3V pin, which is about the same as on the 5V pin!

Since we couldn't test U1 without risking further damage, we simply replaced all three ICs on the second Uno too.

Chip replacement

Both Jaycar and Altronics stock spare ATmega328 ICs, conveniently programmed with the Uno bootloader.

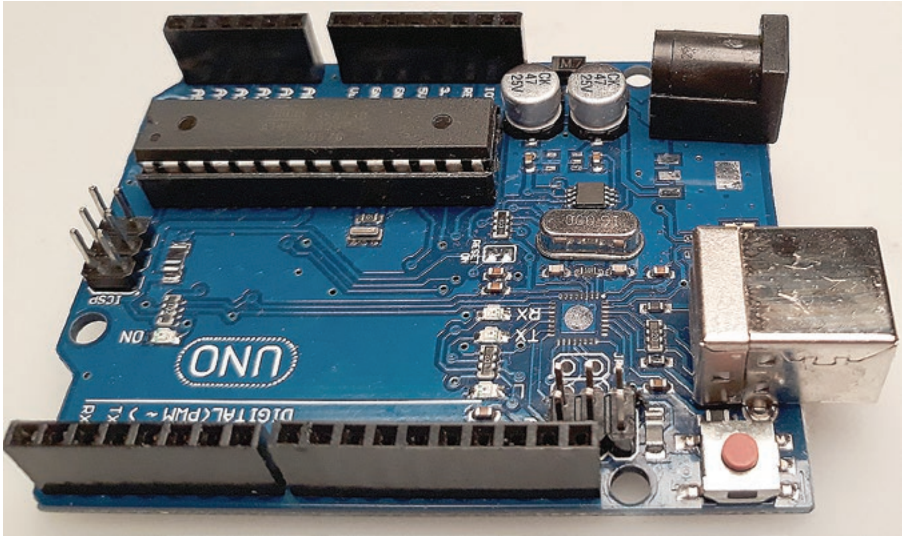


Fig.2: one of our boards after removing the defective parts and cleaning the pads. We've also removed the residual flux; the result is almost like a brand-new board.

If you have a problem with this IC, this part is available over the counter (Jaycar Cat ZZ8727, Altronics Cat Z5126 or Z5125 without the bootloader).

For the other parts, you will probably have to order from a larger supplier like Digi-Key or Mouser.

For U1, we ordered an NCP1117LPST50 regulator. The part we ordered also had a T3G suffix, but this only refers to how the part is supplied (tape and reel in this case).

For U2, we ordered the LP2985-33DBV. The part we used also had an "R" at the end, again indicating that it is supplied on tape and reel.

U3 is an ATmega16u2 in a 32 pin VQFN package, with a part code of ATmega16u2-MU. Again, this had an "R" suffix to indicate tape and reel.

As mentioned earlier, depending on how you plan to use your Arduino, you could just remove a damaged 3.3V regulator and not replace it if you don't need the 3.3V rail.

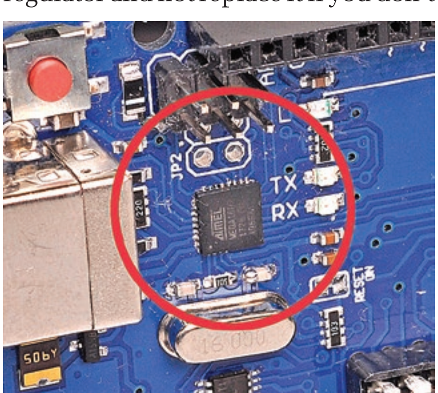


Fig.3: if you apply just the right amount of solder to the QFN pins, with plenty of flux, you should get nice clean joints like these.

Equipment needed

U3 comes in a QFN package, which is short for Quad Flat No-leads. It is very hard to solder or desolder without SMD-specific gear. We used a hot air rework station (available quite cheaply online) and solder paste, as well as the tools noted below.

Removing U1 and U2 is difficult without a hot air station, but possible. Replacements can be fitted with a temperature-adjustable soldering iron, although you may need a fine tip. Tweezers, flux paste and solder braid (solder wick) are also very helpful.

A magnifying glass will make working with these small parts easier. Even a mobile phone camera with digital zoom can let you get in close enough to inspect your work.

Note that flux generates a bit of smoke when heat is applied. Use a fume extraction hood or work in a location with excellent ventilation. We set up a small 12V computer fan to suck the fumes away. It probably isn't good for the fan in the long run, but it is better for our lungs.

Flux removal solution is useful for cleaning up afterwards, as the generous use of flux makes the process much easier. Isopropyl alcohol or acetone can be used if you don't have a dedicated flux removal solution. Take care, as many of these compounds are quite flammable.

Remove the old chips

Naturally, the first step in replacing the defective ICs is to remove the old ones. If you have access to a hot air station, then it will be easy.

Grasp the defective part using tweezers with one hand and lift the board by a few millimetres, holding onto the part to be removed only. If you lift it too high, solder is likely to splash around. Aim the hot air at the part, and after around 20 seconds, the solder will melt and the weight of the board will pull the two apart. If you smell burning or see charring, the air is too hot, and the board may be damaged.

If you don't have a hot air station, you'll need to melt the solder on all the pins together, so they all come away at the same time. One way to do this is to build up a large blob of solder around the part, covering all the pins on both sides. Or if you're fast, you can alternately heat the two sides of the chip and rely on residual heat to keep one side molten while you lift the part off.

Alternatively, you can cut the pins off while the component is still soldered to the board; then desolder the pins individually. But it's easy to damage the PCB tracks when cutting the pins on such small parts, and this is not possible for U3 as it has no pins.

Once the defective components are gone, clean the pads using the flux paste and solder wick. Apply flux to

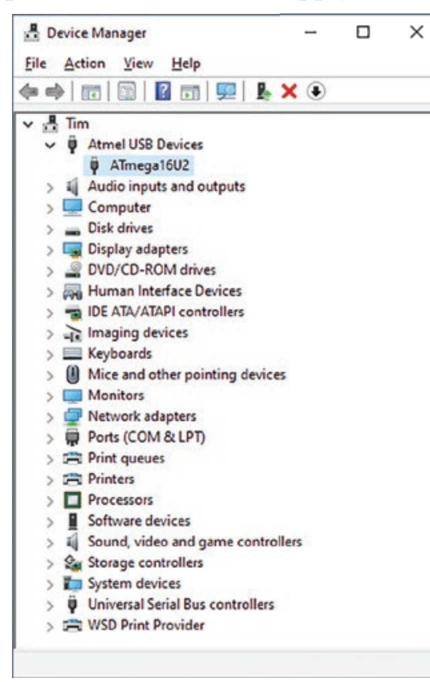


Fig.4: If the ATmega16u2 chip is soldered correctly, Windows Device Manager should show it as a connected device when the board is plugged in.

the pads and rest the end of the braid on the pad. Press down on the braid with the iron and gently slide it to the side. The less residual solder left behind, the better the final result will be. We were able to get the pads nearly looking like they had never been soldered (see Fig.2).

Fitting the replacements

For U1 and U2, apply flux to the pads and rest the parts on the pads. These parts have a different number of pins on each side, so the correct orientation should be obvious. The flux may help to keep them in place, but it's best to also hold them with tweezers.

Apply some more flux to the top of the pins. Clean the tip of your iron, add some solder and apply the tip to one of the pins. For U1, try one of the small pins, as this will be less affected by the large copper track below. The flux will draw solder from the tip and onto the pin.

If necessary, use the tweezers to adjust the position of the part, ensuring it is lined up with the pads and flat against the PCB. Once this is done, solder the remaining pins, turning up the heat for the large tab on U1.

If you get a solder bridge, ensure all the pins are soldered down before attempting to correct it. This will prevent the part from moving. Apply flux, then the braid followed by the iron and gently pull away.

Fitting U3

The QFN part, U3, is a bit trickier to replace; but without much prior experience with QFN, we aced it two times in a row. The pads are so far recessed that it is really difficult getting solder onto them. We tried loading up our iron with solder to get close to the pins, but it didn't work. You may have better luck trying this technique with a very fine-tipped iron.

So we had to use solder paste and hot air. If you have access to a solder stencil to suit a QFN32 part, use it, but this isn't a requirement.

Start by applying a generous amount of flux paste to all the pads, including the large central tab. Squeeze out a small amount of solder paste and mix it into the flux paste along each side of the IC. It should go right into the corners. The amount of paste needed is minimal, perhaps what you could pick up on the tip (not the head!) of a pin for each of the four sides.

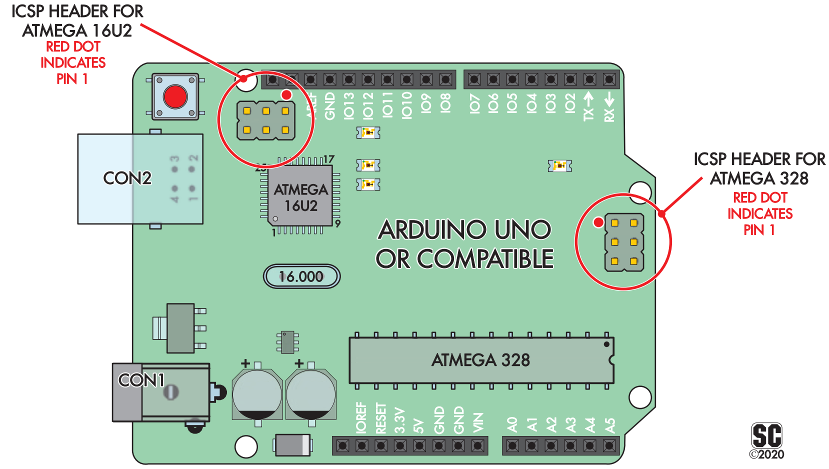


Fig.5: all Arduino Uno boards should have two six-pin in-circuit serial (ISP) programming headers, as shown here; one for each onboard micro.

Sit the part on top, ensuring that the pin 1 marking lines up with that on the PCB. If you have trouble seeing it, position the 'Atmel' text on top of the chip to be closest to the USB socket. Ensure that the IC is located centrally on the footprint and hold it there with tweezers.

Apply heat with the hot air gun directly to the top of the chip; you don't want the air to move the flux or solder paste too much. The flux should soften and flow, and eventually, the solder paste will coalesce towards the pins. You need to ensure there are no grey smears of solder paste left, although there may be silvery balls floating around. This is fine, as they can be picked off later to avoid short circuits.

Once you are sure that U3 has been soldered in place, clean it up by loading the tip of a fine-tipped soldering iron with a small ball of solder. Apply fresh flux paste to the pins and gently drag the tip along one edge at a time. If you have the right amount of solder, a nice-looking fillet should be left behind.

If you get bridges between pins, try again with less solder on the tip to help remove the excess. The combination of surface tension and flux should leave a clearly visible fillet of solder to each pad (see Fig.3 – close-up of QFN pins).

Testing

Before cleaning up the board, you can test that U3 is soldered correctly by trying to connect the Uno to a computer. While the ATmega16u2 does not have any firmware loaded initially, these chips come loaded with a "DFU" (device firmware upgrade) bootloader which means that a Windows computer will recognise that a device is connected (see Fig.4).

If you see a similar device appear, then the ATmega16u2 is communicating correctly, and you can clean any excess flux off the PCB. A fine brush (like an old toothbrush) is handy for cleaning among the pins. Note: do not use a toothbrush for brushing teeth after this!

If it doesn't appear in Device Manager, you need to resolder the chip and try again.

Loading the firmware

As we mentioned a little earlier, the

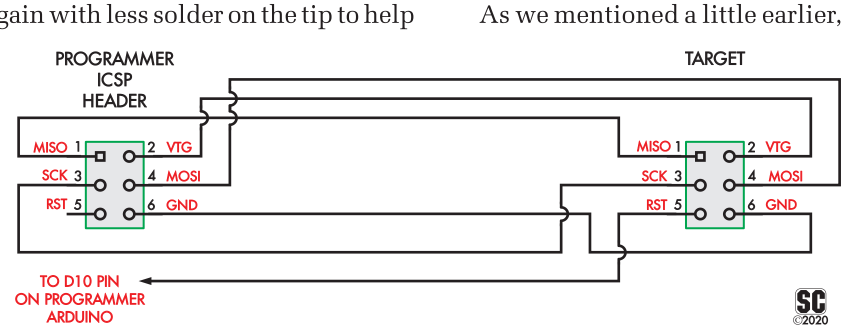


Fig.6: This view of our ISP jumper wire is shown from above (as it would look plugged into the top of the board). The stray male jumper goes to a dedicated pin on the programmer board (pin D10 by default) while the other five pins simply go to the corresponding pin on the programmer ISP headers.

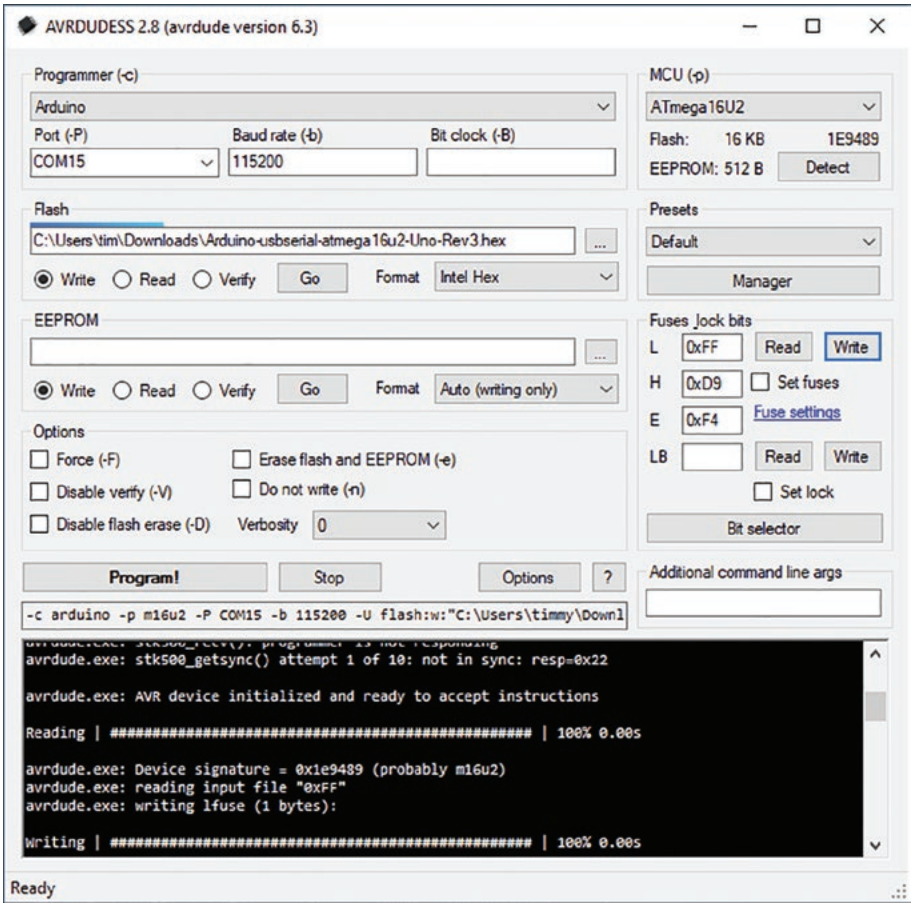


Fig.7: here are the required AVRDUDESS programming settings for the ATmega16u2. The port at top left should be the serial port of the programmer Arduino.

ATmega16u2 needs firmware to be loaded to operate as USB-serial converter. While the DFU bootloader can be used to upload firmware (using the Atmel Flip software), we found that it did not properly set the configuration fuses, meaning that it did not operate at the correct baud rate.

So we'll describe a more general method. This doesn't use the DFU bootloader, but does require a small amount of extra hardware. This method can also be used to load the Arduino bootloader onto a blank ATmega328 chip.

To do this, we use an ISP programmer, which plugs into the 3x2 pin ISP header. The Uno board has two ISP headers, one for the ATmega328 and one for the ATmega16u2 (see Fig.5). The process to program both is practically the same, but the firmware image is different.

These chips can be programmed by using another Arduino board. Any 5V Arduino board with an ISP header should be usable, such as the Uno, Mega and Leonardo (and their clones). A sketch to do this is included with the Arduino IDE software download. The only extra hardware needed is a simple jumper cable to connect the programmer to the target board (see Fig.6).

Make up the cable as shown. You can use a set of individual jumper leads with DuPont headers on each end (packs of these are available from Jaycar & Altronics). Alternatively, do what we did and solder a length of ribbon cable to a pair of 2x3 female headers, with heatshrink tubing used to protect the solder joints.

From the Arduino IDE, open the ArduinoISP sketch from the following menu item: File -> Examples -> 11.ArduinoISP -> ArduinoISP. If you can't find it, try upgrading to the latest version of the IDE. Select the correct board (for use as the programmer) and serial port and upload the sketch.

Programmer software

You also need to load appropriate software onto your PC, to upload the firmware image and fuse settings to the Arduino programmer. Luckily, such a program is also included with the Arduino IDE, and it is called AVRDUDE, the utility that performs the uploading of sketches to the boards. By the way, AVRDUDE is short for "AVR Downloader/UploaDEr".

To make things easier, we will use AVRDUDESS, a graphical interface for AVRDUDE. You have to download this separately, from: siliconchip.com.au/link/aaxh

As AVRDUDE will have been installed along with the Arduino IDE, once installed, AVRDUDESS should automatically detect its presence. With AVRDUDESS running, you need to adjust its settings to be like those shown in Fig.7. Be careful here since selecting the wrong Fuse byte values (L/H/E at right) can 'brick' the chip!

From the top, set the Programmer to "Arduino" and ensure the port and baud rate match the Arduino you are using as a programmer. The baud rate should be 19,200 as this is the default for the ArduinoISP sketch (the code snippet shown in Fig.8 is where to change this if you need to).

Connect the target end of the programmer to the target board at the ATmega16u2 ISP header, ensuring that the pin 1 designations line up, as shown in Fig.6.

The power LED on the target board should light up as the programming cable provides power. If it does not, check the wiring.

We occasionally found that connecting the target board caused the USB connection to the programmer to drop out. Try unplugging and replugging the USB cable in this case.

To do a quick connectivity check, press the "Detect" button at the top right of the AVRDUDESS window. After a short delay, you should see the message in the lower window:

Detected 1e9489 = ATmega16U2

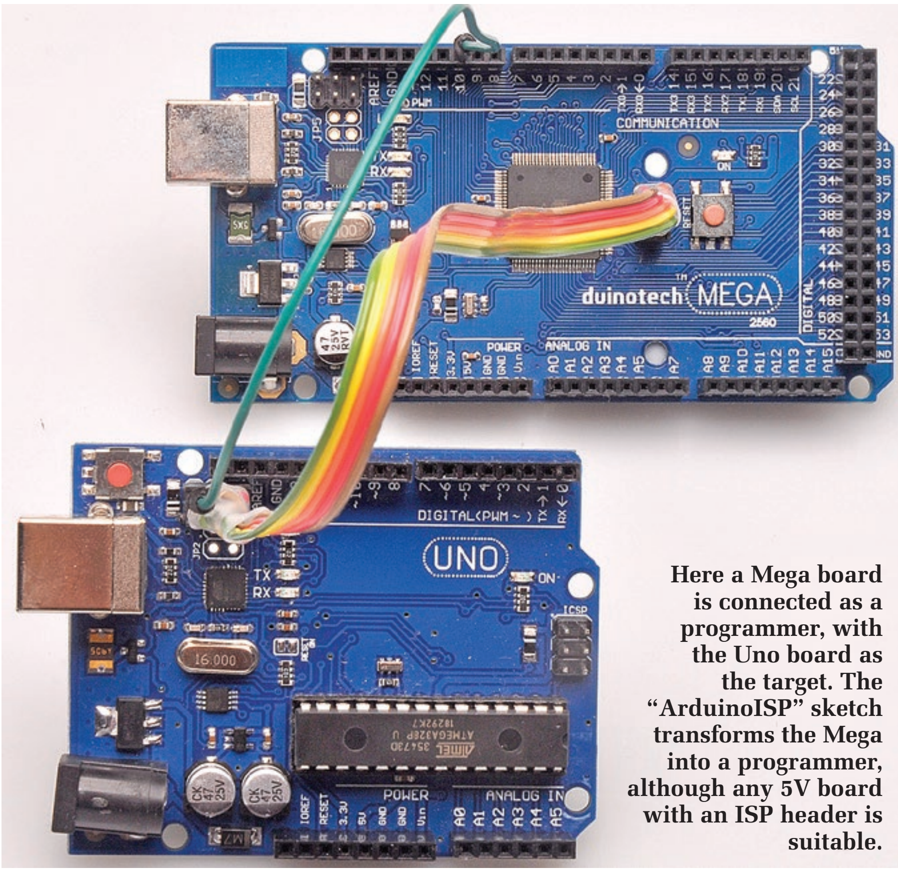
And the MCU selection at top right should match. If you see:

ERROR: Unknown signature 000000

```
// Configure the baud rate:

//#define BAUDRATE  19200
 #define BAUDRATE 115200
// #define BAUDRATE 1000000
```

Fig.8: this small fragment of the ArduinoISP sketch is where the serial port baud rate is set.



Here a Mega board is connected as a programmer, with the Uno board as the target. The "ArduinoISP" sketch transforms the Mega into a programmer, although any 5V board with an ISP header is suitable.

Then the target processor is not being detected. Check your connections and try again.

To upload the firmware, select the "Write" radio button under the "Flash" heading at upper left and then select the firmware file.

You will have a copy of it hiding somewhere in your Arduino IDE folder (on our system, it was in C:\Program Files (x86)\Arduino\hardware\arduino\avr\firmwares\atmegaxxu2\arduino-usbserial\Arduino-usbserial-atmega16u2-Uno-Rev3.hex).

If you are updating the firmware on the ATmega16u2 installed on a Mega board, you need to use the version with "Mega" in the name instead of "Uno".

To make your life easier, we have included the current version of both files in a download associated with this article on the SILICON CHIP website.

Having selected the file, click "Go" under the Flash section. You should see messages like this in your output window:

```
avrdude.exe: verifying ...
avrdude.exe: 4034 bytes of flash verified
avrdude.exe done. Thank you.
```

This means that firmware has uploaded correctly. Once that's done, under the section labelled "Fuses lock bits" at right, click "Read".

The L, H and E (low, high and extended fuses) values should read 0xFF, 0xD9 and 0xF4 respectively, just like our screenshot. We read these from another working Uno.

If not, change them to match, then click the "Write" button in the same section. We only had to change the low fuse byte on our chip. Once this has completed, the ATmega16u2 is correctly programmed.

You can now unplug the programming cable from the target Uno and connect it to a computer via its USB cable. The ATmega16u2 chip should now show up as a USB Serial Device.

Reprogramming the ATmega328

You can also use this approach to install or repair the bootloader firmware on the ATmega328. This is necessary, for example, after plugging a new, blank ATmega328 chip into the Uno board.

The arrangement is the same as shown above, except that you connect to the other ICSP header on the target board.

The required file is called "optiboot_atmega328.hex". Optiboot is the name of the bootloader firmware. We have included this in our .ZIP download to make your life easier.

Once the boards are connected, click the "Detect" button to identify (or manually select) the MCU, write the HEX file to flash and then change the fuse bits.

In this case, they should be 0xFF, 0xDE and 0xFD for the low, high and extended fuse bits respectively. We used AVRDUDESS to read these from another Uno to confirm that they were correct.

Similar firmware files exist for the Leonardo (ATmega32u4) and Mega (ATmega2560) boards and their main processors.

By the way, it's also possible to use an ISP programmer to upload sketch files directly to the ATmega328 on an Uno, bypassing the USB-serial connection.

The connections are the same as for writing the bootloader to the ATmega328 chip. From the Tools menu in the Arduino IDE, select Programmer -> Arduino as ISP. To upload the sketch, press Ctrl-Shift-U or select the Sketch -> Upload Using Programmer menu option.

Note that doing this will corrupt the bootloader settings, so if you want to use the USB-serial link for uploading in the future, you will have to re-instate this using AVRDUDESS, as described above.

Pre-built ISP programmers

If you don't have a separate Arduino board, or find the above procedure awkward, you can purchase a dedicated Atmel in-circuit serial programmer like Jaycar Cat XC4627.

This comes with a 10-pin cable, but a 10-pin to 6-pin adapter is also available (Cat XC4613). Or use Altronics Cat Z6540, which has sockets for both 10-pin and 6-pin cables.

These programmers may need their own drivers installed, and will have a different programmer type, rather than "Arduino as ISP".

Conclusion

We used the process described here to resurrect two Uno boards with around $10 of parts and some time. And we learnt quite a bit about the Arduino system in the process; hopefully, so will you. SC

SERVICEMAN'S LOG

The vacuum cleaner that didn't suck

Dave Thompson

Anyone who works with particular tools or machines a lot gets to know how they sound and feel, and so can quickly tell when they are not working properly. A keen woodworker will know when his table-saw blade is getting dull simply by the noise it makes when cutting.

An obvious sign of a dull blade is that it takes a lot more effort than usual to push the wood through the saw, or that the finish of the cut is not as good as it should be. But a perceptive craftsman will know well before that just because of the different sound the tool is making.

As a musician, I also tend to notice melody and rhythm in almost everything. I know the regular rhythm of our dishwasher when it's working correctly, and sometimes find myself humming along to the harmonic-rich tone our microwave oven emits when it's cooking. If these aren't operating correctly, I'll know.

While this might appear sad or a little weird, it means I can often pick up when something's amiss just because it doesn't sound normal.

We rent our other house to short-term tenants, and as I'm the one looking after it, I get to clean it from top to bottom on average every couple of days. It's quite a time-consuming process.

As a serviceman, I'm always looking for ways to improve how I do this job, and that includes improving the tools I use. If I can buy or make something to do things better, or quicker and easier, I will.

Vacuum cleaners are my bag, baby

Aside from the usual aids such as extendable dusters and good quality cleaning cloths and agents, one essential appliance is a vacuum cleaner. Not only does it keep the house free from dust and dirt, but it also makes it healthier.

It's best to use a vacuum with a HEPA-grade (High-Efficiency Particulate Air) filter or bags. Many vacuum cleaners I've used over the years expelled more dust back into the air than they vacuumed up! While modern designs and improved filter materials make new models more efficient, a lot of those older machines don't make the cut.

These days a good vacuum cleaner needs to be lightweight, efficient, clean, easy to manoeuvre and quick to empty. But models that tick all these boxes can be surprisingly expensive.

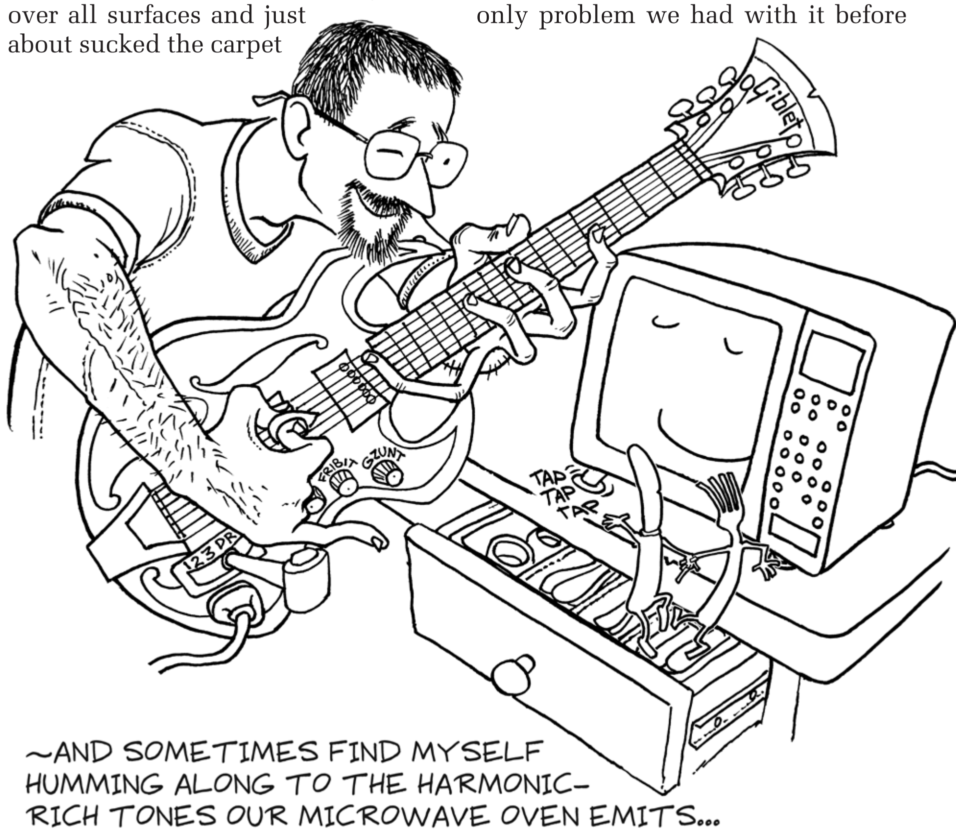
Recently, I started noticing that my 10-year-old Bissell PowerForce Turbo bagless upright model sounded different and it took considerably more effort to push around the floor. I also found that I had to make more passes to pick up visible debris.

When it was new, this cleaner glided over all surfaces and just about sucked the carpet up with the dirt. While it is tempting to just throw money at the problem by buying the most expensive cleaner on the market as a replacement, this wouldn't necessarily result in the best tool for the job.

We recently traipsed around the usual stores looking at the wide variety of new vacuum cleaners and weren't that impressed by many of them, especially by some of the prices. The more we looked, the less inclined I was to buy new and the more convinced that I could refurbish our existing hoover and return it to rude health for far less than the cost of a new one.

Fixing old faithful

This machine has done us well; the only problem we had with it before



Items Covered This Month

- The suckless vacuum cleaner
- An oven tripping the RCD breaker
- Fridge/freezer defrost repair

*Dave Thompson runs PC Anytime in Christchurch, NZ.

Website: www.pcanytime.co.nz
Email: dave@pcanytime.co.nz*

this recent loss of performance was a blown 'headlight' and a broken plastic height-adjustment assembly.

The latter is mounted under the power foot. It alters the height of the brush and air intake above the cleaning surface using a simple mechanical adjuster knob mounted on top of the foot. The adjustment is meant to be used when moving from plain to carpeted floors.

However, I've never changed this setting. We have a mix of short-pile carpets and vinyl floors, and the cleaner works just as well on both with the knob set half-way between the two extremes. This only adds to the irony that the adjuster is the only part that has broken.

I don't know how it broke; one day I noticed one of the two 25mm plastic roller wheels that form part of the adjuster had come away from its axle mount. The whole assembly is pretty flimsy, considering the strain it could potentially be under if one was to lift and drop the machine to the floor from more than a few centimetres.

As is typical, the big-box store we bought the cleaner from doesn't sell spare parts, fobbing us off instead to a vacuum cleaner speciality store. They didn't carry parts for it either, even though this model was widely sold here. Nice one local stores, and you wonder why people increasingly buy online!

I ended up sourcing and buying the part from Amazon; it only cost about thirty bucks delivered, so I was grateful I didn't have to junk the vacuum for want of a cheap replacement part.

The headlight hadn't worked for about half the time we've owned the machine and was dim and next-to-useless anyway, which is why I never bothered repairing it. It is one of those 'features' that seems great in theory, but in practice, appears not very well thought out.

Actually, I think a headlight on a vacuum cleaner is a brilliant idea (LOL!). Not everywhere we want to hoover is well-lit, and illuminating that area can be very helpful. However, this light is mounted on the base of the moving handle assembly. So as soon as I stomp on the pedal to release the handle from its upright resting position, the whole thing tilts back and lights up the walls instead.

This actually throws the area in front of the foot into a contrast shadow. It would have been better to mount the lamp on the foot, which always faces the same way and sits level on the floor. It makes me wonder whether Mr Bissell has ever used his own product; if he did, he would have seen in a flash (pun intended!) how useless this feature is.

The latest repair

This machine has done a lot of work over the years, but as it wasn't some $99 special to begin with, I would only consider junking it if I had no other option.

I noticed that if I removed the hose going from the cyclone to the power head, it had good suction. But for some reason, it just wasn't 'on song' and picking up dirt the way it used to.

I usually either wash its filters in the washing machine, as per the manufacturer's recommendation, or simply blow them clean with my compressor and air gun. Overall performance is usually restored after filter cleaning, but lately, this hasn't worked as well.

Because replacement filters also aren't available locally (noticing a theme?), I once again hit the Interwebs. I found and purchased a twin pack of replacement filters and a new drive belt. It seemed sensible to replace the belt as a precautionary measure, even though I hadn't checked it for wear yet.

These parts came to around $50 delivered, a relatively cheap fix if it got the performance back up to scratch. I'd much prefer to buy this stuff locally and support local stores, but if they don't bother stocking parts, I can't.

Despite my servicing history, I have scant vacuum servicing experience. So I decided to take everything apart, inspect all the parts and replace or repair whatever seemed worn or broken. I would then reassemble the machine in the hope that what I had done would fix the problem. While this is a very cowboy, shotgun approach, it does usually work.

Dissecting the patient

The PowerForce is an easy machine to work on; no lame anti-tamper or purposely-obfuscated screws, just old-fashioned, easy-to-access meat and three veg fasteners. I stripped this one down to spare parts in about 10 minutes with one medium-sized Philips screwdriver and a pair of pliers.

There really isn't much to it; the obvious things that could go wrong are the motor, the filters, the drive belt for the foot brush, and any bearings or bushes that could wear out.

With the machine on the workbench, I took a good look at it. Most of the hard work is done by a high-revving, low torque motor mounted inside the body of the cleaner, near the bottom of the tilting handle assembly. This keeps the centre of gravity low. Many new models have the motor assembly at the top of the handle, which in my opinion makes swinging them around more difficult and harder on the arms.

Above the motor is the 'dirt cup', the reservoir which collects the debris, then a clear plastic cyclone separator assembly sits on top of that. The dirt-laden air is sucked from the bottom, through the 'foot' intake, and enters the cyclone at the top via a flexible hose running up the side of the handle. There it swirls around due to the cyclone design, and any dust and debris (hopefully) drops into the dirt cup beneath.

The remaining air exits through various filters, which trap pollen and other pollutants, making the air (in theory at least) cleaner than when it went in. All components are easily removable; the dirt bowl to be emptied and the cyclone assembly to access three of the five filters.

There is also a rotating brush in the power foot. This belt-driven cylindrical brush spans the whole front part of the foot, just before the air intake, and runs all the time. But it only makes contact with the floor when the machine's handle is moved out of its upright resting position and the power foot sinks to the floor. It's a basic but effective machine.

Repairing the motor

I learned as a boy playing in dad's workshop that running vacuum cleaner motors without load can lead to catastrophic failure, so I tested this one using my non-Variac branded variac. This allowed me to wind up the juice and check the operation of the motor assembly. Straight away, I could see a lot of arcing around the brushes, which also appeared quite worn down.

On closer inspection, I could see the commutator had also been worn smooth. While the motor itself might be a common enough model, it appears to be built into an impeller and duct assembly specifically designed to fit this machine, so simply swapping one from another type of cleaner isn't an easy option.

This motor also has a longer shaft protruding from the rear for driving the foot brush, so swapping out an armature from another motor isn't viable either.

Back in my aircraft engineering days, I refurbished a lot of motors. That typically meant replacing brushes and overhauling the commutator section of the armature as part of the process. Because many vacuum cleaner motors are similar, I hoped finding replacement brushes wouldn't be too difficult.

I removed the clamps holding the brush holders to the motor frame and eased the brushes out. I took them to a local appliance repair centre and asked the guys there (who all have incredible product knowledge) whether they had anything like them in stock.

One guy came back with a few different types, which we compared on the counter, and I bought a set that was very close to the original's dimensions. While the carbon composition might be different – ie, the brushes might be harder or softer – I didn't have the luxury of choice so they'd have to do.

Back at the workshop, the new brushes fit neatly into the brush holders, and while they were probably a little longer than the originals, there was plenty of room in the holders.

The commutator was trickier. It was easy enough to get out, but I couldn't find any information online about the depth of commutator undercut, or even if there should be any in these motors. However, I could see by the unworn part of the commutator, where the brushes hadn't been contacting it, that it was originally slightly larger in diameter and that these segments were undercut.

I'd have liked to have mounted the armature in a lathe and skimmed it flat, but there wasn't a lot of meat left in the copper, so I made do with hand-rubbing it with 180-grit wet and dry sandpaper just to clean it up a little.

I broke off a piece of a junior-hacksaw blade and wrapped lots of tape around one end to create a crude handle. I held the armature carefully in my bench vice and used this make-shift cutter to go around and ease out the areas between the commutator's copper sections, being very careful not to slip and gouge any of the faces.

Once I'd gone right around, I then cleaned up the copper again with sandpaper to knock off any sharp edges I'd created. Leaving them rough would chew the brushes out very quickly.

I reassembled the motor, checking the sealed bearings at each end of the armature at the same time. They seemed OK, and the armature spun quietly and smoothly by hand. I powered it up and tested it; this time there was minimal sparking and it sounded great, so I considered that job done.

While it was all apart, I looked at the headlight. The 12V, 11W bulb had blown. I rummaged around my bits boxes and found a 20W version; bigger is better, right? The shiny tape reflector behind the bulb had partially peeled back; a few dabs of superglue had that secured again.

The roller's drive belt and bearings were next. The new belt was smaller and more pliable than the old one, so it turns out that it did need to be replaced. I spun the roller in my fingers, and the bearings ran smooth and quiet. I also took the opportunity to remove all the long hairs and threads that always seem to wrap themselves around these brushes.

As I reassembled everything, I cleaned anything that looked dirty, removing years of built-up dust and trapped hairs. I found the centres of the main wheels had slogged out, so I cut some small strips of Teflon sheet and wrapped them around the axles before putting the wheels back on. I'll eventually have to do something more permanent, but that's a repair for another day.

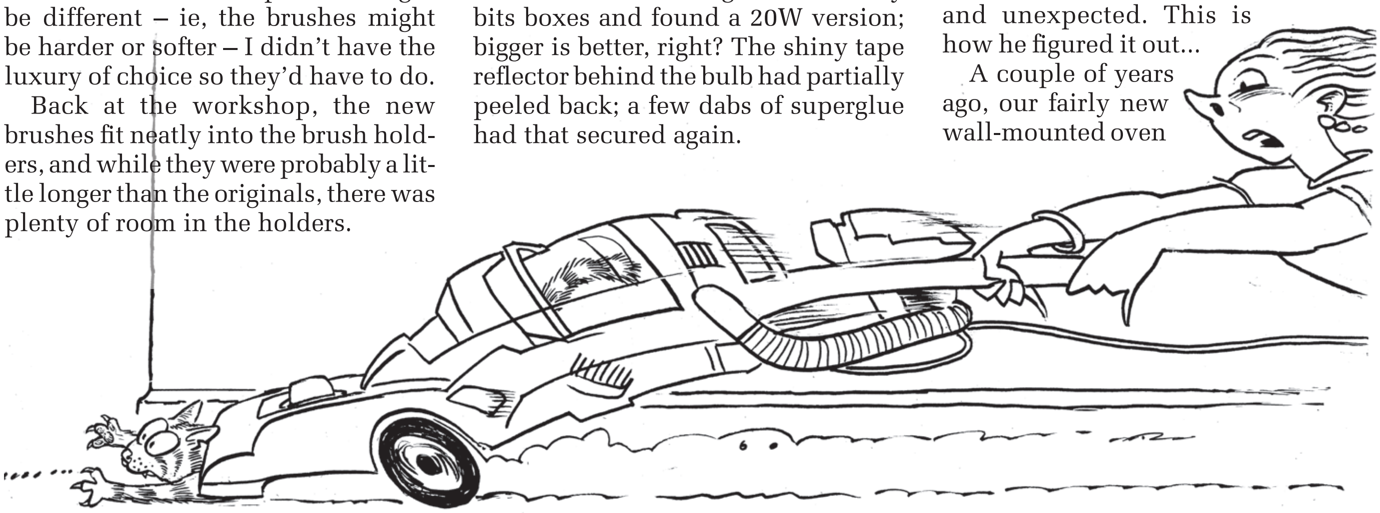
I installed the new filters, plugged the cleaner in and tried it out on the workshop floor. The difference was remarkable; not only does everything run much more smoothly, it is quieter, the suction more powerful and the motor sounds like it used to, all for a fraction of the cost of a new machine.

The only thing that left me baffled was, despite having stripped down and disassembled the whole machine, even though this is the "Turbo" model, I never actually located its turbocharger. How strange!

Oven tripping RCD

J. L., of Toowoomba, Qld, had a very frustrating (and intermittent) problem with his oven tripping an RCD. False tripping of RCDs is unfortunately a common problem, but in this case, the cause turned out to be a bit unusual and unexpected. This is how he figured it out...

A couple of years ago, our fairly new wall-mounted oven



~ EVEN THOUGH THIS IS THE "TURBO MODEL", I NEVER ACTUALLY LOCATED ITS TURBOCHARGER started tripping the RCD on higher heat settings, typically around 220°C. This usually only occurred when the oven reached that temperature, so I surmised that it was happening when the element was switched off. The tripping was only occasional, ie, "nuisance tripping", but it became more frequent over a year or two.

I tried the usual approach: turn off every appliance on that circuit, then switch each one on in turn and see if the RCD would trip. I started with the usual suspects: fridges and dishwashers. The results were mixed. Every time I thought I'd identified the culprit, it would trip again without that appliance switched on, or even plugged in.

This was becoming very frustrating, as each test required heating the oven to a high temperature.

Eventually, it was decided that a 'proper' service agent had to be called. In due course, he arrived and tested the oven temperature, ramping it up slowly – which was precisely the condition under which the RCD would not trip. He determined that the oven should be on a separate RCD and charged us a $100 call out fee.

Since this did not seem very helpful, I tried another approach. The RCD itself appeared to be the same model but older, than another in the same dwelling so I swapped them. But that didn't help. So I tediously repeated the appliance removal tests.

In the meantime, I built the Silicon Chip Earth Leakage Tester (May 2015; siliconchip.com.au/Article/8553) to check the various appliances, and this worked as expected. Some, such as a dishwasher with 'soft' on, showed leakage of the order of 1-2mA when switched on at the wall but with the appliance off. This is not enough to trip a standard (30mA) RCD, even with several such appliances in-circuit.

The next and most obvious culprit was the oven element. I thought this unlikely, but I know that elements can lose their insulation over time (especially if liquid is spilled on them), and can eventually trip the RCD. The only solution then is to replace the element.

I removed the oven element, measured the resistance to work out its nominal power, and the dimensions of the attachment plate. After a week or two of unsuccessful searching, I decided that we could ignore the element for now, since I could not find a replacement through the usual suppliers or even overseas, and that I had no proof that this was actually the problem.

So then I thought back to what had changed since the oven used to work normally. Then I suddenly realised that the rangehood extractor fan over the stove top had never been turned off during my tests, since it has no separate switch (I wish it did). It has a pushbutton to turn on lights and a fan, but I had the impression that this was done via a controller board.

Then I remembered that shortly after the rangehood was installed, it was repaired under warranty. And some time after the repair (which I think involved replacing the main controller board), the halogen lamps exploded (thus ruining a meal). I had noticed that these two lamps ran very, very hot, and that did concern me. So the halogens were replaced with LEDs, which ran much cooler.

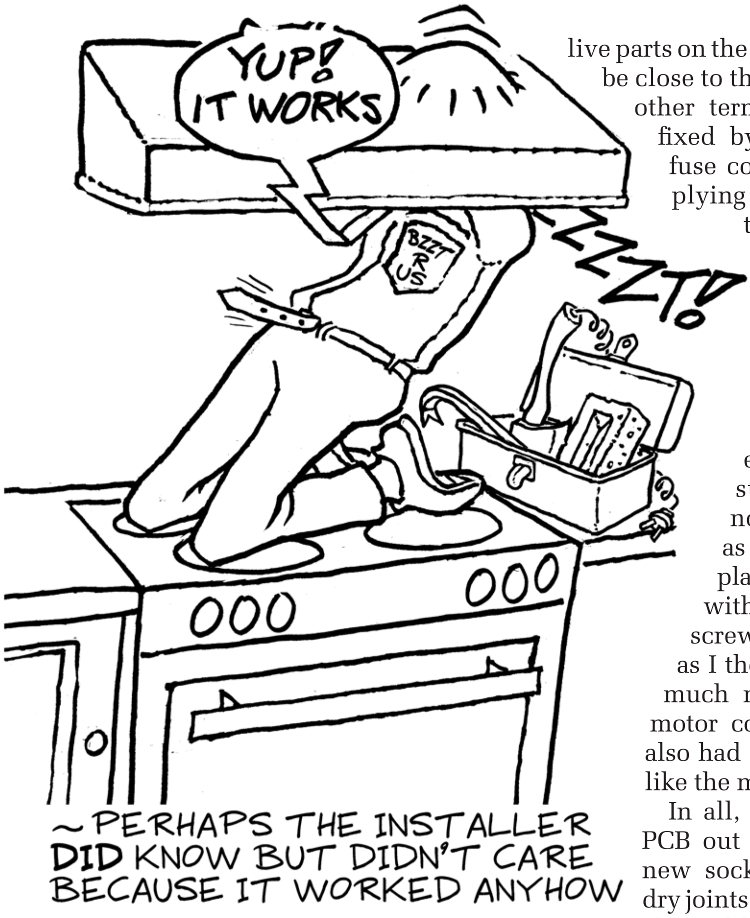
But that led to another observation: a faint glow from the LEDs at night time. I found this strange, but did not get around to investigating it, and put it down to stray capacitance or inductive coupling.

I removed the LEDs and replaced them with another brand of LED, and the faint glow also went. This initially appeared to solve the oven tripping problem, and it was put down to cheap LED drivers. But alas, the problem returned.

I then replaced the LEDs with halogens, and the problem disappeared. But by now I was thoroughly perplexed. Removing the lights altogether also stopped the oven tripping. Testing the light fittings with a non-contact tester revealed a curious and worrying scenario; there appeared to be mains voltage at the socket with the light turned off, but no voltage when the lights were turned on.

A few days later, suddenly it dawned on me that the mains wiring was almost certainly reversed; Neutral was being switched, rather than Active. That would explain the faint glow of LEDs in the night, with perhaps a few milliamps being inductively returned through Earth.

When time permitted, and after suitable safety precautions, I removed the covers from the rangehood controller. The controller is a small box about 90 x 60mm, located in the exhaust path, visible when the grilles are removed.



Upon opening the cover, my theory was confirmed: Active (brown) was wired to N (Neutral) on the PCB via a screw connector, and Neutral (blue) was wired to L (for Line, which I think is the terminology used in the USA for Active). This is precisely the opposite of what it should be, and confirmed my suspicions.

This should have been a quick fix, and the end of the matter. However, upon carefully unscrewing the PCB-mounted connector, it seemed to be quite loose. This worried me, given that it was connected directly to the mains. Perhaps excessive force had been used in the previous repair to tighten the screw, or perhaps it was a cold solder joint, or both.

So the unit had to come out, which entailed removing connections for the mains, the motor, lights, and an IDC connector for the switch panel.

I managed to resolder the connector easily enough. However, I was not happy with the fuse arrangement. It was one of those barrel-type fuses, with a connector on the side and at the end. The soldering on these was, in my opinion, poor.

But worse, the exposed metal meant that when the cover was replaced, the live parts on the fuseholder would be close to the main board and other terminals. That was fixed by resoldering the fuse connectors and applying heatshrink tubing to both exposed terminals.

Upon reinstallation, I noticed that the push-on light connector had one wire connected by a copper strand. This was not visible before, as it was shrouded in plastic. I replaced this with a PCB-mounting screw-type connector, as I thought it would be much more robust. The motor connector terminal also had a dry solder joint, like the mains connector.

In all, I had to take the PCB out three times to fit new sockets and resolder dry joints. This was all complicated by one "recycled" connector which would not accept a wire. This sounds trivial, but remember that reinstalling the controller requires one to have their head in the rangehood itself, bent over a stovetop, and twisted around. The non-compliant connector was high up and difficult to access.

Also, some of the mains wires had been tinned before being inserted into the screw terminals. I don't think this is good practice, as it necessitates a tighter turning of the screws to obtain a good mechanical contact, and that could be why the connector came adrift.

Furthermore, temperature and time can make the solder flow, leading to a loose connection. So I cut off the ends and re-stripped those wires.

Eventually, all was reassembled and checked, and everything worked perfectly, even with LED lights. Most importantly, the oven no longer tripped the RCD. But I was unhappy to have to do all this work when the board supplied with the rangehood should have been built to a better standard in the first place. It came in what is supposedly an up-market kitchen fitting.

So I surmised that a small leakage current was always flowing due to the reversed polarity of the controller. This reversal did not affect the operation of the unit as such, but it did mean that the external lamps were always at mains potential. This in itself was not enough to trip the RCD, but apparently, it was when combined with the high current pulse at oven switch-off.

It puzzled me why the unit was incorrectly wired. Perhaps the installer did not know the difference between L and N. Perhaps the installer did know, but didn't care because it worked anyhow. So beware of incorrectly wired appliances and sockets – I have subsequently heard of people switching off appliances, but not unplugging them, and receiving a shock due to similar wiring problems.

Fridge/freezer defrost repair

T. M. retired from the refrigeration industry a few years ago and after 40 years working with commercial refrigeration equipment – he knows a thing or two about fridges. He never liked working on domestic units but faced with warm beer, he had no choice but to delve into such a repair. It was an interesting experience, as he narrates...

I noticed the temperature in the fridge side of our 10-year-old Whirlpool two-door fridge/freezer wasn't quite what it used to be. I had set the temperature on the front keypad to 4°C but a measurement indicated that it was actually 9°C!

I used a datalogger to check the temperature over the next couple of days and it was gradually getting higher. But the freezer seemed to be working fine, maintaining around -16°C.

My first thought was that the motorised damper that allowed the cold air from the freezer into the fridge was not opening. This damper opens/closes to allow cold air from the freezer section into the fridge, maintaining the desired temperature. But on inspection, the damper was fully open but there was minimal airflow into the fridge.

Air is channelled from the freezer by a fan located above the finned evaporator, which also circulates air in the freezer. I could hear the fan running so this was not the culprit; it was evident that the evaporator was iced up and after removing several panels, that proved to be the case.

But this is a frost-free unit so that should not happen. A frost-free system works by automatically defrosting several times a day, thereby preventing ice buildup. The resulting meltwater is channelled away into a tray in the bottom of the fridge to be evaporated; usually, the hot discharge piping from the compressor passes through the tray to accomplish this.

My next thought was that the defrost element was faulty but a resistance check gave a satisfactory reading for a 750W element.

The next possibility was the defrost thermostat (or "Klixon") attached to the evaporator. This has normally-open contacts when warm, closing when cold. It's a mechanical safety device that terminates defrosting, should the controlling defrost timer device fail, thus preventing a mini Chernobyl!

This also tested good, however, I was somewhat mystified by this encapsulated device as it had six wires coming out of it; usually, only two are required to perform the safety function. I identified the two wires that were open when warm. So what were the other four wires for?

These remaining wires were attached to the fan and a multi-pin plug that exited from the freezer compartment and went down to the controller PCB. I thought there might be a problem with this board, as I expect the compressor and evaporator fan to switch off for several minutes each time the unit performs a defrost cycle and I was not observing this. Nor could I measure any voltage across the defrost element.

A fault with this control board would be bad since it doesn't lend itself to component replacement due to a heavy coating of resin.

I searched the web for information relating to the control electronics without success. A large local supplier of Whirlpool spares said that replacement control PCBs were no longer available. I finally located what I thought was a replacement on a UK website; it looked identical but had a different part number and at a price of £260 plus freight, I wasn't about to chance it being compatible.

I decided to modify the fridge instead to control the defrost cycle independently of the fridge electronics. This could be done quite easily with a mechanical defrost timer but I prefer using a programmable controller that gives me more options for controlling the cycle instead of just on/off.

I have quite a collection of refrigeration parts in my workshop, including a few such controllers.

The replacement seemed a simple task. I would allow the fridge electronics to manage everything other than defrosting. I would program the controller set point to a very low (unachievable) temperature, then I would connect a double-pole relay to the controller's compressor output terminal. This relay would remain energised at all times except when defrosting.

The compressor and the evaporator fan would be wired through the NO contacts of that same relay and therefore the normal operation of the fridge would be controlled by the fridge onboard electronics, which from time to time would try to defrost it for a short time with no result.

When my controller entered the defrost state, it would open the relay, thus halting the compressor and the evaporator fan and enabling the inbuilt controller defrost relay which was now connected to the element via another two-terminal defrost Klixon I fitted. The original Klixon was left in place due to the mysterious four additional wires; the two wires originally connected to the element were disconnected.

The added controller was mounted on the back of the fridge in a position that allowed the display to be easily observed and the buttons accessed for fine-tuning.

But when I fired up the fridge, nothing happened other than the display showing the previous set points for the fridge and freezer. It should have entered the alarm mode due to the high cabinet temperature. What was going on?

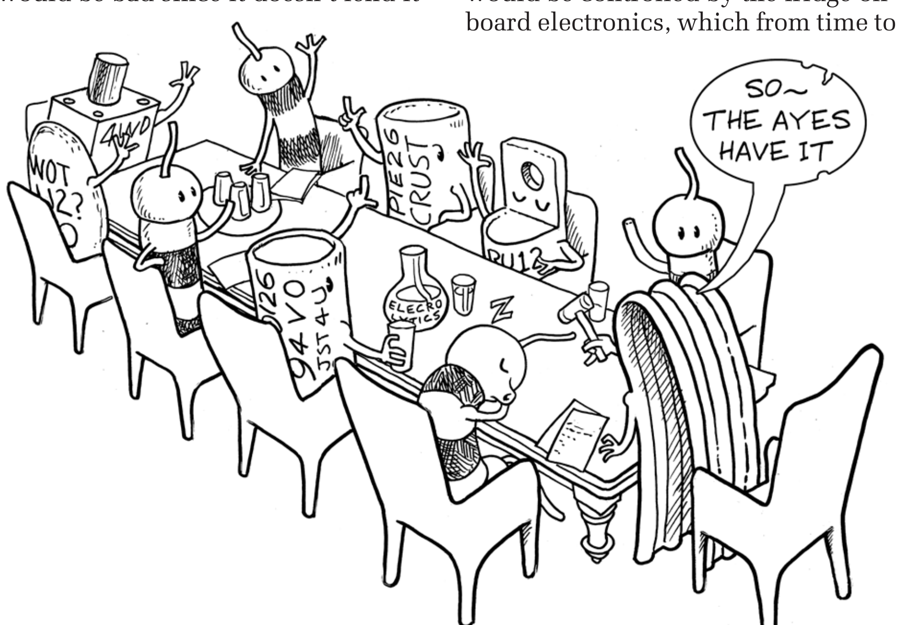
It seemed that the fridge electronics would not initialise after I had made my changes. The only change I had made from its perspective was disconnecting the defrost element from the original Klixon, so I tried reconnected it and the fridge fired up.

The control PCB likely performs a diagnostic check at power-up and if the defrost element is open-circuit, it refuses to continue. But hang on a minute, I thought, if it was correctly sensing that the defrost element was OK, how was it not able to drive it?

Anyway, I decided that the best course was to try to trick the control board into thinking that the defrost coil was still connected, even when it was not (so that the added control board could drive it instead). I decided to try connecting the coil of a 230V AC-powered relay as a dummy load.

Eureka! The fridge powered up and operated normally. I guess the control PCB isn't that fussy about the actual resistance between those two wires, as long as it isn't very high; the relay coil has a resistance of around 3.8kΩ compared to the defrost coil at 80Ω. But that was enough to fool it and so I left this relay permanently wired up, in the back of the fridge.

Everything is now working fine, with my added controller managing the defrost cycle as required. I made a few adjustments over a couple of days to optimise the defrost timing and it's now working normally. SC



...I DECIDED THAT THE BEST COURSE WAS TO TRY TO TRICK THE CONTROL BOARD

We can help you brew that perfect beer . . .
or anything else that demands a constant temperature

PROGRAMMABLE THERMAL REGULATOR

by Tim Blythman and Nicholas Vinen

Precision temperature control is an integral part of many industrial processes. If you are interested in making your own brewed or fermented foods as a hobbyist, you will find that it's important to accurately maintain the temperature of the process to get the best results.

From time to time, we have tried to make our own cheese, beer and cider (not at the office, of course!).

For beer, malted barley is fermented by yeast to create alcohol and develop flavours. The fermenting activity also adds effervescence to the finished product.

The fermentation (say, for homebrew beer or cider) takes place in a food-grade plastic container. Good results *may* be achieved by merely keeping the vessel in a room where the temperature does not vary much, perhaps wrapping it with a blanket in the cooler months.

But for consistency and to ensure that fermentation completes correctly (if it doesn't, that's when bottles start to explode!), you need a way to monitor and control the brew temperature. Proper temperature regulation is one reason that commercial breweries can ensure that each batch of beer tastes the same as the others.

Even keeping the brew vessel in a thermostatically controlled room may not be sufficient.

As the fermentation progresses, the yeast activity rises and falls. The heat generated varies, which can alter the temperature of the brew from the inside, even if the outside temperature is steady.

Thus we need a means of both measuring and changing the temperature of the brew.

We have chosen Peltier devices for this as they have the ability to both heat and cool; they only require a low-voltage DC supply, and they are easy to control. They are not the most efficient devices, but are adequate for small scale operations.

Sous-vide cookery

Another application for the Thermal Regulator is sous-vide cookery. While the term French 'sous-vide' literally translates to 'under vacuum', the vacuum is not critical. The success of sous-vide cookery is mostly due to precise temperature control.

We'll go into a bit more detail about this later, but the important thing is that a tightly controlled temperature leads to consistent and repeatable results.

By keeping the food hot enough for long enough, you ensure that any bacteria is killed, and thus it is safe to eat.

Other areas of cookery which work well with precise temperatures include the tempering of chocolate. Taking the chocolate along a well-defined temperature profile alters its structure and produces a glossy appearance and crisp texture when the chocolate hardens.

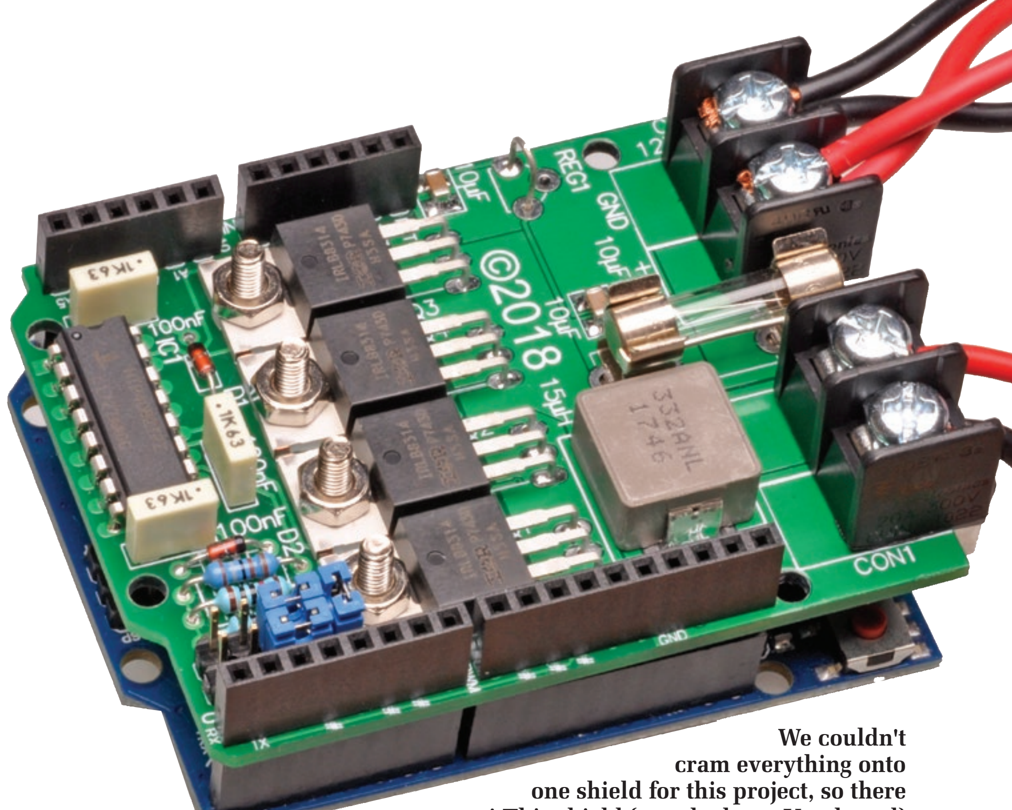
One of the intriguing possibilities with this device is that you could use it to keep food at a safe storage temperature (around 4°C, like the inside of a refrigerator) for many hours and then at a preset time, heat it up and cook it, so it is ready for you to eat.

If doing this, we suggest you modify the software to trigger an alert if the food temperature went significantly above 4°C in storage mode, so you know that it is safe to eat.

And more

Many people who have worked in a laboratory will be familiar with the laboratory water bath as a way of keeping test samples at a fixed temperature. Naturally, the Thermal Regulator is well suited to this application too.

We've even joked about using the Thermal Regulator as a personal air-conditioner. Joking aside, the radiator does produce a refreshing breeze when it's set to heat, so we reckon it actually would do that job pretty well.



We couldn't cram everything onto one shield for this project, so there are two! This shield (attached to a Uno board) is designed to drive Peltier devices at up to 20A in bridge mode, meaning the current can be reversed and the Peltier can be used to perform heating or cooling. There's a number of surface mounted devices on this shield, but none of them are too small, so construction is not difficult.

Thermal Regulator electronics

The Thermal Regulator electronics consists of three main parts. An Arduino Uno board (or compatible) provides a microcontroller as well as some power regulator circuitry.

A Peltier Driver shield (Arduino add-on board) implements a high-power full H-bridge which is controlled by the Arduino. This is used to drive the Peltier devices.

A second shield (the Interface shield) has numerous inputs and outputs; it is primarily concerned with sensing what is happening with the Peltier devices and can also drive other devices such as pumps and fans.

We'll expand on these later. You will need to be familiar with the Arduino IDE to construct this project; it can be downloaded for free from siliconchip.com.au/link/aatq

As this circuitry has so many potential uses, we've designed the control circuit to be as flexible as possible. Before continuing, you may wish to read the accompanying panel, which describes how Peltier devices work.

The inspiration for this article

It was thinking about projects like the 2003 Peltier Esky ("Tinnie Cooler") which gave us the idea for this series of articles.

That project involved quite a large heatsink and fan attached to a single Peltier module to try to get all the waste heat out and keep the Peltier running efficiently. If you use several Peltier devices to try to pump more heat, you end up needing a huge heatsink.

While simple and relatively cheap, this is not an ideal solution.

Features:

- *Active cooling and heating*
- *Controls 200W+ worth of Peltier devices*
- *Utilises multiple temperature sensors*
- *Arduino-based for flexibility*

Possible uses:

- *Cheesemaking*
- *Beer/Wine/Cider/Kombucha brewing*
- *Tempering chocolate*
- *Sous-vide cooking*
- *Computer cooling*
- *Laboratory water bath*
- *Aquariums (especially large tropical)*
- *Personal air-conditioner*
- *Improved cooling for laser cutters*

Consider, for example, that a car engine puts out a vast amount of heat (hundreds of kilowatts in some cases). While early engines were air-cooled, most manufacturers quickly moved to liquid cooling. It is much easier to remove all that heat with a bit of water flow, which can then go to a large radiator with sufficient surface area to transfer that heat to the air.

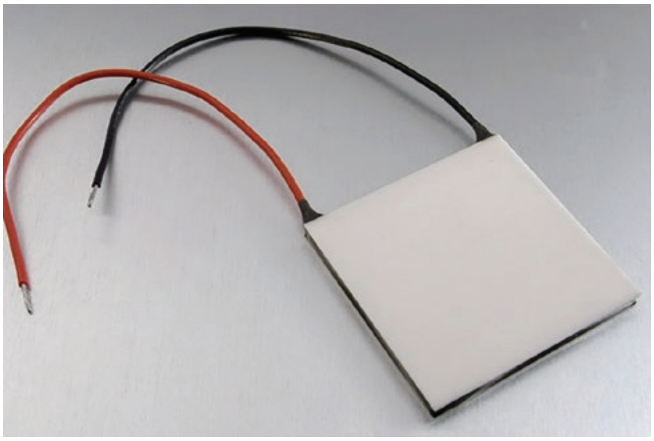
So we thought, why not apply the same principles to Peltier devices? Small radiators as used in water-cooled computers are now readily available at modest cost, and the required fans, pumps and tubing do not cost much either. We then bought some parts and performed a series of experiments which brought us to develop what we are presenting here.

One example

Sous-vide cookery is a good example to demonstrate what our resulting hardware can achieve.

As we mentioned, the term 'sous-vide' translates to 'under vacuum'. This term has little to do with the process except that the items to be cooked (typically meat, fish or eggs) are usually vacuum-sealed into a waterproof bag before being

How Peltier devices work



A Peltier device is effectively an electric heat pump with no moving parts. An electric current through the device causes heat to move from one side to the other. It consists of one or multiple junctions of dissimilar metals, across which a voltage is applied. The general construction of such a device is shown in the accompanying figure.

The laws of thermodynamics do not allow heat or coldness to be 'created'; these are merely a consequence of energy being moved from one place to another. For example, electric heaters convert electrical energy to heat energy in a 1:1 ratio. Unfortunately, the law of entropy means that we must expend energy to move this heat energy around. Hence the process cannot be 100% efficient.

The reverse of the Peltier effect is called the Seebeck effect, where a temperature difference is converted into a voltage. The energy delivered by that voltage comes from the thermal energy flowing from the hot side to the cold side. This is the effect used by temperature-sensing thermocouples and thermopiles.

The Seebeck effect can also be observed in Peltier devices, although they are not designed with this in mind and so are not very efficient. For example, if power is applied to a Peltier device for a few seconds (enough to cause a temperature difference) and then removed, a voltage can be measured at the device's terminals. This is due to the Seebeck effect of electricity generated from the residual temperature difference.

A Peltier device consists of an array of alternating materials, resulting in alternating junctions with opposing behaviours. They are arranged so that heat is transferred from one side to the other, by keeping each type of junction on its own side.

We last published a project using a Peltier device in 2003 (**siliconchip.com.au/Article/3969**). This involved adding active cooling to a small Esky (chilly bin) to help get drink cans cold. That project also had a feature in that it could be used as a heater; one upside of the Peltier effect is that it is reversible. If the direction of the current is reversed, then the heat flows in the opposite direction.

You may have used this type of cooler. They do a fair job, but most are no competition for a regular household refrigerator or air-conditioner, which use a compressor and do not suffer from the side-effects noted below.

While Peltiers have the benefit of reversibility and no moving parts, they do have their downsides. In particular, the materials which provide the strongest Peltier effect are not good thermal insulators; in effect, the heat can leak from the hot side back to the cold side. This effect becomes stronger as a higher temperature difference is generated across the device.

Practical Peltier devices are typically made of semiconductor materials with a finite resistance. As such, they are also subject to resistive heating due to the current flowing through them. This is calculated as I^2R, so a doubling of current will result in four times as much dissipation. But the amount of heat that is pumped is proportional to the current, so Peltier devices work best when demands on them are modest.

Peltier devices are also typically made out of brittle ceramics. These are necessary to provide electrical insulation while allowing heat to be effectively conducted to the working surfaces.

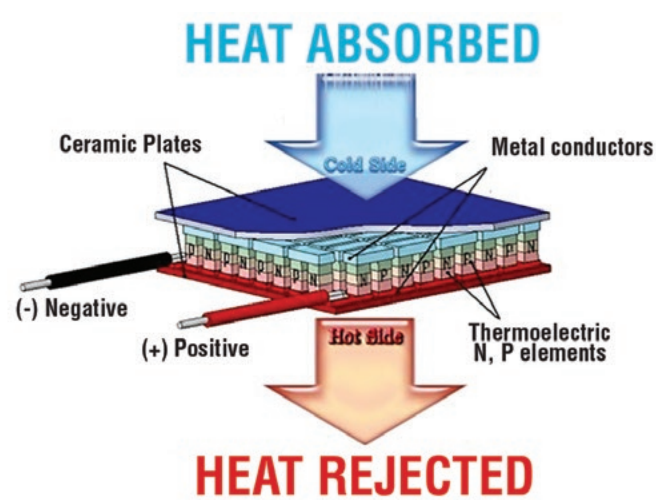
Safely driving a Peltier

Rapid changes in current can cause a temperature gradient; the resulting temperature changes can create thermal stress and even cracking. Using techniques like PWM (pulse width modulation) to modulate the current must be done carefully to avoid damage. At the very least, the PWM frequency should be high enough to sidestep these effects.

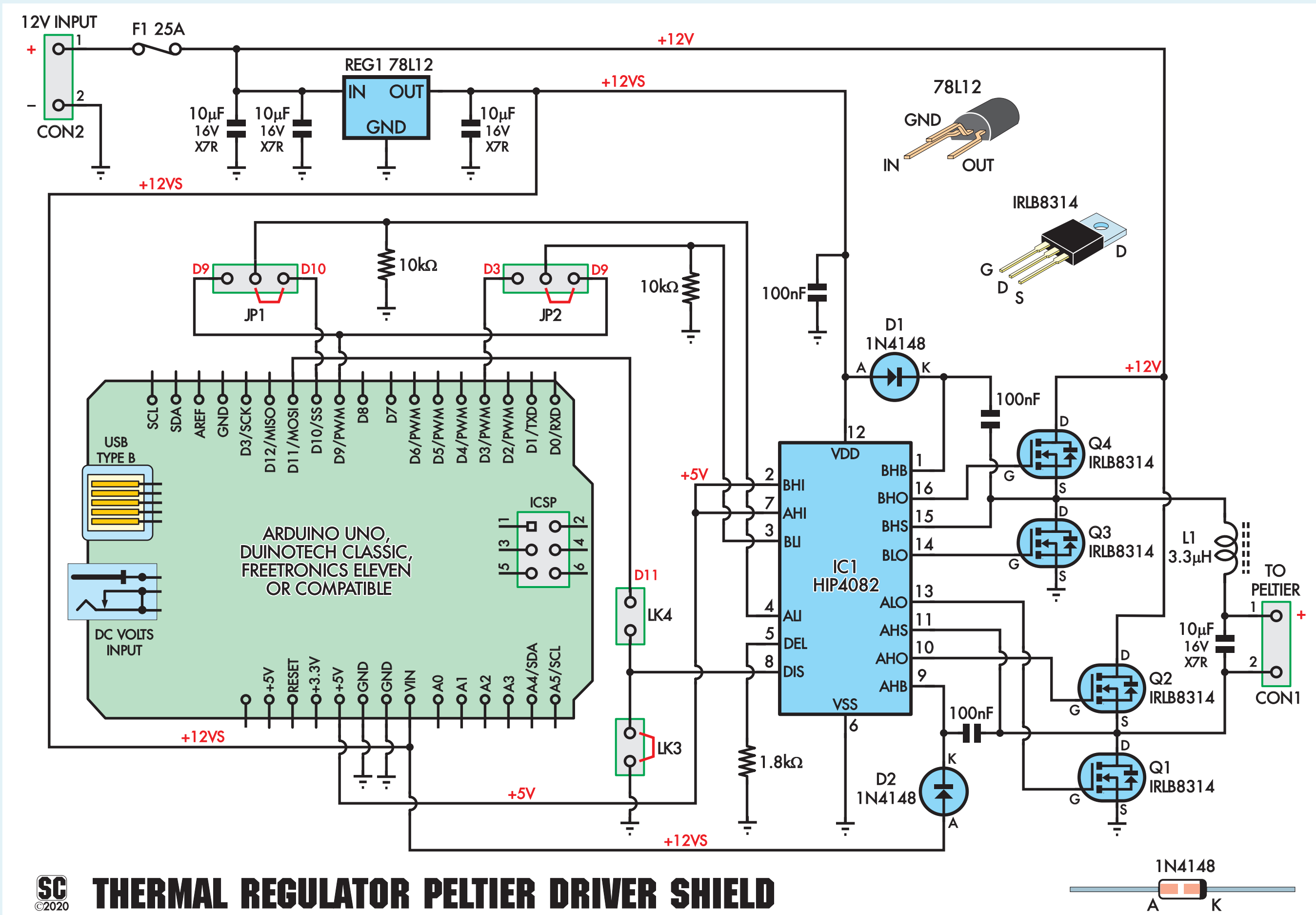
Many Peltier device manufacturers specify that low ripple power (of the order 5-10%) should be supplied to the devices. For optimal results, a pure DC voltage should be applied.

There is another reason to avoid PWM. Consider the case of pure 6V DC being applied to a Peltier device compared to 12V DC at a 50% duty cycle. When we look at the I^2R losses, we can see that these are doubled in the 12V case. Although the 50% duty cycle means power is applied half the time, double the voltage means that the I^2R effect is quadrupled.

Our Peltier Driver shield has been designed with these factors in mind. It delivers nearly pure variable DC across the full range of positive and negative voltages, allowing both heating and cooling. This also has the effect of making the power source's life a lot easier!



A Peltier device is usually made from an array of semiconductors which are electrically connected in series, but thermally in parallel due to the way the interconnectors are arranged. This way, when a voltage is applied, heats flows from one side to the other, depending on the voltage polarity. Image source: after https://cpb-us-e1.wpmucdn.com/sites.suffolk.edu/dist/f/759/files/2014/02/2.jpg



THERMAL REGULATOR PELTIER DRIVER SHIELD

Fig.1: the Peltier Driver shield has four Mosfets in an H-bridge configuration (Q1-Q4), an LC filter to smooth the voltage across the Peltier devices and one HIP4082 bridge driver (IC1). Its control pins can go to different Arduino pins depending on the settings of links LK1-LK4.

immersed in a temperature-controlled water bath.

A cheap alternative is to use a 'snap-lock' type sandwich bag. Careful sealing of the bag can ensure that most of the air is removed before sealing.

The bag has the effect of keeping the water separate from the food so that it does not dilute any flavours.

The removal of air by the vacuum process also means that there are no air bubbles which might cause the bag to float to the surface and not be fully immersed.

The aim then is to use the water bath to achieve a precise food temperature. For example, a piece of beef cooked medium rare should have a core temperature of 60°C.

Immersion in the water bath is a good way to accurately and consistently hit this target.

Thus our Thermal Regulator needs to be able to reach and maintain a steady temperature in a water bath to be useful in this application; ideally, it should be capable of heating to well over 60°C (we hit 75°C+ in testing).

One of the interesting things about sous-vide cooking is that you can cook at much lower temperatures than you might expect, as long as you maintain that temperature for long enough. This creates textures and flavours that are very different from what you get with boiling, baking, frying etc.

There's a lot more to sous-vide cookery than this; we simply want to explain why you might need such a thing as a precisely controlled water bath.

There are many guides to the sous-vide process, and you should do further research before trying this technique (eg, via a Google search).

We also mentioned that brewing and fermenting could be enhanced by implementing accurate temperature controls.

In this case, your brewing or fermenting vessel can be placed inside the water bath, such that the temperature-controlled water practically surrounds it.

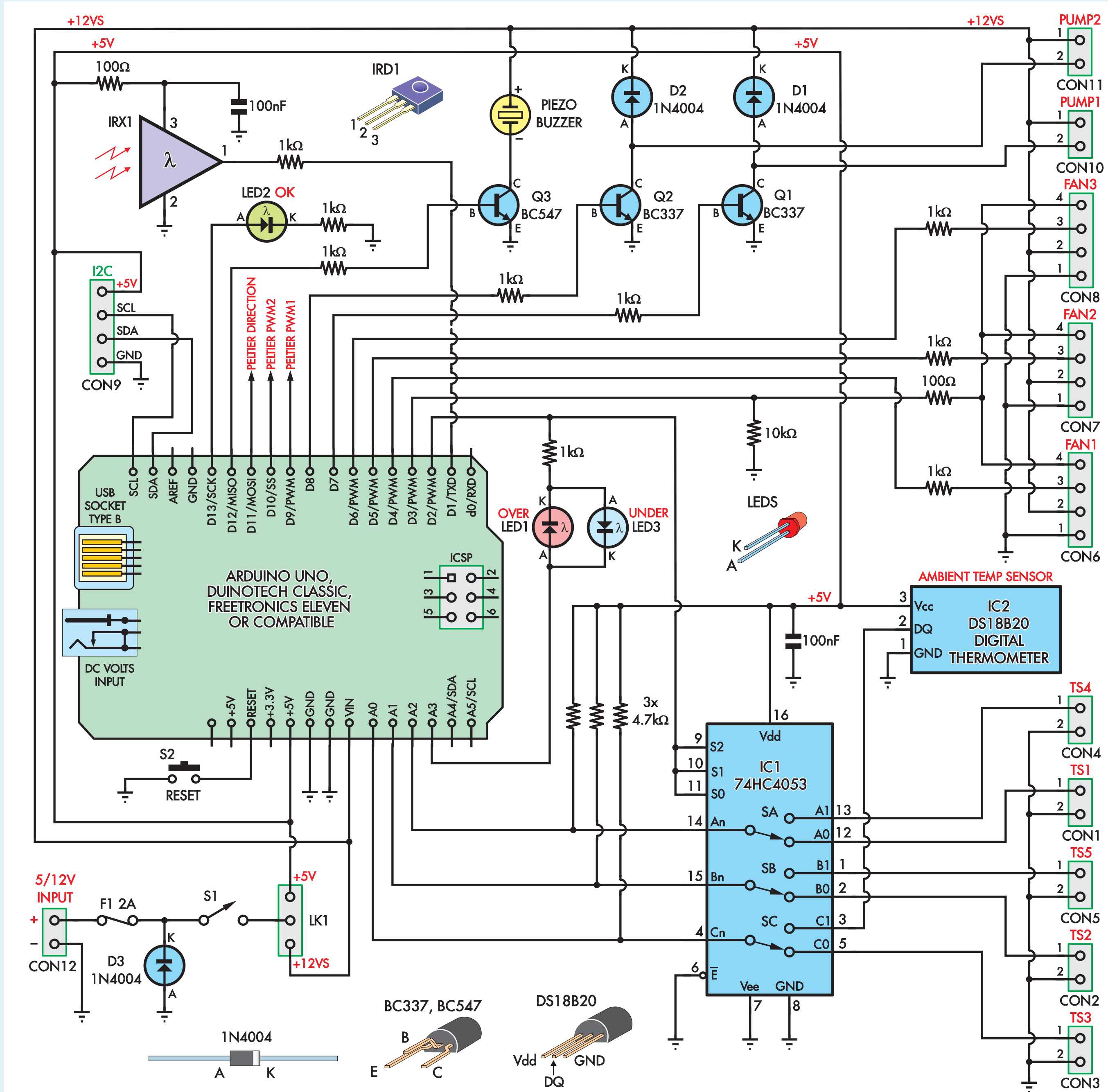
Having the bath itself being inside a well-insulated container (we used a small foam cooler for our experiments) reduces the demands on the Peltier devices and minimises external effects such as drafts.

The Peltier Driver shield

Fig.1 shows the circuit of the Peltier Driver shield. As mentioned earlier, it is based on a high-power H-bridge. DC power is fed in via terminal block CON2 and fuse F1, then to optional 12V regulator REG1.

REG1 is only needed if the supply voltage is above 15V, as many Arduino boards cannot sustain more than 15V at their VIN pin.

Otherwise, REG1 can be linked out or omitted entirely if 12V is available from one of the other attached boards. The regulated 12V power (from whichever source) is also fed to the VDD pin (pin 12) of IC1, an H-bridge Mosfet driver IC. It also has a maximum VDD of 15V, although it can control a bridge which handles up to 80V.



THERMAL REGULATOR INTERFACE SHIELD

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Fig.2: the Interface shield monitors up to five thermistors, and it can drive several auxiliary 12V devices which may be required, including fans and pumps. Multiplexer IC1 allows through analog inputs to sense six temperature sensors, as some analog inputs are reserved for I²C serial communications.

IC1 has its control inputs fed from jumper links LK1-LK4. These allow IC1's input pins to be connected in different combinations to various PWM capable pins on an Uno board. Two 10kΩ pull-down resistors ensure that the pins are in safe states (with the H-bridge shut down) when the Uno is in reset, not programmed etc.

The 1.8kΩ resistor connected to IC1's DEL pin (pin 5) sets the turn-on delay and thus the dead-time of the Mosfets to around 200ns.

Diodes D1 and D2, and their associated 100nF capacitors form the 'bootstrap' circuits which provide high enough voltages to drive the gates of high-side Mosfets Q2 and Q4, using the output square waves to form a charge pump.

IC1 also has its own 100nF supply bypass capacitor.

Mosfets Q1-Q4 are four IRLB8314 N-channel types in an H-bridge configuration.

These can switch 30V at over 100A with sufficient cooling, although the current is limited by other parts of the circuit such as PCB tracks and connectors.

Using an H-bridge means that the direction of current flow can be reversed, and the duty cycle can also

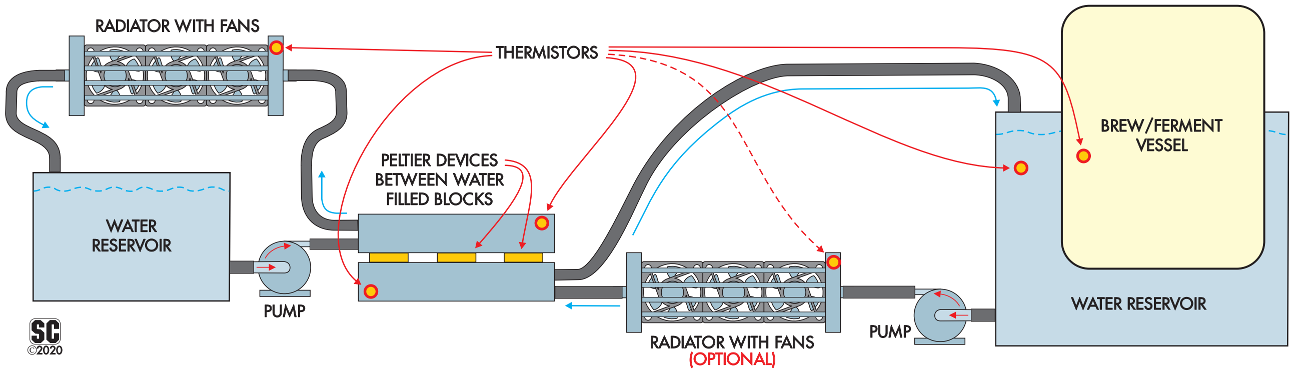


Fig.3: this 'circuit' shows how the Thermal Regulator could be used to control a sous-vide cooker or for making cheese or fermenting beer or wine. While the two loops make the hardware a bit more complex, this makes it capable of moving more heat around, necessary to achieve the higher temperatures needed for cooking.

be controlled by rapidly switching the H-bridge between two states.

The driver (IC1) is needed as the high-side Mosfets are N-channel varieties.

Thus their gates need to be taken above their source pins, ie, above the supply rail; the bootstrap circuit provides the means to do this. The driver also ensures that the Mosfet gate capacitances can be charged and discharged rapidly to provide a high PWM frequency so that we can filter it to get a smooth voltage across the Peltiers.

The Mosfets' low on-resistance of around 2.4mΩ means that minimal heatsinking is required; at modest currents (up to about 20A), the PCB itself provides sufficient heatsinking.

Between the output of the H-bridge and the output connector, CON1, is an LC low-pass filter comprising 3.3µH inductor L1 and a 10µF multi-layer ceramic capacitor. This forms a sort of crude 'buck' DC/DC step-down converter.

When a high enough frequency PWM signal is applied to the control inputs of IC1 (around 300kHz), the output is effectively DC. This also means that the current drawn from the nominally 12V rail is effectively DC, so no bulky bypass capacitors are required on the board.

One way of analysing this circuit is to assume that the Peltier devices have an effective resistance of around 1Ω (12A @ 12V).

We can then calculate that the 300kHz PWM signal is attenuated by a factor of 100 (around 40dB) and so the ripple is kept well below the recommended 5%.

This shield is suitable in any case where variable, relatively smooth high-current unregulated DC power is required.

The part chosen for L1 in our prototype has an 19A rating, but even if this is upgraded, the PCB traces and connectors max out at around 20A. The Mosfets limit the supply voltage to 30V.

Interface shield

The Interface shield (circuit shown in Fig.2) connects to up to six temperature sensors, can drive up to three PWM-capable fans and two small pumps.

One of the temperature sensors is a DS18B20 fitted to the PCB to sense ambient temperature; the remaining five channels suit either DS18B20 digital sensors or low-cost NTC thermistors (via CON1-CON5).

The shield also provides three status LEDs (red, green and blue), a buzzer and an infrared receiver for user input.

Four-way header CON9 breaks out the Arduino's I²C peripheral. Though this suits many sensors and modules, our primary intent is to drive a character LCD module similar to those we described in March 2017 (siliconchip.com.au/Article/10584).

This sort of display is easy to drive and well suited to showing a large number of changing parameters, such as temperatures and fan speeds, in near real-time.

No I²C pull-ups are provided on the board, as these are fitted on the LCD interface module.

CON12 allows power at 5V or 12V (set by JP1) to be fed into the shield. D3 provides reverse polarity protection by conducting enough current to blow fuse F1 if the supply is reversed. Switch S1 can be used to switch this supply on or off.

If JP1 is set to the 12V position, power is fed to the Uno's VIN pin which in turn provides regulated 5V back to the shield via the Uno's 5V regulator and pin. The 5V position feeds power directly to the 5V pin.

The jumper can also be left off, if, for example, 12V (VIN) and 5V rails are available from elsewhere, such as an attached Peltier Driver shield.

Although the Uno has six ADC channels (analog inputs), two of these pins are shared with the I²C peripheral and so cannot be used. Thus IC1, a 74HC4053 triple two-way analog multiplexer, is used to switch the A0, A1 and A2 analog input pins between CON2, CON3 and CON1 respectively in one state, and IC2 (the DS18B20), CON4 and CON5 respectively in the other state.

The control inputs for all three multiplexer channels are connected together, to digital pin D2 on the Uno. The output-enable ($\overline{E}$) pin is connected to ground, so the three switches in IC1 are always active.

The A0, A1 and A2 pins have separate 4.7kΩ pull-up resistors to the 5V rail, which provides parasitic power if a DS18B20 is fitted or forms the top half of a voltage divider circuit if an NTC thermistor is fitted.

CON6, CON7 and CON8 are four-way plugs for the connection of PWM-capable fans. Their 12V and GND supplies are taken from the VIN pin and GND pin of the shield.

The tachometer outputs are fed to Arduino pins D4, D5 and D6 respectively via 1kΩ resistors. These can be set as digital inputs to sense the fan speeds.

A common PWM signal to the fans is provided from Arduino pin D3 via a 100Ω resistor. This line also has a

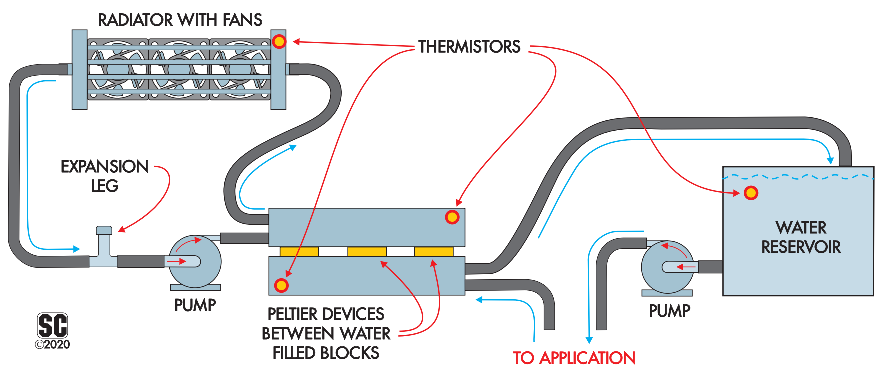


Fig.4: this is a variant of Fig.3. The vessel on the left-hand loop has been replaced by an expansion leg, the opening of which should be the highest part of the loop to avoid spillage. You can use the water from the right-hand loop to cool or heat whatever you need (such as a personal air-conditioner made from another radiator and some fans).

10kΩ pull-down, so the fans are off during reset.

CON10 and CON11 are for the control of small 12V pumps. Each is switched by a low-side NPN transistor (Q1 and Q2), controlled by Uno pins D7 and D8 via 1kΩ resistors.

Snubbing diodes D1 and D2 are connected directly across the outputs at CON10 and CON11, to absorb any back-EMF spikes when the pumps switch off.

Similarly, piezo buzzer PB1 is controlled by NPN transistor Q3. Its base is driven from Arduino pin D12 via a 1kΩ current-limiting resistor.

Of the three onboard LEDs, LED2 is driven directly by pin D13 going high and sourcing current through a 1kΩ resistor. LED1 and LED3 are connected in anti-parallel between pins D2 and A3 with a 1kΩ series resistor. LED1 lights when A3 is high and D2 is low; LED3 lights when D2 is high and A3 is low.

Naturally, both cannot be on at the same time. This arrangement means that the LEDs may flicker when D2 is being switched to scan the temperature sensors, but this only happens briefly.

Infrared receiver IRX1 is powered via a 100Ω resistor and bypassed by a 100nF capacitor. Its output is fed to Arduino pin D1 via a 1kΩ resistor. The UART peripheral also uses D1, so it cannot be used at the same time as the receiver.

Pins D9, D10 and D11 are left free and are intended to be used to control the Peltier Driver shield.

We have written several functions and routines to control the Interface shield, including such things as thermistor calibration curves and interrupt-based tachometer speed signal processing.

A minor limitation of the code as written is that it only supports the single DS18B20 fitted to the PCB. It's possible to read the temperature from other DS18B20s running on parasitic power from CON1-CON5 by altering the code, but this will considerably slow down temperature sampling.

We did this because we found the performance of the cheap NTC thermistors to be adequate.

Power

Anything to do with moving significant amounts of heat around requires a fair amount of power. We used four 5A Peltier devices in our prototype. The fans, pumps and shield add up to no more than an amp.

Most Peltier devices are rated to run at up to 15V. Thus we need around 21A at approximately 15V. The reduced I^2R losses are a good reason to use a slightly lower voltage like 12V, which is also more common.

For our prototype, we used an ATX computer power supply capable of delivering 22A from its 12V rail.

While this sounds quite close for comfort, the supply's other output rails (5V, 3.3V etc) have practically no demand.

Hence, the power supply stays comfortably within specification overall, and the power supply did not show any signs of stress under continuous operation.

Alternatives include a 15V or 13.8V open-frame power supply module or a high-current bench power supply.

We even did some initial testing using our 45V/8A supply from October-December 2019 (siliconchip.com.au/Series/339), although this is a poor use of its talents!

We'll show how we rigged up the ATX power supply; other options will probably be quite simple in comparison.

Other hardware

As you might imagine, there's a bit more to this project than the electronics. Fortunately, most of the parts are readily available at online sites such as AliExpress and eBay.

Before construction, we recommend you thoroughly read about our designs to see what you need, as there is a fair bit of flexibility possible.

As mentioned above, our main heat transfer medium is water. It has a good heat capacity (it can hold a lot of thermal energy for a given mass) and it has fair thermal conductivity (it's easy to move heat energy in or out of water). Plus, there is a lot of off-the-shelf equipment suitable for working with water.

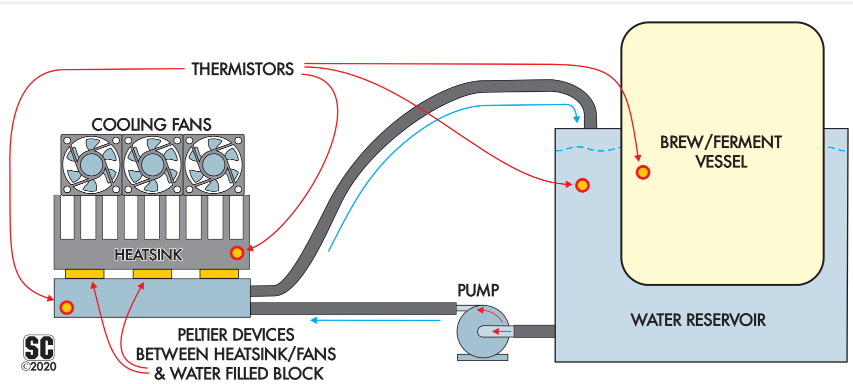


Fig.5: the minimal viable hydraulic circuit. For simplicity, we use a fan and heatsink combination instead of a second water loop. While not quite as effective as a radiator, this sort of configuration can move a few hundred watts of heat.

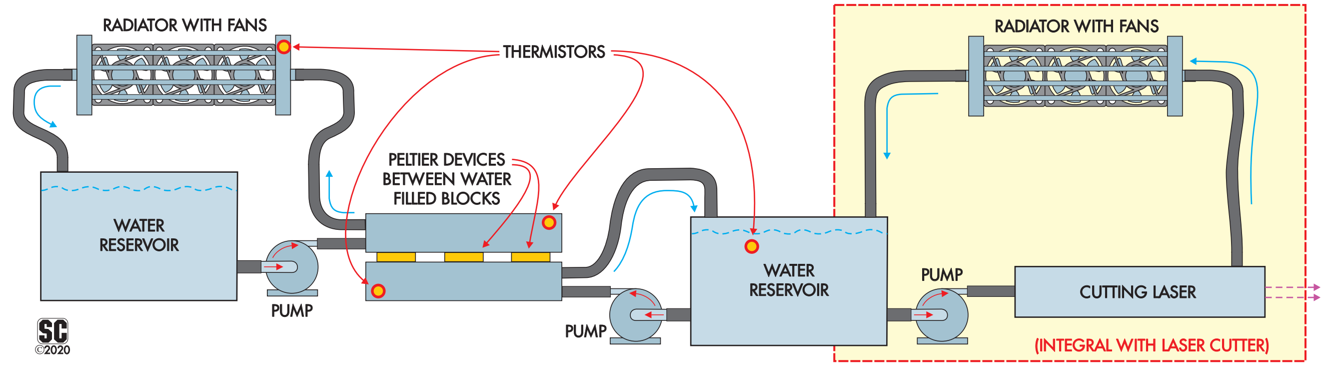


Fig.6: this is the arrangement that we have installed onto our laser cutter, to help 'boost' the laser cooling on hot days. It reduces the laser temperature by around 6°C compared to purely passive cooling (which is pretty good when you consider that with passive cooling, it operates at 10°C above ambient).

For example, the pumps we are using are similar to what might be used to circulate water in an aquarium.

Naturally, you should take care that there is no chance of water getting in the electronics (or vice versa).

The thermal loop

We manage the temperature of the water bath by circulating water through one or more loops. The movement works to keep the water mixed so that there are no hot and cold spots. Figs.3-6 show some variations on the water 'circuits' that are possible with our hardware.

Fig.3 shows the set-up that you might use for fermentation, while Fig.4 shows a general heating/cooling application and Fig.5 shows a simplified fermentation application (which would be cheaper to build but possibly less effective).

Fig.6 shows how we used the Thermal Regulator to pre-cool the water for our laser cutter, reducing the laser's operating temperature on hot days (more on that later).

You may realise from these diagrams that the water loop(s) mean that we can keep the radiators/heatsinks/fans which dump the 'waste heat' into the air well away from what we are trying to regulate.

This is a key benefit to using water to transfer heat.

Using a larger volume of water means that the setup will be more robust to external changes, but will take longer to reach its target setpoint. The aim here is to move the heat to or from where we want it as effectively as possible. The loops allow the heat to be moved easily.

The parts required

Many of the parts we used were obtained as part of a kit. These kits are typically sold for water cooling computers (eg, for overclocking). We also had to get a few other miscellaneous bits and pieces.

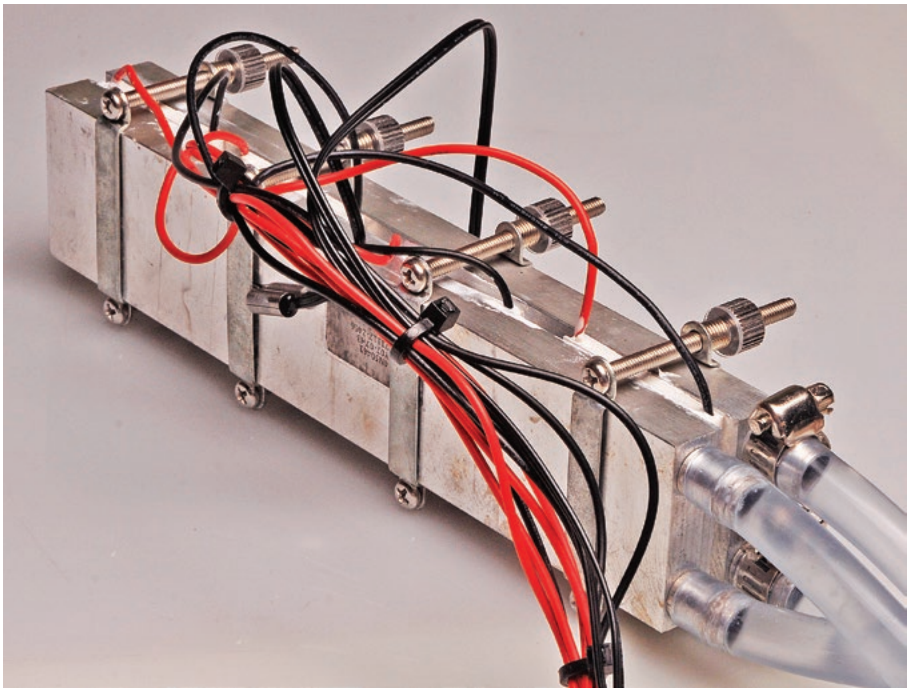
The water is moved by small 12V submersible pumps. These are cheap and draw around 300mA each. The water is not being pumped to any great height, as it is generally around a closed circuit, so a high pressure or 'head' is not needed. Generally, as long as the water is moving to some degree, we can maintain the level of heat transport we need.

To join everything together, we used flexible silicone tubing. We obtained this as part of our kit, although you can also get it from hardware stores like Bunnings or camping stores. We found that the most useful size has an inside diameter of approximately 8mm and is a good friction fit to the barbed fittings on the other parts.

Although the tube is a tight fit, we

These pumps are small and only draw around 300mA. They are sealed and thus fully immersible (the impeller is coupled to the shaft by magnets). Since they are not raising the water to any great height, not much power is needed. The main thing to ensure is that the intake is always fully submerged, as they are not self-priming.

The brass fittings are a snug fit for the transparent hose we used and did not show any signs of becoming detached. But we still used hose clamps to make sure. The tubing that was supplied with our kit with quite soft, so we replaced this with some thicker tube bought locally.



This assembly is held together by clamps, with the Peltier devices sandwiched between water blocks. The black wires visible lead to thermistors which are also held in place by the clamps. Not visible is a small amount of thermal compound between the heat-conducting surfaces.

didn't trust this completely. To secure the tubing, we used small (6mm-16mm) hose clamps.

Where we needed to bend the tube at a sharp angle, we used small barbed brass elbows and T-pieces. These too should be secured in place with hose clamps.

The final part of our primary circuit is the water block. This consists of a block of aluminium with two barbed fittings at one end. It provides a good thermal interface between the water and the Peltier devices, allowing heat to be readily transferred.

The water enters at one end, passes up and back along the block and back out the other fitting. While aluminium is not the best thermal conductor, it is cheap and easy to work with.

In a typical application, the Peltier devices are clamped to the flat surfaces of the water block with thermal compound in between, forming a tight fit over a large area that conducts heat well.

Naturally, the Peltier devices have two sides, and whatever heat is removed from one side needs to be dealt with on the other side. The simplest method is to use a heatsink block which is actively cooled by fans.

In our 45V 8A PSU design (see earlier link), we used a pair of high-powered fans on a heatsink and found this to be capable of dispersing a few hundred watts.

We ran some trials using this technique with Peltiers and it fared well, but not as well as a proper radiator.

The better technique uses a second water loop to remove heat from the other side of the Peltier device.

This uses a second pump and associated piping similar to the water bath. The water from the second loop goes through a fan-cooled radiator.

The radiator is like a smaller version of the radiator in a car. Water passes through the radiator and air is moved over it by the fans.

If the water is warmer than the air, then the water is cooled (and the air is warmed). If the water is cooler than the air, then it is warmed.

The radiator works better because it has a larger area for transporting heat and moves more air, but it is also a more complex arrangement.

This is the arrangement we have fitted to our laser cutter.

In these photos, you can see the various thermistors used throughout the rig. We can tell a lot about how the system is performing by the temperature readings. In particular, the temperatures at the hot and cold sides of the Peltier devices indicate how hard they are working and indicates the best strategy is for extracting the best thermal performance.

We will explain more later, but at times it is beneficial to switch off power to the Peltier devices. And of course, we use other sensors to measure the temperature at our water bath to be able to reach the target temperature, and know when we have done so.

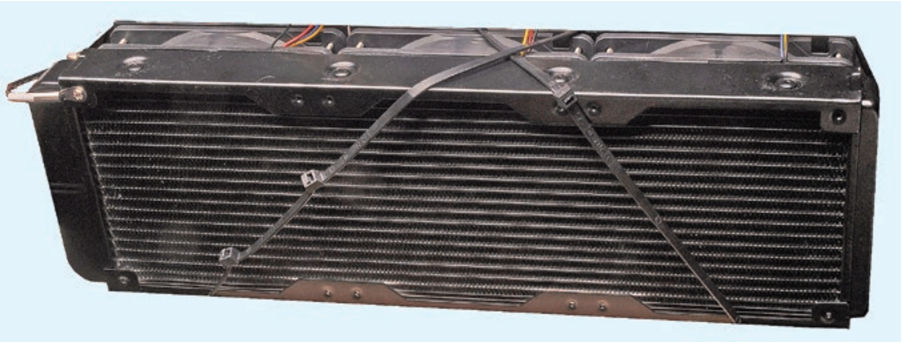
Water vessel for brewing ...

Another part that is not included in typical computer water-cooling kits is the water reservoir. The choice of this will depend on your application.

For our final implementation of a 'boost' cooler for our laser cutter, we simply used the existing water reservoir, which was a plastic lunchbox. You can see the original passive cooling system we built for our laser cutter in our article from June 2016 (**siliconchip.com.au/Article/9960**).

While you might be tempted to think that, for the fermentation application, you could circulate the fermenting liquid directly past the Peltiers, we strongly recommend against this. We could see no assurances anywhere that the parts we used were food safe and in any case, any beer left behind in the fluid circuits would be very difficult to clean out.

Beer is slightly acidic, and many cleaning solutions are strongly



This radiator is more effective at removing heat than the heatsink and fans. This is due to its larger effective surface area.

Parts lists – Programmable Thermal Regulator (Arduino/Peltier)

1 set of fluid-handling hardware (see text and below)
1 Arduino Uno R3 or compatible (ATmega328-based) board
1 Peltier Driver shield (see below)
1 Interface shield (see below)
1 high-current DC power supply (see text)
1 20x4 alphanumeric LCD screen with I^2C interface
[Silicon Chip Online Shop Cat SC4203]
1 length of light-duty figure 8 cable (for LCD screen)
1 4-way polarised header plug plus pins (for LCD screen)
1 universal infrared remote control
[Jaycar XC3718, Altronics A1012]

Fluid-handling hardware (single loop)

4 5A Peltier devices
1 water vessel to suit your application
1 small 12V DC water pump
[eg, www.aliexpress.com/item/32810010753.html]
1 40x200mm aluminium water block
[eg, www.aliexpress.com/item/4000299552495.html]
1 water block mounting kit
[eg, www.aliexpress.com/item/32323128854.html]
1 200mm-long heatsink (to suit water block)
[Jaycar HH8530, Altronics H0536]
2 80mm 12V fans or to suit heatsink
[Jaycar YX2512, Altronics F1050]
mounting hardware to suit fans
a few metres of 8mm internal diameter flexible silicone tubing
several elbows and tees to suit tubing
4+ 6-16mm hose clamps
1 tube of thermal paste
various cable ties

Fluid-handling hardware (twin loops)

4 5A Peltier devices
2 water vessels to suit your application
2 small 12V DC water pumps
[eg, www.aliexpress.com/item/32810010753.html]
2 40x200mm aluminium water blocks
[eg, www.aliexpress.com/item/4000299552495.html]
2 water block mounting kits
[eg, www.aliexpress.com/item/32323128854.html]
a few metres of 8mm internal diameter flexible silicone tubing
several elbows and tees to suit tubing
8+ 6-16mm hose clamp
1 tube of thermal paste
various cable ties
1 fan radiator, 360mm type recommended
[eg, www.aliexpress.com/item/32833463954.html]
1-3 12V fans to suit radiator (eg, 120mm fans)
[Jaycar YX2574, Altronics F1165]
mounting hardware to suit fans

Peltier Driver shield parts

1 double-sided PCB coded 21109182, 53.5mm x 68.5mm
1 10-way stackable header (11mm pin height)
1 8-way stackable header (11mm pin height)
2 6-way stackable headers (11mm pin height)
2 2-way barrier terminals, 8.3mm pitch (CON1,CON2)
1 5x2-pin header (LK1-4)
3 jumper shunts (LK1-4)
2 M205 PCB-mount fuse clips (F1)
1 25A M205 fuse (F1)
1 3.3μH 19A SMD inductor, 14.0 x 12.8mm
[eg, Pulse PA4343.332ANLT; Digi-Key 553-4025-1-ND]
4 M3 x 9mm machine screws
4 M3 hex nuts

Semiconductors
2 1N4148 small signal diodes (D1,D2)
1 HIP4082 H-bridge driver, DIP-16 (IC1)
[Digi-Key HIP4082IPZ-ND]
1 78L12, TO-92 (REG1; optional – see text)
4 IRLB8314 N-Channel Mosfets, TO-220 (Q1-Q4)
[Digi-Key IRLB8314PBF-ND]

Capacitors
3 100nF MKT or multi-layer ceramic
4 10μF 16V* X7R ceramic, 3216/1206 SMD package
[Digi-key 1276-6641-1-ND]
** higher voltage versions required if DC supply >15V*

Resistors (all axial 1/4W 1% metal film)
2 10kΩ 1 1.8kΩ

Peltier Interface shield parts

1 double-sided PCB coded 21109181, 53.5mm x 68.5mm
1 10-way male pin header
1 8-way male pin header
2 6-way male pin headers
1 PCB-mount blade fuse holder (F1; optional)
1 2A blade fuse (F1)
5 2-way vertical polarised headers (CON1-CON5)
4 4-way vertical polarised headers (CON6-CON9)
3 5.08mm-pitch PCB-mount two-way screw terminals
(CON10-CON12)
1 SPDT R/A PCB-mount toggle switch (S1; optional)
[Altronics S1320]
1 3-pin header and jumper shunt (LK1)
1 6mm tactile switch (S2)
1 piezo buzzer (PB1) [Jaycar AB3459, Altronics S6104]
5 10kΩ/100kΩ NTC thermistors with cables
[eg, www.aliexpress.com/item/32916207487.html
or www.aliexpress.com/item/33057351310.html]
5 two-way polarised header plugs with pins (if thermistors
don't come with a suitable plug)
light-duty figure-8 cable (if sensor wires are not long enough)

Semiconductors
1 74HC4053 triple 2-channel analog multiplexer, DIP-16 (IC1)
1 DS18B20 digital temperature sensor, TO-92 (IC2)
2 BC337 NPN transistors, TO-92 (Q1,Q2)
1 BC547 NPN transistor, TO-92 (Q3)
1 red 5mm LED (LED1)
1 green 5mm LED (LED2)
1 blue 5mm LED (LED3)
3 1N4004 400V 1A diodes (D1-D3)

Capacitors
2 100nF MKT or multi-layer ceramic

Resistors (all 1/4W axial 1% metal film)
3 4.7kΩ 1 10kΩ 9 1kΩ 2 100Ω

alkaline. The fittings may not be able to withstand these sort of chemicals.

Thus for brewing and fermenting applications, we suggest using a large water bath in which the brew vessel is placed. Assuming that you are using one of the plastic 25L units, a plastic storage container like those available from discount variety stores and hardware stores is the simplest option.

The larger container behaves as a water jacket. It does not need to enclose the smaller brew vessel completely, but should come most of the way up the sides of it to improve the surface area over which heat is transferred. A hole cut in the larger vessel's lid (forming a seal of sorts around the brew vessel) will reduce the amount of evaporation that might occur and thus reduce the power needed to maintain temperature.

Such a large vessel can lose (or gain) heat from the surroundings due to its large surface area, so a modest amount of insulation may help; something as simple as a towel may suffice.

… and cooking

As we mentioned, the higher temperatures used for sous-vide cookery will tax the Peltier devices more. For this application, we recommend that you use a small foam cooler. We used one designed to hold six drink cans during testing. Its small size minimises the area through which heat is lost and also the volume of liquid to be heated. But it's large enough to fit most items you would cook.

These coolers can be found online or at disposals and outdoor stores. Check that it comes with a lid, as a fair degree of evaporation can occur at the temperatures used. You must also take care during use as the temperatures reached can be high enough to cause scalding.

Because the food is sealed into waterproof bags during the sous-vide process, there is minimal risk of contamination due to contact with non-food-safe parts. You might like to double-bag to be sure.

To implement the two-loop variant of our design, you will need a second vessel. The insulation on this is not so critical as the radiator and fans are simply trying to keep the second loop's temperature near ambient anyway. It may be handy to have a lid, though, to prevent a long-term loss of water through evaporation. We used a plastic ice-cream tub as the second water vessel for our tests.

Another thing to be cautious about is the possibility of bacterial/algal contamination, particularly if you are using the Thermal Regulator for cooking. Bacteria and algae can flourish in warm water. For example, the circulation of warm water which is exposed to the air has been implicated in cases involving Legionnaire's disease, such as those found in industrial cooling towers.

Naturally, you should take care to prevent the water from the cooling loops coming near anything that may be consumed. You should also discard and replace the loop water regularly as this will help limit the accumulation of pathogens.

If you are familiar with the brewing process, you will know how crucial proper cleanliness is for good results.

Measured performance

We found that under well-insulated conditions, our water bath got up to around 70°C with an ambient temperature of 18°C. For these tests, our main water vessel contained around two litres of water in an insulated foam cooler; the second loop was about a litre held in a (clean) ice-cream container.

In these tests, a good amount of water vapour is produced, resulting in evaporative cooling which forces the Peltier devices to work harder.

We got down to around 2°C when cooling. Getting close to the freezing point of water is the limiting factor. We saw frost on the Peltier devices, so it was clear that some parts were dropping below freezing.

A small foam cooler such as that shown here is a good choice for sous-vide cookery with the Thermal Regulator. A high degree of insulation is needed, and the snug-fitting lid minimises the amount of water and heat that is lost to evaporation.

The typical time to reach these extremes is about half an hour using four standard 5A devices running at around 11V. So you can see that the temperature ramp is not rapid. Good thermal insulation is necessary for reaching the temperature extremes.

We calculated that the secondary water loop cooled by the radiator has about double the heat removal capacity as the simple heatsink solution.

Consider that in all cases we are effectively trying to move heat between an ambient atmosphere (the air being circulated by the fans and through the radiator) and the water bath, the closer these temperatures are, the easier our task will be. Indeed, it is when the temperature differential across the Peltier devices is the largest that they struggle most.

For example, during some of our initial testing, while trying to cool hot water, we noted that it was more effective to shut down the Peltier devices and allow thermal conduction to move the heat. Powering the Peltier devices simply added more heat to the system (I^2R losses), which also had to be removed.

Sous-vide cookery is the application we envisage that requires the most extreme temperatures, so insulation is essential for good results there. In some cases, you could pre-heat the water using a kettle and then let the Thermal Regulator reach the target temperature and keep it there; that would be faster than starting with cold water.

Coming next month

That's all we have space for in this issue.

Next month, we will describe how to build the two shields, program the Arduino and put the whole system together. In the meantime, if you want to build a Thermal Regulator, now would be a good time to figure out the system configuration you will need and order the parts. You may be able to start building the piping and heat transfer assemblies if those parts arrive quickly.

The software we'll also present next month has several different operating modes, such as setting a target temperature which the unit then maintains, providing maximum heating or cooling, as well as one mode where it follows a preset temperature 'profile' when triggered. SC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03/20

WANT TO "PROBE" A VEHICLE'S EHT?

You'll need this

by Dr Hugo Holden

1000:1 AC EHT Probe for Ignition Systems

It's surprisingly tough to measure the actual output voltage of an automotive (or aircraft/boat) ignition system. You can't use a standard high-voltage probe because the voltages involved are way too high; they can exceed 50kV! Nor can you use a standard EHT probe because these are designed for DC use and will severely distort a fast-rising (or falling) AC waveform. This simple design is the answer.

Peak voltages from the ignition coil secondary windings are typically in the range of 10-30kV but can be higher – and can exceed 50kV in some circumstances.

These high voltages occur for a very brief time across a spark plug's terminals before spark ionisation, or under any test condition when the spark plug is not connected.

This 'open-circuit' coil secondary voltage value is an important ignition system parameter.

The rate that the voltage increases with time is another important parameter. A fast rise time to the spark ionisation voltage is thought to be beneficial in overcoming the ohmic resistance of fouled spark plugs, because less energy is dissipated due to a shorter time interval before spark ionisation.

Also, a certain voltage threshold is always required to initiate spark ionisation (the spark's early phase, known as phase one).

This voltage depends on the spark plug's gap and the composition of the gases and the gas pressure and temperature between the gap.

However, during the spark's burn time (phase two), the spark plasma has a low impedance, and the spark gap voltage is relatively low – just 30V with some aviation spark plugs and around 1000V for a typical automotive spark plug.

By comparison, in free air (ie, outside the cylinder and not under pressure, a typical automotive spark plug has a gap voltage of around 600V.

To measure the high initial pre-spark ionisation peak voltage or the open-circuit output voltage of the spark generating system, you need a special probe with a flat frequency response also having the ability to avoid corona discharge, which is a big problem with potentials over 30kV.

Making the measurement

Ideally, we want to use an oscilloscope to capture these spark events. So we need to scale down the typical 30kV open-circuit voltage down to say 30V (ie, dividing it by a factor of 1000) and feed it into the typical 1MΩ//15pF input impedance of a scope. This needs to be done while maintaining a broad frequency response, so that the recorded waveform maintains its original shape.

We also need to make sure that the oscilloscope (and user!) is not at risk of damage from these high voltages.

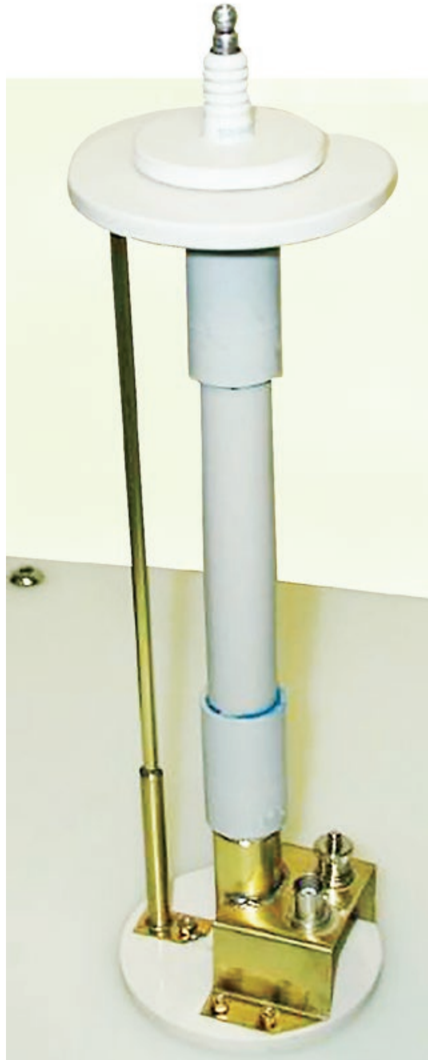
While inexpensive high-voltage or "EHT Probes" are generally available (eg, to measure CRT anode voltages), they are meant for measuring static DC voltages. We published a design to build a low-cost EHT probe in the April 2010 issue (siliconchip.com.au/Article/121). That design is capable of measuring up to about 25kV.

But this type of EHT probe gives very low false readings on fast rise-time waveforms; the rise times of ignition system secondaries are in the microsecond range, and the high-order Fourier components can be in the 100kHz to 1MHz range.

High-voltage compensated probes which can handle 40kV are available, but they are hard to find and expensive. Also, on some common ignition system tests, they could be pushed passed their maximum ratings. Worse, the probe tips do not easily interface with insulated spark plug connectors, which are the best way to link up circuits running at these high voltages.

Also, the probe needs to have a total load resistance of at least 50MΩ, so there is little loading of the system being tested. This equates to 1kΩ/V for a 50kV test. A 200MΩ load is feasible, yielding 4000Ω/V, however, the higher the resistance, the more low-pass filtering effects occur due to distributed capacitance. High-frequency compensation, therefore, becomes a little more difficult.

A high series resistance value leads to a low-pass filter effect, because even just 1pF of stray capacitance results in a significant low-pass filter being formed. For example, with 100MΩ and 1pF, the filter created roll-off (-3dB) point is only 1.6KHz.



My probe design

Fig.1 and the photo at left show my probe design. I'm using a spark plug as a feed-in element, by trimming the metal part away. Bramite (similar to Garolite) was used as insulating material along with PVC tubing, and parts of the assembly are glued with Torr Seal from Varian Vacuum Technologies (a white epoxy resin which is also

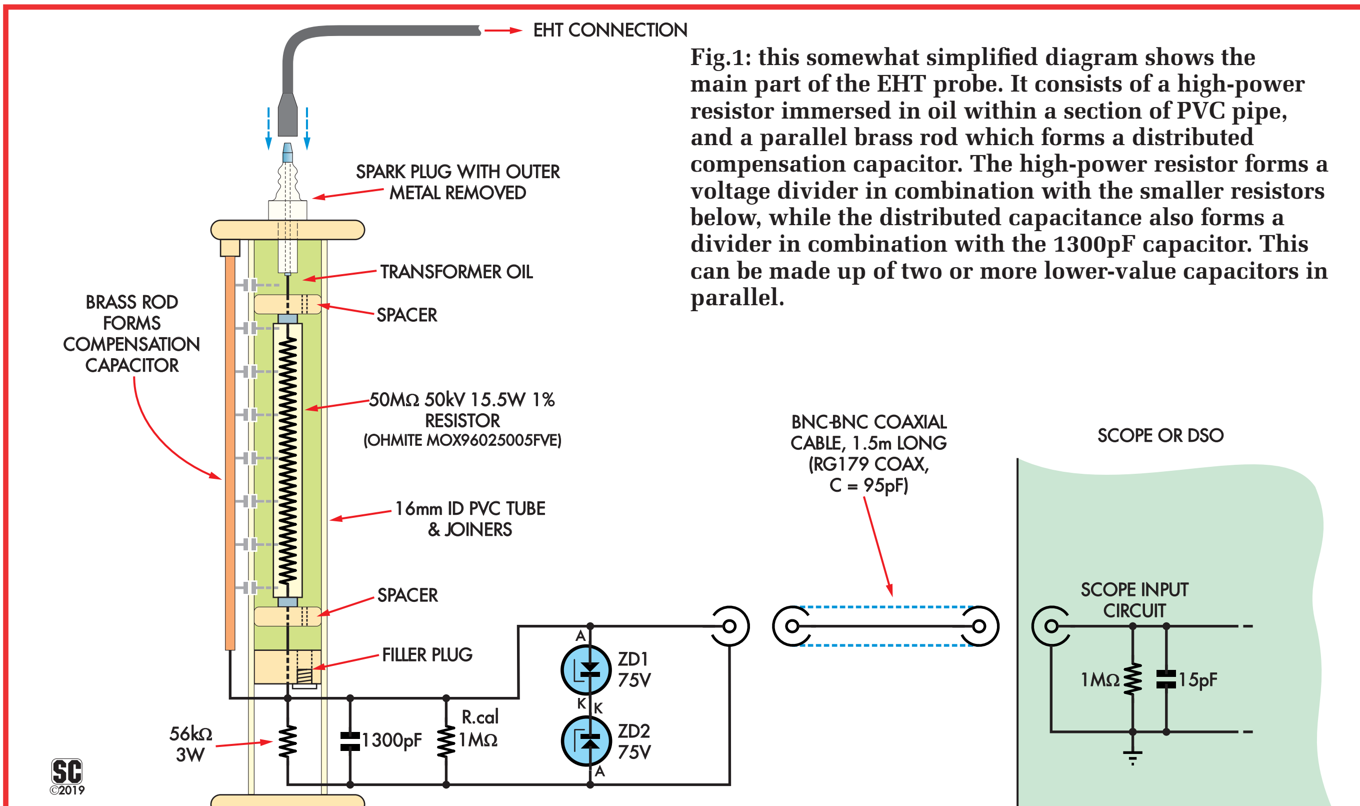


Fig.1: this somewhat simplified diagram shows the main part of the EHT probe. It consists of a high-power resistor immersed in oil within a section of PVC pipe, and a parallel brass rod which forms a distributed compensation capacitor. The high-power resistor forms a voltage divider in combination with the smaller resistors below, while the distributed capacitance also forms a divider in combination with the 1300pF capacitor. This can be made up of two or more lower-value capacitors in parallel.

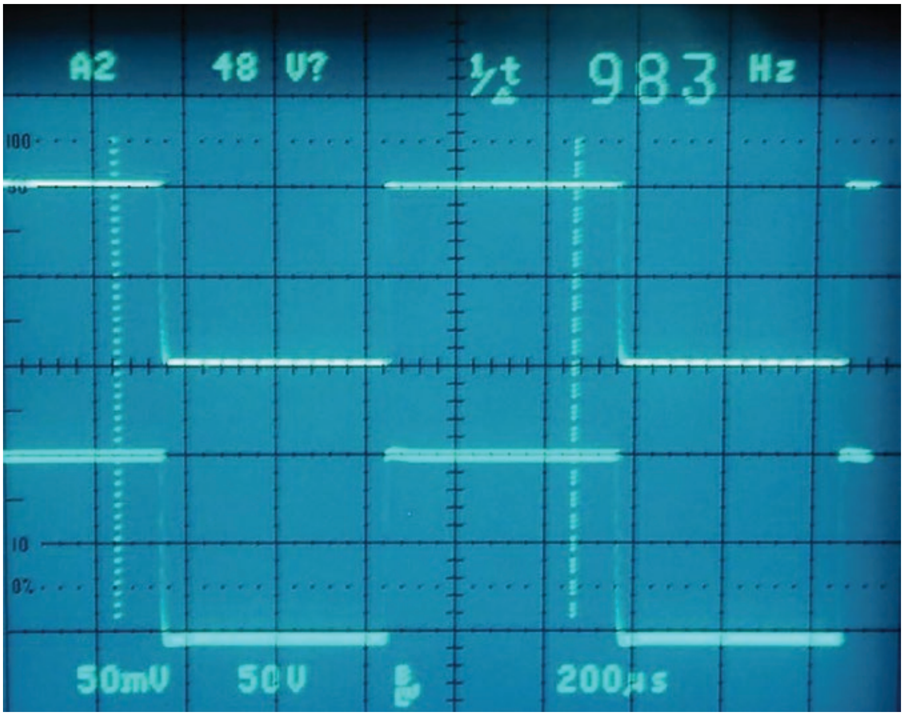


Fig.2: the upper trace shows the 100V peak-to-peak square wave I'm applying to my prototype while the lower trace shows the resulting 100mV peak-to-peak waveform at the output. You can see from its shape, with no apparent undershoot or overshoot, that the probe is correctly compensated.

an excellent insulator).

The input capacitance of the probe is a little lower, at about 2pF, compared to a spark plug which is typically around 8-10pF. The typical output capacitance of an automotive ignition coil is around 50pF, and the HT wiring contributes another 10pF or thereabouts.

As shown in the diagram and the photo, the main body of the probe is made from PVC pipe. This is filled with oil and houses the 50kV resistor. Without the dielectric oil, the corona discharge becomes very difficult at peak voltages over 30kV. The oil solves this problem.

The main compensation capacitor is a brass rod which runs alongside this oil-filled tube, acting as a high-frequency coupling capacitor distributed along the length of the resistor by proximity.

It's connected directly to the low-voltage end of the 50kV resistor and supported by the upper insulating plate.

It must be mounted parallel with the 50kV resistor and centred 30mm from the middle of the PVC pipe for correct operation. That means there will be around 18mm from the edge of the rod to the edge of the pipe, depending on the exact outer diameter of the pipe.

This dimension is critical for correct operation.

There are effectively three resistors in parallel at the bottom of the divider: 56kΩ, 1MΩ and the 1MΩ input impedance of the scope. These combine with the 50MΩ resistor to provide the 1000:1 division ratio at DC and low frequencies.

At higher frequencies, the compensation capacitor and 1300pF of capacitance form a capacitive voltage divider with a similar ratio, in parallel with the resistive divider.

The 75V zener diodes were added just in case any corona discharge occurs accidentally, which could harm the oscilloscope input amplifiers.

Construction

Start by using a 16mm hole saw to cut two round pieces of Bramite. Place the Bramite sheet on a sheet of scrap timber which is firmly supported at either end, so that you drill won't go into anything critical while doing this. The resistor leads can pass through the central guide holes.

Cut three larger discs from the Bramite using much larger hole saws; one around 22mm in diameter, one around 44mm and one around 64mm. (Tip: you can buy a hole saw set which will have most of the required sizes).

Enlarge the central holes in the 22mm and 44mm discs so that the body of the spark plug will fit through both.

Now make a hole in the middle of one of the PVC end caps for the spark plug body to pass through, plus a small hole in the other end cap for the resistor lead, as well as a larger one, to suit the filler plug.

Use the end cap with two holes as a template to trace them out in the middle of the brass sheet, which will later be bent into a bracket and attached to this end cap.

Glue the 22mm and 44mm discs together, and glue the PVC endcap to the bottom of the 44mm disc. Now place one of the spacer discs over one of the resistor leads and feed this lead up through the PVC endcap and two round plates. Cut this lead short, then solder it to the tip of the spark plug.

Next, pull the resistor back down so that the spark plug is reaching down inside the PVC endcap and seal around the spark plug using the Torr Seal epoxy, so that it is oil-tight.

Spread some epoxy all around the edge of the spacer and then slide the PVC pipe over the resistor. Spread a generous amount of epoxy around the end of the pipe, then push it into the end cap firmly. Allow the epoxy to set, with the pipe' right-way-up' so that the upper spacer is resting on top of the resistor body.

Place the second spacer over the remaining resistor lead, spread some epoxy all around its edge and push it up into the pipe as far as it will go. Make sure that the resistor is fully wedged between the two spacers so

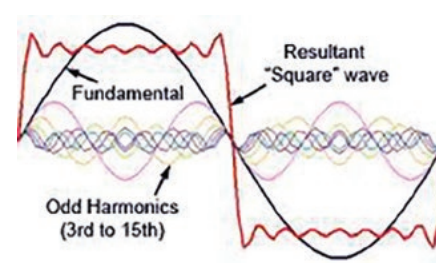


Fig.3: Fourier theory says that a square wave can be formed from an infinite number of sinewaves with different amplitudes and phases. The higher-frequency sinewave components have lower and lower amplitudes as the frequency increases. This means that you can tell whether the frequency response of a device is flat by feeding a square wave into its input and looking at the resulting shape at the output.

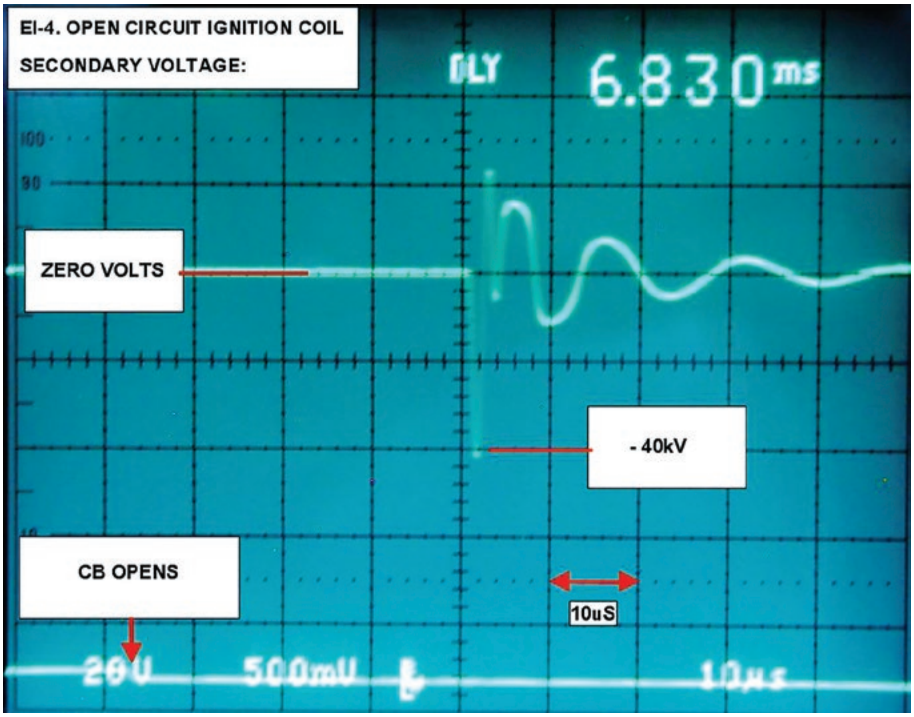


Fig.5: the output voltage of an unloaded ignition coil being driven by a Tung-Sol EI-4 capacitor-discharge ignition (CDI) system, captured using the probe described here. No sparks or corona discharges are occurring, resulting in an extremely high peak voltage of -40kV, which matches well to the expected peak of 39.6kV as determined by the coil turns ratio and primary voltage. After the initial discharge, the residual coil magnetic field energy and energy stored in the coil's distributed capacity decays away in an oscillatory manner, due to the self-resonance of the ignition coil.

it won't move later.

It's also a good idea to push some epoxy into the hole surrounding the resistor lead, if you can get in there.

Up-end the whole assembly, resting it on two equally tall objects on either side, so that it sits vertically, until the epoxy on the second spacer has set.

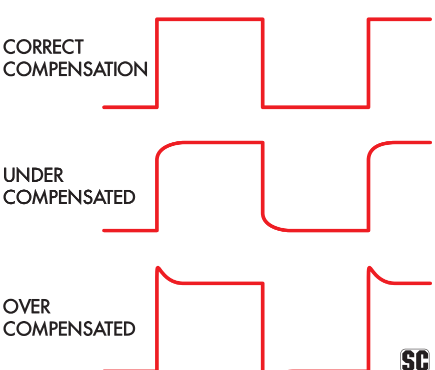


Fig.4: compare your calibration waveform to the three shapes shown here. If it looks nice and square, like the one at the top, you're finished. If it's rounded (under-compensated), reduce the value of the 1300pF capacitor. If it has overshoot (over-compensated), increase the value of that capacitor (eg, by adding a low-value ceramic capacitor in parallel).

Bend the remaining resistor lead so that it will pass through the small hole in the end cap that you drilled earlier, once the end cap is fitted onto the end of the pipe. It should be long enough to reach through the cap; if not, extend it by soldering on some stiff wire. Glue on the end cap using more epoxy, and also seal around the wire exit.

Now is also a good time to coat the inside of the hole you made for the bung with epoxy and press it in. Make sure it will be oil-tight when the epoxy sets.

Now up-end the assembly, again resting it on a couple of blocks and let the epoxy set. The next step is to pour a little transformer oil into the oil filler hole. Wait a few minutes and check that you don't have any oil leaking out anywhere. If you do, you will need to drain it, clean it up and apply some more epoxy to seal the leak areas. Then try filling it with oil again.

If it looks good, add a bit more oil, then a bit more, then start pouring it in slowly until the pipe is almost full of oil. Wait a while for any air bubbles to surface, then add a little oil until it's just about full. Leave a small air bubble inside to allow for thermal expansion.

Screw the plug into the bung to seal it up and clean up any oil that squirts out around the edges. Do it up tight so it won't accidentally come loose; that could be messy! It's a good idea to silicone around and over the bung as insurance against oil leaking out.

By the way, if you can't get a proper oil filler bung, you could consider drilling and tapping the end cap to accept a regular screw thread, but if you're going to take that approach, it may be necessary to thicken the end cap material by gluing one or more PVC discs inside it, to give enough 'meat' for the screw to form a good seal.

Final assembly

Drill the holes you marked earlier in the brass sheet and bend it to form a bracket to support the PVC pipe (see photo). Also, drill a hole to fit the BNC socket next to the pipe. Make sure the resistor wire end exiting the pipe won't touch this, as the bracket will be Earthed.

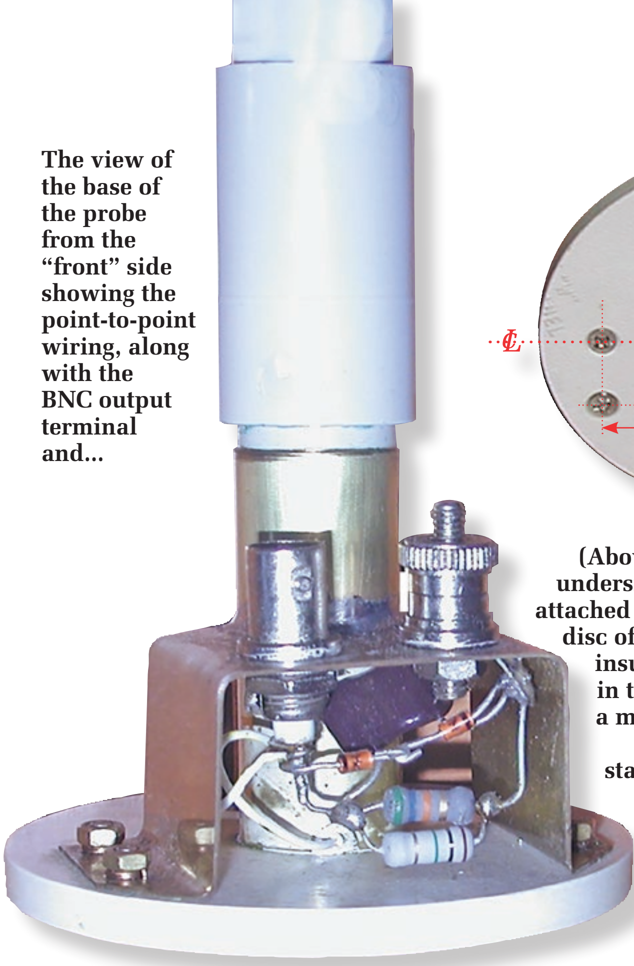
I glued a 50mm wide sheet of brass foil around the bottom of the tube so that I could solder it to the bracket; however, you could also use a section of large diameter brass tube or come up with some other arrangement to attach the bottom of the tube to the supporting bracket.

Once it has been secured, bend the projecting resistor lead over (making sure it isn't contacting any of the metalwork), trim it and solder it to the central pin of the BNC socket. If you've used brass foil or a brass tube at the base of the PVC pipe, as I did, you will need to solder an insulated wire to the resistor lead instead and feed it through a hole in the supporting tube, then seal it up.

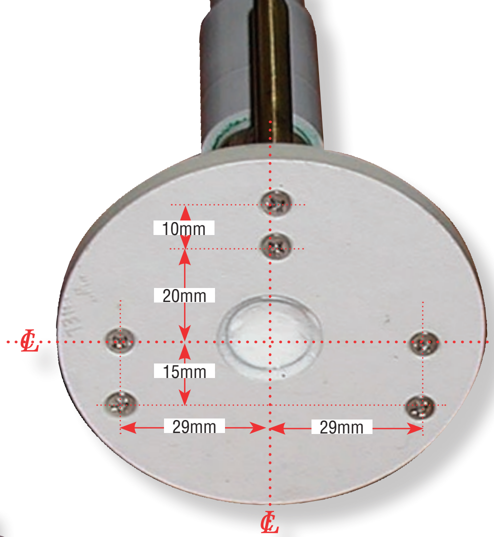
Now solder the few other electronic components between the BNC ground tab and the end of the power resistor lead, with the zener diodes wired back-to-back across them. See the accompanying photo, which shows how I arranged the components.

Try to leave the 1MΩ resistor and 100pF capacitor accessible, as you may need to replace these with different components during calibration.

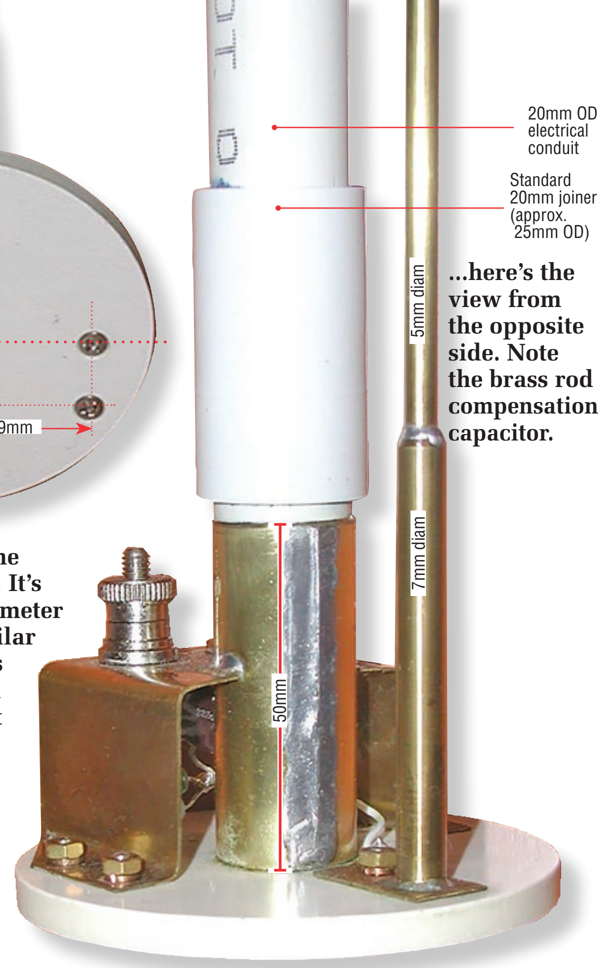
Now cut the brass rod so that it's just a bit too long to fit between the top and bottom plates. As you can see from the photo, I made a bracket from a small brass plate and some brass tubing. This had the advantage of both holding the rod in place and



The view of the base of the probe from the “front” side showing the point-to-point wiring, along with the BNC output terminal and...



(Above): looking at the underside of the probe. It’s attached to an 80mm diameter disc of Bramite or similar insulation, which is in turn mounted on a much larger sheet for working stability. All holes should be countersunk.



...here’s the view from the opposite side. Note the brass rod compensation capacitor.

also providing a convenient place to make the electrical connection.

However you do it, make sure the rod is fixed in place and parallel with the PVC pipe, with the dimensions described above - the critical one being the 30mm from the centre of the PVC pipe/resistor to the centre of the brass rod.

I held the top of the brass rod in place by inserting it into a blind (shallow) hole drilled in the inside face of the top plate. I soldered the 5mm rod to a length of 7mm diameter rod, to make it easier to tap the bottom of the rod for an M3 screw to make the electrical connection. I then soldered this 7mm rod to the bracket, as shown in the photos. But there are other ways of doing this.

Regardless, you will need to run a wire from the bottom of the rod to the bottom lead of the resistor in the PVC pipe and solder or clamp it at both ends.

Calibration

You should find that your probe provides very close to a 1000:1 division ratio when connected to a device with a 1MΩ input impedance. Note that many DMMs have a higher input impedance than this, at least when measuring volts. If you want to use a DMM for calibration and it has a 10MΩ input impedance, clip a 1.1MΩ resistor across the DMM’s leads for the tests.

For the first test, use a relatively high voltage DC source such as a 48V supply or a bench supply wound up to maximum.

Measure the voltage across the supply outputs using your DMM and write it down, then connect the probe tip to the + supply and the output ground to the – supply. Measure the voltage at the BNC cable tip, keeping in mind the above comments about input impedance.

You should get very close to 1/1000th of the voltage. For example, if your test supply measures 48.4V, you should get 48.4mV at the probe output.

If you get a higher value, you can slightly reduce the value of the 1MΩ resistor in the probe to compensate. Similarly, if its output is low, slightly increase the value of the 1MΩ resistor.

AC calibration is just as, if not more critical than DC calibration. For this, you need a function or pulse generator capable of producing a 1kHz square wave of similar.

Ideally, it should be able to deliver a square wave of around 100V peak-to-peak. I used a Tektronix PG506 calibration generator.

If you only have a low-voltage pulse generator, you should build our Precision Signal Amplifier from the October 2019 issue (**siliconchip.com.au/Article/12025**). It’s a simple and relatively cheap device which can boost the output of a function generator up to about 30V peak-to-peak, just sufficient for this calibration procedure.

The AC calibration is set by the 1300pF (1200pF || 100pF) capacitor. This forms a divider with the brass rod, which acts as an HF coupling capacitor distributed along the length of the resistor. Fig.2 shows my probe’s square wave response with the probe plugged into the input of a Tektronix 2465B scope.

The upper trace is the input voltage which is a near 1kHz, 100V peak-to-peak square wave from the PG506 generator. The lower trace is the output voltage which is close to 100mV peak-to-peak. Without the compensation capacitor network consisting of the brass rod and 1300pF capacitor, the output waveform bears little resemblance to the input waveform and looks more like a sinewave.

I used sinewave testing to determine that the probe has a flat response from DC to over 1.5MHz. The highest frequency of interest in an automotive ignition system is about 300kHz.

But you don't need a sinewave sweep to check the frequency response; a single square wave test will do the job much more easily and quickly.

According to the Fourier theorem, a square wave or rectangular wave is composed of a fundamental frequency and a plethora of harmonic frequencies, the higher-order ones being responsible for the rapid rise on the leading edge of the waveform.

This is shown in the simplified diagram of Fig.3.

Therefore, if a square wave is passed through the system, it is immediately apparent from its shape at the output whether the frequency response across a broad range of frequencies is flat or not.

If the HF response is limited, the fast rising and falling edges are rolled off. If the rising and falling edges are peaked, then the HF response is excessive. If the flat top of the wave has distortions or bends or tilts, then the medium frequency (MF) or LF responses are abnormal.

Most oscilloscopes have a calibration output voltage which is a square wave, so that the compensation capacitor on the 10:1 probe being used can be set for a flat response. The procedure for calibrating this probe is much the same, except that you may need to replace the 100pF capacitor with a higher or lower value to achieve calibration.

Fig.4 shows what square waves look like at the output of a probe which is correctly compensated, under-compensated or over-compensated.

If your square wave looks like the one in the middle, you need to reduce the value of the 100pF capacitor (try removing it entirely first).

If it looks like the one at the bottom, then you need to increase the value of the 100pF capacitor or connect another low-value 100V capacitor in parallel.

As noted in the parts list, it's best to use NP0/C0G ceramic capacitors here as they do not change in value with temperature.

Otherwise, your probe's calibration could be different on cold and hot days. They're also extremely linear for the best possible performance. *SC*

Parts list – 1000:1 AC EHT Ignition Probe

1 spark plug
1 200mm length of 20mm outside diameter PVC conduit
2 PVC end caps to suit conduit
1 450mm x 225mm x 6mm (or similar) sheet of Bramite (#)
1 100 x 50mm sheet of 1mm thick brass plate
1 250mm-long, 5mm diameter brass rod
(***or*** 1 200mm long, 5mm diameter rod and 1 50mm long, 7mm diameter rod)
1 1/8" NPT female bung and matching plug
1 50MΩ 50kV 15.5W 1% resistor (Ohmite MOX96025005FVE) [Digi-key, Mouser]
1 1200pF 100V NP0/C0G ceramic capacitor [eg, Kemet C322C122J1G5TA]
1 100pF 100V NP0/C0G ceramic capacitor [eg, AVX SR151A101JAR]
1 56kΩ 1% 3W resistor [eg, Stackpole RSMF3JT56K0]
1 1MΩ 1% 0.25W resistor
2 75V 1W zener diodes
1 chassis-mount BNC socket
1 1.5m-long RG179 coaxial cable fitted with BNC plugs at each end
Various brass machine screws, washers and nuts
1 tube of Torr Seal epoxy resin
1 one-litre bottle or can of transformer oil

(#) *Bramite is a material used as the backboard in meter boxes. It should be available from electrical wholesalers.*

Easy-to-build
Active Hifi Bookshelf Speakers
Part 3: building the Optional Subwoofers

We've finished the active bookshelf speakers (and they sound really great!). But even they can be improved with the addition of a subwoofer or two! In this final instalment, that's exactly what we are going to do. Normally you'd only need one sub but if you build two, you'll have some great stands as well.

by Phil Prosser

The subwoofers are designed to operate as a pair. This allows you to use them as stands for the bookshelf speakers, and our design is optimised for this condition.

However, you can place them elsewhere in the room. As long as you don't put them too close to a wall, the sound quality should not be affected (ideal speaker placement is always a bit tricky anyway).

Construction of the subwoofers is essentially the same as the main speakers, the main differences being: the cabinets are taller, there's only one (large) driver in each which goes on the side rather than the front, and the two passive crossovers are replaced with a single active crossover. That makes the plate amplifier a bit larger than the one used in the main speakers.

As the cabinet construction steps are the same, we won't repeat them. Fig.17 shows the cuts and holes that you need to make. This time you will need three 600 x 1200mm sheets of 15mm ply rather than two, plus you will hopefully have already cut the subwoofer 2 front panel when you made the speaker boxes.

For further details, refer to the accompanying construction photos. We installed two braces in the enclosure to make the walls quite stiff. While the subwoofer isn't expected to run a rock concert, we do want the enclosure to be solid and "inert". One brace is below and the other above the cutout for the Altronics C3088 driver. We glued and screwed these to the walls from the inside.

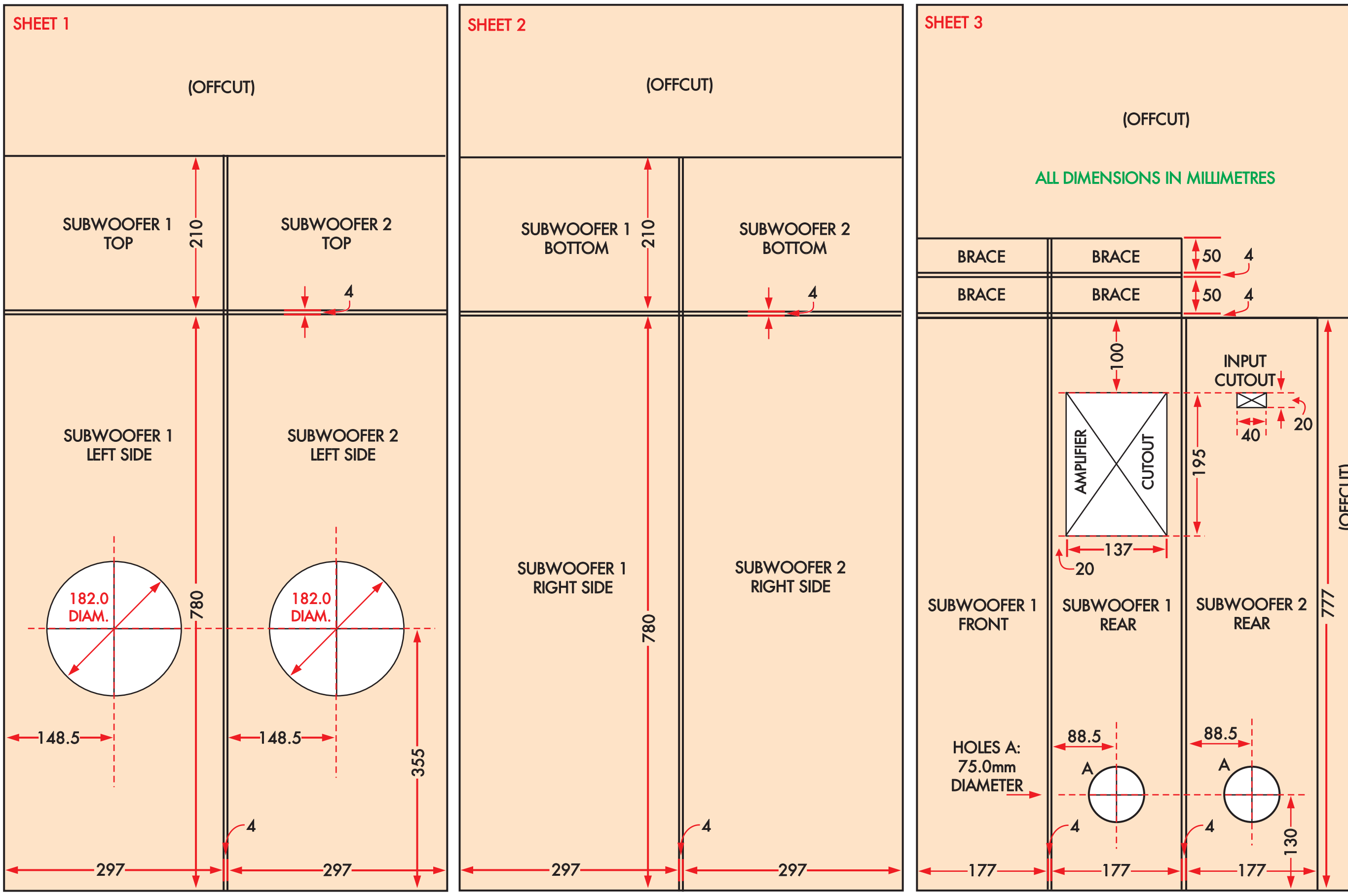


Fig.17: the subwoofer panels are cut from three 600 x 1200mm sheets. As with the monitor speakers, you can cut two of the sheets down the middle. So you don't need to purchase a fourth sheet for just one panel, the last piece is made from one of the bookshelf speaker off-cuts (see Fig.13, last month).

Should your application be different from ours, or you'd prefer not to use the subwoofers as speaker stands (eg, small children about!), you could build them in a different shape, such as a cube.

They would need to have an internal volume of 35 litres, with a 75mm outer diameter (72mm inner diameter) PVC pipe port 130mm long. Again, try getting this within ±3mm.

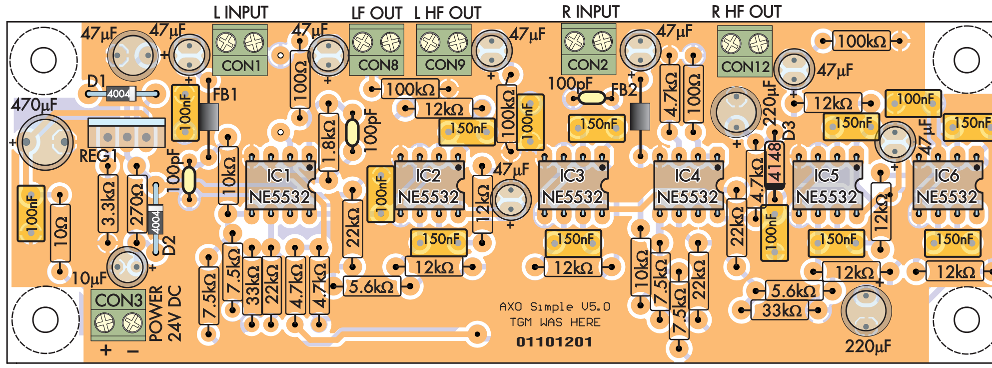
Building the active crossover

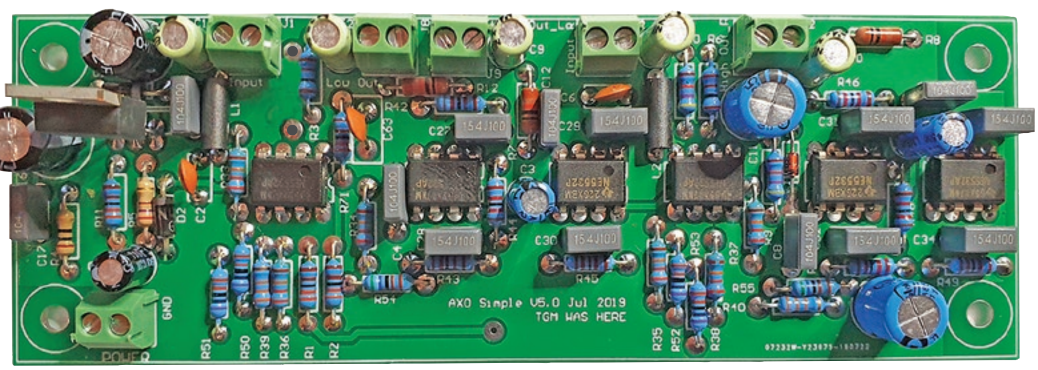
Before you can assemble the sub plate amplifier, you need to build the active crossover. This uses a PCB coded 01101202, which measures 132 x 45mm. Its overlay diagram, Fig.18, shows which parts go where.

Start by mounting all the resistors. These are all 1/4W metal film types. It's best to check the value of each lot with a DMM set to measure ohms before fitting them, as the colour bands can be hard to distinguish. Follow with the two ferrite beads, which you can slip over resistor lead off-cuts before soldering

To avoid flexing and movement of the subwoofer panels, they should all be braced, as shown in these photos. We mainly used offcuts from the sheets of plywood, along with some scrap timber we had on hand. We screwed and glued all panels and braces to ensure they won't vibrate loose down the track.

Fig.18: just one of these active crossover boards is needed *per pair* of subwoofers. Assembly is pretty easy as most of the components are pretty small. Just watch the orientation of the ICs, regulator, diodes and electrolytic capacitors and make sure all the solder joints are well-formed.
The matching photo below will also help you place the components. In particular, note the orientation of the NE5532 ICs – in all cases either their notch or the dimple marking pin 1 must go to the right (even though that makes their labelling upside down)!





the leads to the board where indicated.

Follow with the three diodes, ensuring that they are orientated with their cathode stripes as per Fig.18, and note that D3 is the only 1N4148 small-signal type.

Next, mount the NE5532 op amps. Given that this will be installed within a subwoofer (and all the vibration that entails), we suggest that you solder them directly to the board, rather than using sockets.

Regardless, ensure they are all orientated correctly, as shown in the overlay diagram.

Then fit the screw connectors, with their wire entry holes facing away from the other components. Go on to solder the ceramic and MKT capacitors, none of which are polarised. These will be printed with a code indicating their value, eg, 155 for 150nF (15 x 10^5).

After this, install the electrolytic capacitors. They are polarised, and their longer leads indicate the positive side, which must be fitted facing the + symbols on the PCB (the stripe on the can indicates the negative lead).

Fit the LM317 regulator vertically, with its metal tab orientated towards diode D1, and the board is complete.

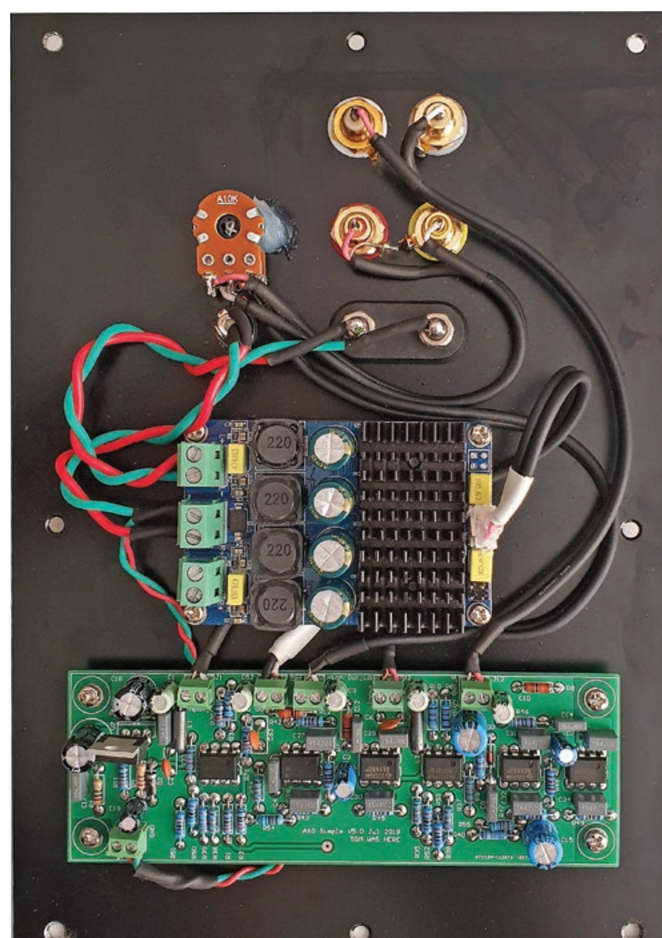
Subwoofer plate amplifier

You can now build the subwoofer plate amplifier, which is substantially the same as the main amplifier, with the addition of the active crossover board.

Because of this, it's a bit larger, at 165 x 250mm. Cut and drill it as per Fig.19, using the same technique as you used for the earlier plate amplifier

You will also need a second small plate for mounting the binding posts on the passive subwoofer, which is identical to the one you made for the main speaker (Fig.15, last month).

Once you've attached the controls, connectors and amplifier board, mount the active crossover using the same type of spacers, screws and washers as for the amp module.



Here's the completed amplifier/crossover plate shown in the diagram opposite. The only thing we'd add to this are several cable ties to keep all the wiring secured.

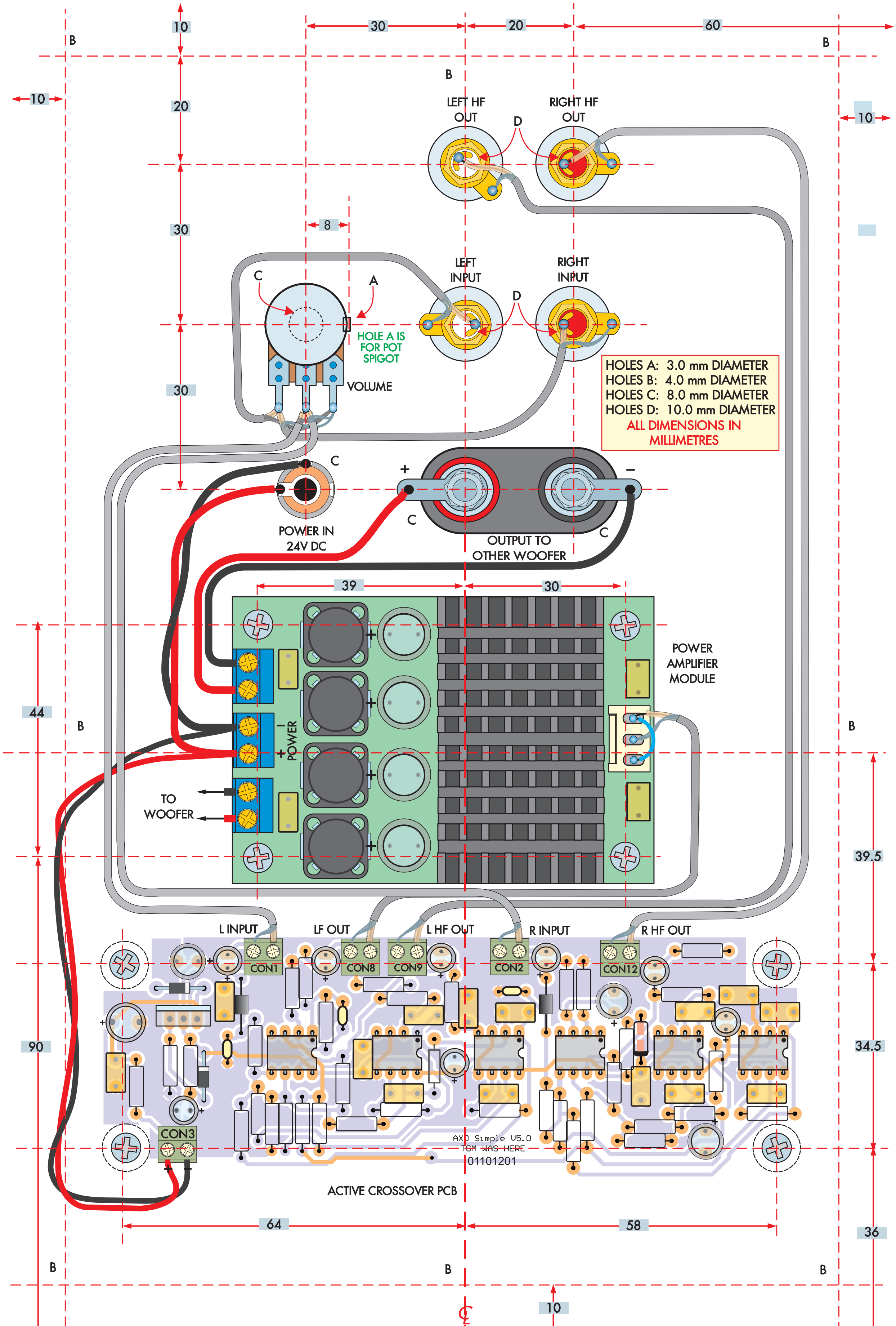


Fig.19: this combination diagram shows the metal plate for the subwoofer (at 250 x 165mm, it's a little larger than that for the speakers) with all holes dimensioned. It also shows the location of all modules and connectors. The volume pot in this case is a dual gang type, because the left and right inputs are paralleled (ie, mono). Just be careful to make the connections as shown here, using shielded cable, and you should have it up and running in no time.

This assembled sub also shows some more of the bracing we installed (again using offcuts) and, just as importantly, the woven acetate wadding applied to the interior of the sub boxes. The easiest way to fasten the wadding is with an industrial stapler; thumb tacks and even carpet tacks will also work if you don't have acces to a stapler.

Then wire it all up, as shown in Fig.19.

With the main amplifier, the 'output' from the wipers of the volume control potentiometer went to the polarised input header on the amplifier module.

With this amplifier, those connections instead go via two separate shielded leads to the "L INPUT" (CON1) and "R INPUT" (CON2) terminals on the active crossover.

CON3, the DC power input for the active crossover, is wired in parallel with the power supply to the amplifier module.

The "LF OUT" terminal of the active crossover (CON8) then goes via a shielded cable to the input of the amp module, with the left and right input channels wired together (shown as a blue wire bridging the two outer terminals).

"L HF OUT" (CON9) and "R HF OUT" (CON12) on the active crossover are then wired, via another pair of separate shielded cables, to the two additional RCA connectors on this plate, for connection to the main amplifier inputs.

Final assembly and testing

Now solder a pair of thick wires (or a figure-8 cable) to the 200mm woofer driver and mount it in the box as you did the woofer for the main speakers.

Make sure the wiring is long enough to pass out the hole in the back of the box and be attached to the plate amplifier or binding posts.

You can now test the unit by turning the volume control right down, plugging it into the 24V DC power supply and connecting a low-frequency signal source (<90Hz) to the inputs. Turn the volume up slowly, and check that you can hear some bass.

This will be very 'dull', so you may need to crank up the volume to see or hear the output.

Turn the volume back down, and connect the "high outputs" to the inputs on the main speakers. Turn the main speaker volume right up to maximum and the subwoofer volume right down. Switch on, and slowly turn the volume up again.

Check that you get clean, undistorted sound.

If you don't, but the main speakers work well by themselves, the chances are that you have an assembly error with the active crossover.

Remove it from the plate amplifier and go over it carefully, checking that all the components are of the correct type, orientated correctly and there are no dry joints or short circuits.

Assuming it's all good, it's just a matter of attaching the plate amplifier and binding post panel to the back of the subwoofers, again using some foam tape to ensure they are well sealed. SC

A 3/4 rear shot of the completed system, showing the main speakers on top and the subs underneath. Note the location of the ports at the back and the woofer driver(s) on the side(s). Because bass is largely non-directional, the subs can be placed away from the main speakers if you prefer. As you can see, it's possible to get a very nice finish on the plywood if you take enough care and smooth out any rough patches before you stain/paint it.

VINTAGE RADIO

By Ian Batty

Toshiba 7TH-425 "fan" wall radio

This distinctive radio from around 1961 is a seven-transistor superhet receiver. But it doesn't look like a radio at all. It looks like a wall clock has somehow been crossed with a fan! It's certainly very distinctive. You could even call its looks unique. As you would expect from Japanese manufacturer Toshiba, it's also innovative and features impressive miniaturisation for its time.

Visually, this radio is a knockout. You might be excused for thinking it's a fan of some sort. But the large dial, calibrated in kilohertz, should be a giveaway. Behind the outrageous front panel, it's a fairly conventional seven-transistor superheterodyne AM radio receiver.

It's clearly designed for wall hanging, and later models provided a 3.5mm phono socket to accept audio from other devices. As it has two internal speakers, it's quite useful for boosting the volume from a small record player or tape recorder.

It was certainly meant to stand out, and the wall hanging allows it to remain out of the way in busy, cramped living areas while adding a unique decorative touch.

Aimed at the US market, it features the well-known CONELRAD (Control of Electromagnetic Radiation) markers that would be used in times of national emergency, albeit in reduced emphasis compared to many American radios of the day. The system, established in 1951, became the Emergency Broadcasting System in 1963.

A brief history of Toshiba

The Meiji era of Japan lasted from 23 October 1868 to 30 July 1912. It was one of rapid uptake of western industrial technologies and production methods. In 1873, the Ministry of Engineering commissioned Tanaka Hisashige to develop telegraphic equipment. His factory Tanaka Engineering Works (built in 1875) was one of the forerunners of Toshiba.

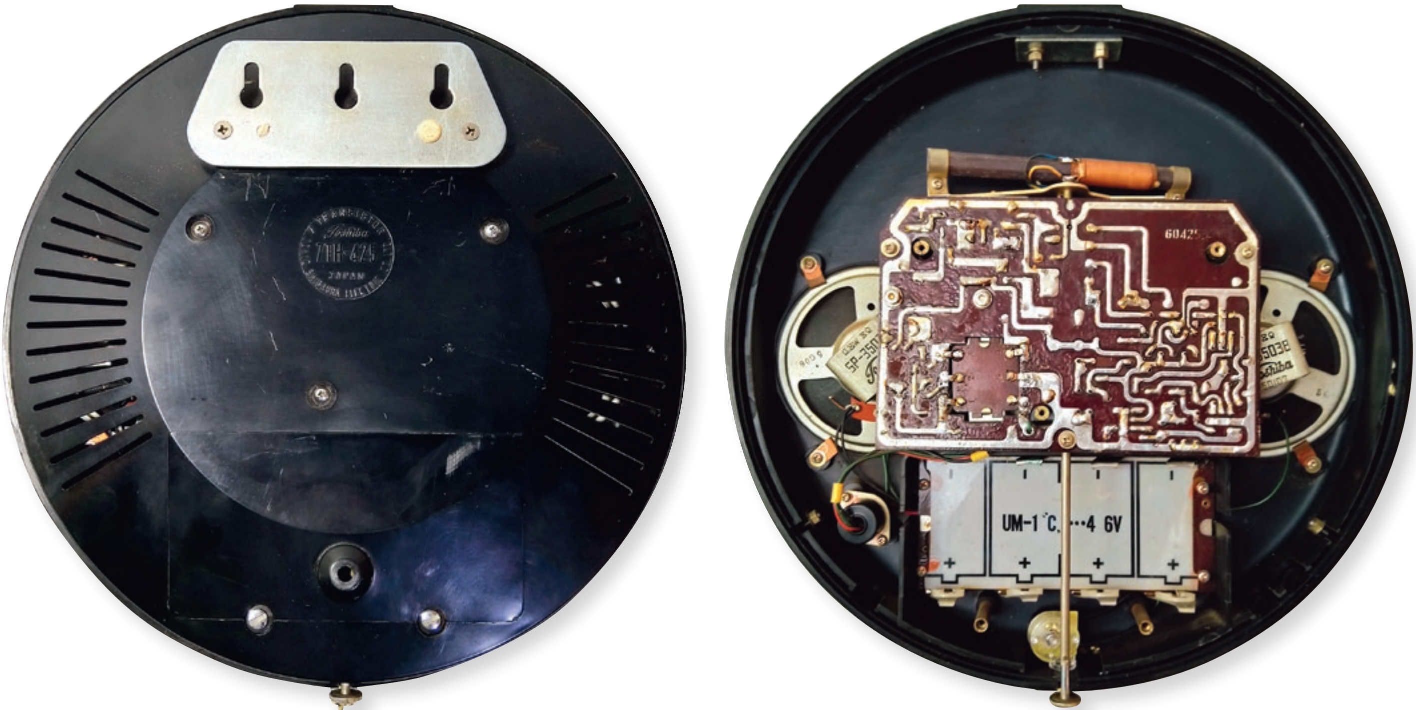
Separately in 1890, Fujioka Ichisuke and Shoichi Miyoshi established Hakunetsusha (changed to Tokyo Electric Company in 1899), to primarily manufacture light bulbs. The same company went on to manufacture the double-coil electric light bulb.

By the 1930s, iron and steel rationing had severely cut back on production of household appliances. Eventually, demand started to grow in the late 30s for home appliances that incorporated the advances made in heavy electric machinery. This led to the merger of Shibaura Engineering Works (formerly named Tanaka Engineering Works) and the Tokyo Electric Company, forming Tokyo Shibaura Electric Co Ltd.

The combined company did well during WWII by producing radios, generators and other military supplies for the state, but was hindered by bombing raids on their factories.

Postwar reconstruction, beginning with the resumption of heavy machinery manufacturing, took off in the 1950s with the re-establishment of electronics and communications industries. Sales and profits grew quickly as Tokyo Shibaura created novel products and developed original technologies.

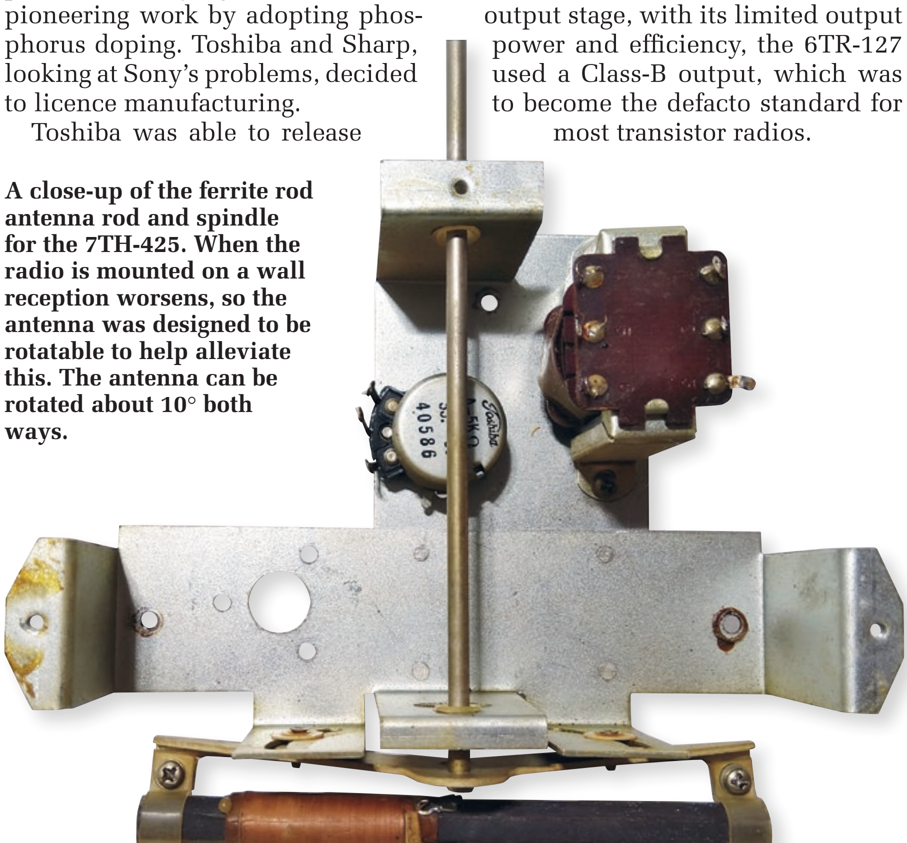
Around 1978 the company formally abbreviated its name to "Toshiba" and continues today as an innovator and supplier of heavy industrial machinery, semiconductors, computer and consumer goods. Their 1996 Libretto, a PC-class 'palmtop', which is just a bit bigger than a VHS cassette, is an outstanding example of ingenious miniaturisation.



The Toshiba 7TH-425 has a chain attached to the bottom of it; this functions as the power switch when pulled but it can also be used to attach keyrings etc to the radio. Often, due to the age of the radio, this switch will rust and stop working, so it's a good idea to check that first when repairing this set. Adjacent to the power switch is a long rod which is used to adjust the orientation of the antenna, as shown in the photo below.

Sony was the first Japanese transistor radio manufacturer, releasing their TR-55 in 1955. Sony had trod a long and often frustrating path to get to production, defying Bell Laboratories' pioneering work by adopting phosphorus doping. Toshiba and Sharp, looking at Sony's problems, decided to licence manufacturing.

Toshiba was able to release their first transistor radio, the six-transistor 6TR-127 in 1957, just two years after Sony's TR-55. The delay paid off; where Sony's drive to be first to market led to the use of a Class-A output stage, with its limited output power and efficiency, the 6TR-127 used a Class-B output, which was to become the defacto standard for most transistor radios.



A close-up of the ferrite rod antenna rod and spindle for the 7TH-425. When the radio is mounted on a wall reception worsens, so the antenna was designed to be rotatable to help alleviate this. The antenna can be rotated about 10° both ways.

Circuit description

All transistors in the set are Toshiba manufactured 2SA/2SB series germanium PNPs, and it uses a negative power supply (ie, positive ground). This makes the circuit simpler and easier to understand.

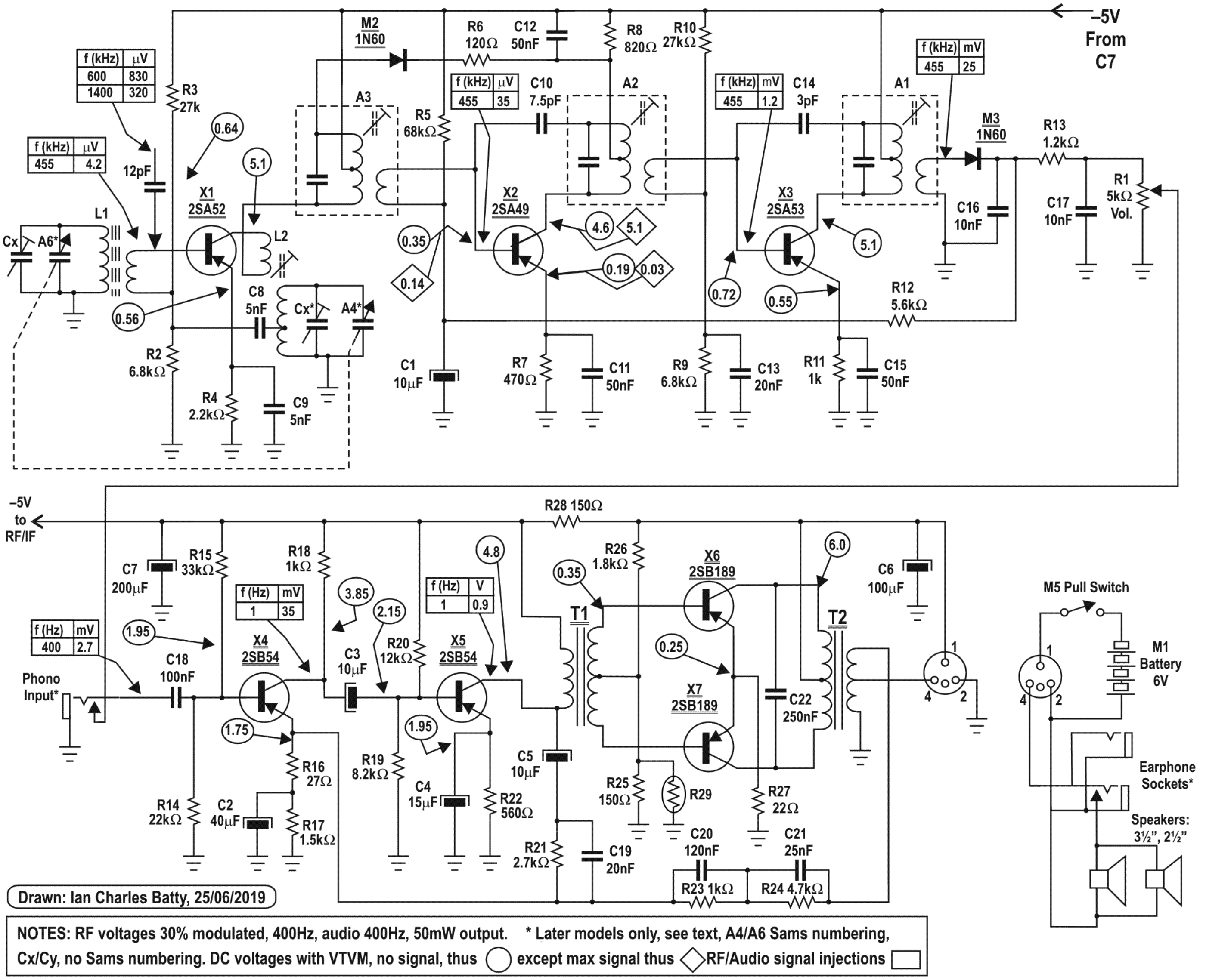
Converter X1, a 2SA52 (similar to an OC45) uses self-excitation and base injection, with the LO signal fed back via the antenna coil's secondary.

The 455kHz IF signal from the converter is developed across the tuned, tapped primary of first IF transformer A3. Its untapped, untuned low-impedance secondary feeds first IF amplifier X2, a 2SA49 (also similar to the OC45). It's an alloyed-junction type with significant collector-base capacitance.

It's neutralised by 7.5pF capacitor C10, connected between its collector and base. X2's collector feeds second IF transformer A2's tapped, tuned primary.

A2's untuned low-impedance secondary feeds second IF amplifier X3, a 2SA53, again similar to the OC45. It also has significant collector-base capacitance. Neutralisation is applied from its collector to base by 3pF capacitor C14.

X3's collector feeds third IF transformer A1's tapped, tuned primary, and A1's untuned, untapped second-



This circuit diagram was redrawn from the SAMS Photofact (551-14) documents for the Toshiba 7TH-425. It's worth noting that this circuit differs from the "original" schematic which can be found on the inside rear cover of the radio (missing from this set). These changes may have been regional, or due to difficulties in obtaining certain components etc. Some of the changes, apart from numbering, include: R13 → 12kΩ; C22 → 120nF; R22 → 2.2kΩ; many of the 10μF capacitors were marked as 8μF etc. You can find a photo of this "original" schematic at: siliconchip.com.au/link/aau1

ary feeds demodulator M3, a 1N60 diode. M3's output feeds audio via IF filter C16-R13-C17 to volume control pot R1.

The DC voltage at M3's cathode feeds the AGC line via 5.6kΩ resistor R12, filtered by capacitor C1, through to the base of first IF amplifier X2. Forward bias for X2 is provided by 68kΩ resistor R5, but this is counteracted by the AGC voltage, reducing the forward bias on X2 with strong signals, and thus its gain.

X2 is decoupled from the supply via 820Ω resistor R8. AGC extension diode M2 (another 1N60) connects (via R6) from the collector end of X2 to the signal end of first IF transformer A3's primary, opposite the converter's collector).

With no signal, M2's cathode is some 200mV less negative than its anode, putting it into reverse bias. As the AGC becomes active, M2's cathode voltage becomes more negative. As X2 approaches cut-off and reaches the end of its possible gain reduction, M2 comes into conduction and shunts some of the signal voltage developed at A3's primary.

This improves the AGC action, allowing the set to handle much stronger stations without excessive volume rise or the risk of saturation.

Audio amplification is handled by a four-transistor circuit. X4 and X5, both alloyed-junction 2SB54s similar to the AC125 (the successor to the OC71) operate with combination bias. My set has audio from volume control pot R1 coupled directly to X4's input, but later versions included a change-over 3.5mm phono socket as shown on this diagram, allowing an external source to be fed to the base of X4 instead.

Transistor X5 drives phase-splitter transformer T1's primary. Its secondary provides matched anti-phase signals to drive the low-impedance bases of output transistors X6 and X7. These are both 2SB189s, similar to the OC74. Shared 22Ω emitter resistor R27 helps equalise gains between X6 and X7, as well as providing some local negative feedback.

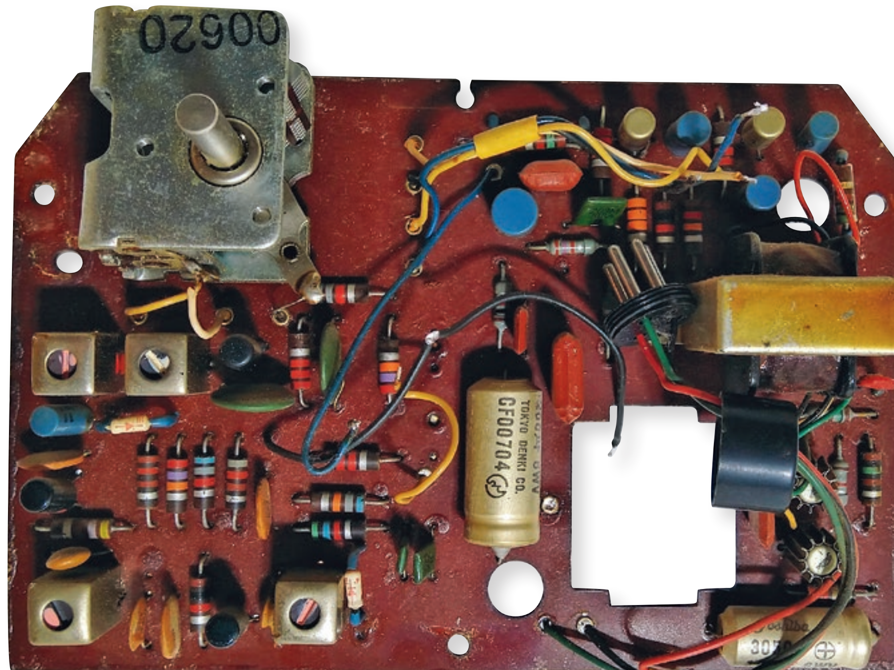
The bias circuit comprises 1.8kΩ resistor R26 and 150Ω resistor R25, in parallel with thermistor R29, providing about 100mV of Class-B bias for X6 and X7. Quiescent (no-signal) current is about 5mA for the pair.

The output transistors' collectors drive output transformer T2, which matches their output characteristics to the two speakers. T2 has two taps: a low-impedance tap for the speakers, and a higher-impedance tap that provides feedback for the audio section, via a tone control filter network (R21-C19-C5) back to the bottom end of T1's primary (ie, X5's collector) and also the emitter of first audio stage transistor X4.

The feedback is frequency-dependent, conditioned by 1kΩ resistor R23 shunted by 120nF capacitor C20, in series with 4.7kΩ resistor R24 shunted by 25nF capacitor C21. The aim is to compensate for the excessive treble response of the 7TH-425's two small loudspeakers. There's also some top-cut applied by 250nF capacitor C22, between the two output transistor collectors.

Construction

Most components are mounted on a conventional phenolic (brown) printed circuit board. A metal chassis supporting the ferrite antenna, the phase splitter transformer and the tuning gang overlays the circuit board. It's a bit of a mechanical bodge.

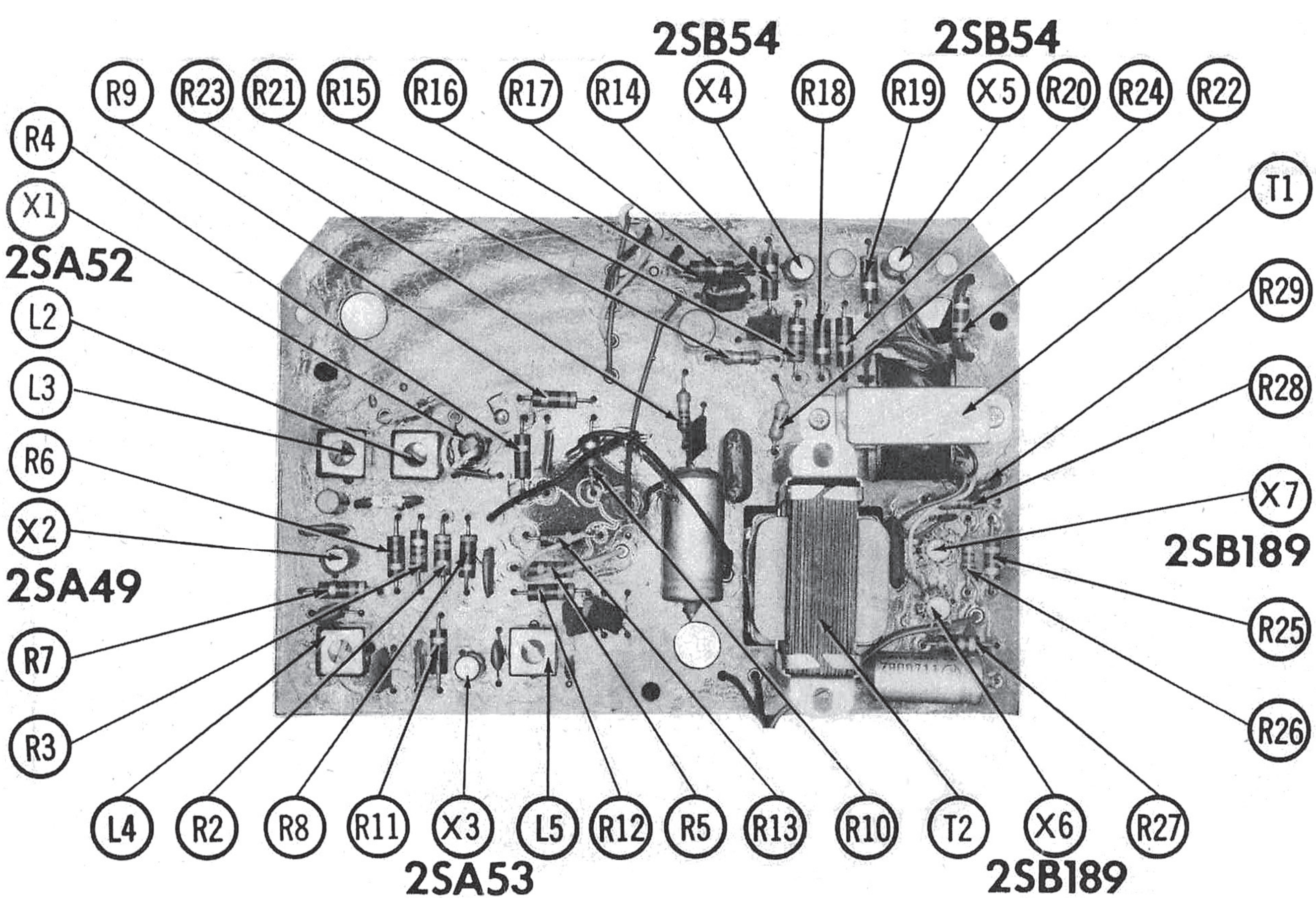


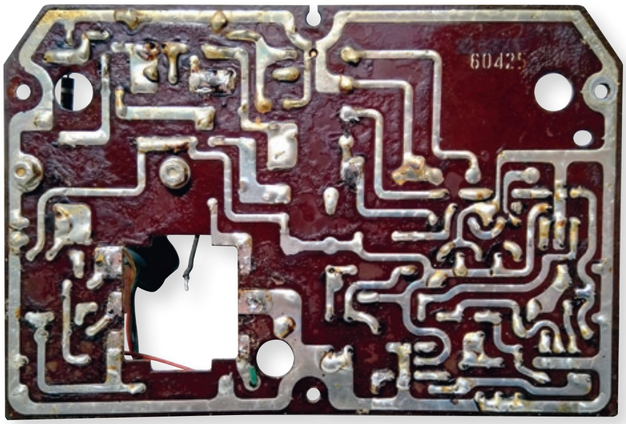
The top of the 7TH-425 phenolic circuit board, with the SAMS overlay diagram shown below.

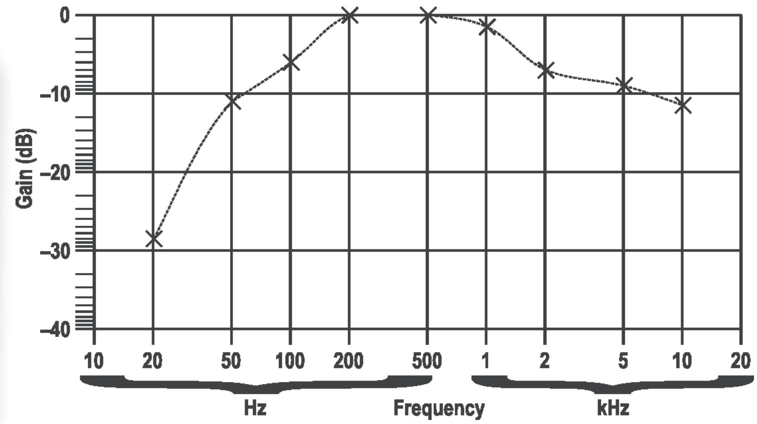
While I was able to take measurements from the unobscured rear of the board, and to get access to all alignment points, the metal chassis blocks access to sections of the component side. The output transformer is soldered and attached to the circuit board, while the phase splitter transformer attaches to the chassis, but its solder tags reach through a square cutout to the solder side of the board. It's far from ideal.

Cleaning it up

This was an easy one as it just needed a little bit of work. The case







Right: the radio's frequency response was equivalent to similar portables.

and dial were in great condition. The power switch had disintegrated, but I found a replacement switch online for a few dollars. Otherwise, it was OK electrically. A quick check showed it could benefit from alignment, and this brought it up to full performance.

Testing and performance

My signal test voltages were about what you'd expect, but the converter's emitter and base voltages came out about half those indicated on the circuit diagram.

Attempting to inject a test signal into the base interrupts the LO signal, so I used my substitute method of coupling via a small 12pF capacitor. While this doesn't indicate the actual signal voltage at the base, it does allow anyone to replicate the results. This gave an IF signal of around 4.2µV, a creditable sensitivity.

Overall, its performance is about what you'd expect. Being wall-mounted, you may be unlucky enough to find your favourite local station is off one end of the antenna rod. Our old enemy, the law of cosines, may prevent reception of a favourite station, but the silver knob behind the power switch does allow you to swing the ferrite rod a few degrees either way, for better pickup.

Under my test conditions, and for the standard 50mW output, it needs around 290µV/m at 600kHz and 250µV/m at 1400kHz. Signal-to-noise ratios exceeded 20dB in each case.

On air, it was able to pull in my reference 3WV over in Western Victoria with ease. RF bandwidth is just better than ±2kHz at -3dB; at -60dB, it's ±32kHz. AGC action is acceptable; a 40dB increase at the input gave an output rise of just 6dB.

Audio response is 85~1100Hz from volume control to speaker. From antenna to speaker, it's 130~1250Hz. But it sounds better than these figures suggest.

A typical set with an upper -3dB point just over 1kHz would be -6db down (or worse) at 2kHz, But as the frequency response graph above shows, the response dips at 1kHz, but flattens off towards 10kHz, due to the design of the feedback network.

Audio output is about 230mW at clipping, with 270mW at 10% THD. At 50mW, THD is around 3.4%; at 10mW, it's about 2.5%.

Turning to the low-battery performance now, at 3V, it clips at 50mW, with 4.5% THD at 30mW output. There was a notable asymmetry between the two half-cycles which indicates a mismatch in the output transistor pair.

Distortion increased with lower output power levels; the extreme was 8% at 1mW output.

Conclusion

Toshiba is famous for its innovative designs. Their early transistor sets often combine stunning visuals with sound engineering. So I am fond of this radio.

But I already have the quirky 9TM-40 "Robot" sitting under my bench. With its unique visual design and elaborate electronics, you can expect to see an article on that set from me in the near future.

Different versions

As mentioned earlier, later sets added a 3.5mm phono input socket. Those revised sets also had two 3.5mm output sockets, as shown in the diagram, which my set also lacks.

Like many other Japanese sets, one of the speaker sockets (the lower on in the diagram) disconnects the internal speakers and routes audio to an external speaker; the upper socket leaves the internal speakers in circuit and connects the external speaker in parallel, presumably for earphone listening while allowing others to hear program through the speakers.

Special handling

Like the Bush TR82C I described in the September 2013 issue (siliconchip.com.au/Article/4404), it's important not to try levering the control knobs off. Remove the volume knob first by running two lengths of string or dial cord at right angles underneath the knob. Pulling on the strings and rocking the knob will ease it off. Repeat this for the tuning knob.

I found the taking them off the first time to be the most difficult, but was able to remove the volume knob with firm finger pressure after that.

Further Reading

At the time of writing this article, I could not find a circuit diagram for the 7TH-425 online. But Howard W. Sam's Photofact sheets are available internationally for around $20 plus postage.

Photofacts are thorough and very informative. Some would consider them better than the manufacturer's documentation. Postage costs do vary widely between shops, so be sure to check the total price first.

I used the Photofact sheet as a source when drawing my own circuit diagram, reproduced here. Be aware that the circuit's component numbering follows the Photofact progression, left-to-right, as I prefer. SC

ASK SILICON CHIP

Got a technical problem? Can't understand a piece of jargon or some technical principle? Drop us a line and we'll answer your question. Send your email to silicon@siliconchip.com.au

Arduino compilation problem

For many years I have used the Arduino IDE (integrated development environment), with reasonable success. However, this has come to an end; each time I try compiling a program (even a blink program), I get the following error message:

```
Invalid library found in
  c:\Users\admin\documents\
  Arduino\libraries\
  Arduino_low_power:
  missing name from library.
```

The low-power library is in the main library file, not a contributed library. I am wondering if you can recommend someone who can help resolve this problem. Your magazine has been and continues to be a great help for my beekeeping project. (M. O., Sutherland, NSW)

● It looks like that Arduino Low Power library has become corrupted. Delete the directory:

```
C:\Users\admin\documents\
  Arduino\libraries\
  Arduino_low_power
```

and you should be able to compile sketches again. You can then re-install this library via the Library Manager, and hopefully, the installed version should be free of the problem that is plaguing you.

New actions for Remote Monitoring Station

I am in the process of building the Arduino-based 4G Remote Monitoring Station (February 2020; siliconchip.com.au/Article/12335).

Everything is going well so far, and I have successfully set up a ThingSpeak account. But I am having a bit of trouble following your Arduino code. It is obviously very clever, but I need a bit more spoon-feeding on using it to do what I want.

Can you give me examples of how to set up the code as follows:

1) To send an SMS alert to the selected phone number if a specific input to the Arduino goes high.
2) To send an SMS alert if a selected analog input exceeds a set voltage.
3) To set an Arduino pin high upon receipt of a text message from the authorised number with a particular word.

Since you have provided the Arduino code for this project at no charge, I suggest that you add the examples I have mentioned above to the download package on your website. Highlighted comments at those areas of the code would also be helpful.

Many thanks for any help you can provide and congratulations on a great project and magazine. (G. C., Toormina, NSW)

● To send an SMS alert to the selected phone number if a particular input to the Arduino goes high, copy the block from lines 93-101 and replace the condition on line 94. For example, change:

```
if(gnssValid&&(
  gnss.speed>100.0)){
```

to:

```
if(digitalRead(pin)==HIGH){
```

To send an SMS alert if a selected analog input exceeds a set voltage, copy the block from lines 93-101 and replace the condition on line 94. For example:

```
if(gnssValid&&(
  gnss.speed>100.0)){
```

becomes:

```
if(analogRead(pin)>value){
```

In this case, 'value' is a number between 0 and 1022, representing a range from 0V up to a tiny bit under the micro's 5V supply rail voltage, which may not be exactly 5V. So, for example, a value around 500 corresponds to a threshold of approximately 2.5V.

To set an Arduino pin high upon receipt of a text message from the authorised number with particular word you can use the following code. But note that this requires an exact match, ie, the same letter case and no other characters in the message before or after the word. Add the following at line 146:

```
if(strmatch("WORD",msg))
  {digitalWrite(pin,HIGH);}
```

In this case, the word is WORD, and 'pin' is the number of the digital pin that you want to send high.

Modifying Tunable HF Preamp for AM

I want to modify the Tunable HF Preamplifier (January 2020; siliconchip.com.au/Article/12219) for connection to a standard AM radio, to improve reception in fringe areas. Would it be feasible to just change the number of turns on T1 to extend the range down to the AM broadcast band? If not, has Silicon Chip produced an article/kit for AM radio range boosting? (G. R., Denistone, NSW)

● Yes, the frequency range can be extended down to the AM band. The tuning capacitor range allows this, but you need a 500µH inductance in the input tuned circuit.

This would give a tuning range from 520kHz to about 2MHz. With the toroid shown, this means about 156 turns; that may be difficult to manage on that size core.

It would be easier to use a fixed choke of 470µH instead. Adjusting the trimmer capacitors on the back of the tuning capacitor would extend the tuning range to just below the broadcast band. You may have to experiment with the number of turns wound around this inductor, as the impedance of the antenna is rather indeterminate.

Relay substitution for Charge Controller

I have recently purchased the PCB to build your Universal Battery Charge Controller (December 2019; siliconchip.com.au/Article/12159). While awaiting its delivery, I managed to assemble almost all of the other parts required, except the relay. Unfortunately, my local Altronics stockist shut down, so getting parts from them is now rather expensive in New Zealand.

In my collection, I have a relay identical in almost all respects except that it has a 3V, 44Ω coil. My reading of the article and the schematic suggests that I can change the 56Ω resistor between the relay coil and the collector of Q3 to 75Ω or 82Ω to maintain the coil current within a suitable range. I checked and found that this relay latches with 5V and an 82Ω series resistor, drawing around 25-30mA.

Am I on the right track, or should I keep on searching for another relay? I built and used the Charge Controller for 12V SLAs (April 2008; siliconchip.com.au/Article/1796) very successfully and thought it was time for an update. Some parts may even get recycled! Thanks in advance for your assistance and great magazine content. (W. G., Dunedin, NZ)

● Your idea of using that relay with an 82Ω series resistor seems fine. It's good that you've already checked that the relay remains latched under those conditions.

Higher current Battery Charge Controller

Your December 2019 Clever Battery Charge Controller is almost what I wanted, but not quite, as I need to be able to handle at least 30A for my system.

I wonder if it would be possible to beef up the current path through the device using heavy wires soldered to the appropriate PCB tracks, heavier connection bolts and a 3AG fuse, plus the addition of multiple Mosfets to share the current, mounted on a heatsink.

If I modify your design in this way, will it handle up to 50A, or do I need a more elaborate method? One particular concern is whether the driver used has sufficient capacity to drive multiple Mosfets. If not, would you consider a follow-up article for people like myself who need to control higher currents? (D. T., Yallourn North, Vic)

● Unfortunately, it isn't as simple as that. The IRF1405 Mosfet can handle much more than the 10A rating we have given; it is the slow switch-on speed (and thus long partial conduction time) which limits the performance of the circuit. Adding more Mosfets in parallel would only make that worse as the Si8751 driver would have a larger capacitance to drive, making it even slower.

We will consider designing an uprated version using a higher-speed Mosfet driver and possibly multiple Mosfets in future. It will definitely need wider tracks, bigger connectors and a higher-rated fuse.

LCD screen brightness control problem

I built your Micromite-based GPS-synched Frequency Reference (October & November 2018; siliconchip.com.au/Series/326). When I got it going, the orientation of the LCD Screen was incorrect for the program set up. You kindly replaced it with one with the correct orientation.

Unfortunately, with this new screen, manual backlight adjustment only gets to a very low brightness. I cannot read the screen if I have my workshop bench lights turned on, for example. I need to turn them off and only have low light in the room. This did not happen with the original, rotated screen.

I am wondering if there is some simple fix to overcome this. I haven't any data on the device, so I am a bit unwilling to start trying things without first checking with you. (I. P., Loganholme, Qld)

● It seems that some otherwise identical-looking LCD screens use a different method for backlight control. One of our other readers wrote in to say:

I'm absolutely delighted with my Micromite BackPack V3 and Tim Blythman's CFUNCTION software drivers for the ILI9488 colour touchscreen display.

However, I discovered a small problem with manual dimming of the dis-

Building the Majestic Speakers with 16-inch woofers

I have purchased all the parts to build the Majestic speakers featured in the June 2014 issue of Silicon Chip. I would like to re-use a good pair of 16in woofers from a set of Kenwood KL-777D speakers which I have in my possession. You can view their specifications here: siliconchip.com.au/link/ab0l

What changes would I need to make to use these? (M. T., Naracoorte, SA)

● Allan Linton-Smith responds: the KL-777Ds are a classic and desirable vintage five-way speaker, as long as the drivers are not damaged and the woofers don't rub or buzz.

Unfortunately, the Kenwood woofer specs don't include Thick or Small parameters, probably because they had not been invented then. Hence, it is difficult to know what modifications (if any) would need to be made to the Majestics.

They do mention that the sensitivity is 98dB, but that may have been for one of the other five drivers in the enclosure. They also give a frequency response from 22Hz-22kHz, but that was in 1970 before truth in advertising – if you get my drift!

From experience, I would say that most Alnico woofers from that period were only capable of handling 40-65W RMS, but were designed for good bass and sensitivity. Amplifiers were very weak in those days! 10W RMS was considered powerful for a hifi amp. So the woofers usually had a high VAS and a high QTS. Therefore, these woofers may work better in a sealed enclosure.

If building these speakers as suggested, I suggest a listening test: block off the port with a temporary plug and listen with and without the plug, to see which way sounds better.

From the photos, it looks like the KL-777D enclosure was smaller than that of the Majestic. I think it used a rear-firing port, as there is no port visible on the front.

The main negative in using these drivers is that they are slightly bigger than our recommended woofers, with an overall diameter of 405mm compared to 385mm, so will require a bigger cutout. If they fail (very possible after 40 years of service), it may be difficult to replace them with the slightly smaller modern drivers given the larger hole.

play. I tend to use manual dimming because I like to save one control pin, and display dimming is pretty much set-and-forget for me.

It appears that the LED "A" pin on the display (pin 8 on the 14-pin header) is a voltage control on the latest display I purchased, rather than current control on the two previous displays I used (one from AliExpress and the other supplied in a SILICON CHIP kit, which seemed to be identical).

The problem is easily resolved by replacing the 100Ω pot (VR1) with a 10kΩ or 20kΩ pot, and connecting the free end to ground.

Generating sidereal time pulses

Is to possible to generate a signal at the sidereal time frequency (just over 1Hz) with a Maximite? If so, how? (R. M., Melville, WA)

● Yes, it is possible, but the calculations are a bit involved. You would need to ensure the Maximite had an accurate oscillator, then use one of its timers and some fairly complex calculations to generate the pulses.

It would probably be easier to simply build the circuit we presented in the Circuit Notebook section of the November 2015 issue (**siliconchip.com.au/Article/9400**), which uses a PIC16F628A and a GPS receiver. The software for that project is available for download from our website.

Automotive coil tester wanted

For a while now, most cars have used dedicated ignition coils to fire their respective spark plugs. Thus a four-cylinder car will have four individual coils, a six-cylinder car will have six coils etc. These coils are simple units but run at extremely high energies, and can be dangerous or even lethal to the unwary.

In tracking down problems such as misfires, I have found that the average mechanic will simply replace one or all coils as a matter of course; an expensive and wasteful practice. I guess this is fair enough because most of the spark testers on the market are decidedly crude and require both extensive experience and extreme caution to use.

So I would like to suggest a good spark tester as a future project. Preferably it would be able to run tests on the bench and measure the spark energy under load. (N. S., East Lismore, NSW)

● We published a Spark Energy Meter in our February and March 2015 issues (**siliconchip.com.au/Series/283**). You may also find the AC EHT Probe for Ignition Systems described in this issue useful (starting on page 90). Or the High Energy Ignition System (Nov-Dec 2012; **siliconchip.com.au/Series/18**), which has a spark test feature.

Confusion over SMD PIC32 orientation

I purchased an Explore 100 PCB and programmed PIC32 from you, but when I went to solder in the PIC32 IC, I was stumped. The article says to line up the dimple on the IC with the pin 1 mark on the PCB. But my IC has two dimples, one on opposite corners, one larger than the other. Which one do I go by? (T. V., Burpengary, Qld)

● We've found this to be a pretty common occurrence on the Microchip PICs we purchase. The only reason we can think of that they would add a second dimple is to aid with automated assembly, but the data sheet for the PIC32MX470F512L doesn't show a second dimple on the package, nor was there one on the chip used to build our prototype.

The data sheet does show that the pin 1 dimple is in the lower left-hand corner when the chip is orientated so that you can read the text printed on it. Most of the time the pin 1 indicator is the smaller dimple, but we've had one less common surface-mount PIC where it was the larger one. In your case with the PIC32MX470, it will most likely be the smaller dimple.

Upgrading Explore 100 firmware

I built a couple of Explore 100 modules a couple of years ago, and they are working well, but the other day I saw there was an updated firmware image available for the Micromite Plus (v5.05.02).

So I thought I would bring it up to date, as I do with all my BackPacks. I used my PICKit 3, and it was a breeze on the first Explore 100 module; I didn't run into any problems.

But when I went to reflash the second Explore 100 module, it could not get the chip ID. I am supplying the boards power from the PICKit.

There is only one difference between the two boards; one board has the MCP120 fitted (IC2), which connects to the micro's $\overline{\text{MCLR}}$ pin, also used for programming. I wonder if this is the reason why programming failed and if anyone else has had this problem.

I may need to remove the MCP120 IC or feed in +3.3V power externally to successfully reflash this second board. (R. S., Epping, Vic)

● It seems possible that the MCP120 could interfere with programming if you are supplying power from the PICkit. That's because the PICKit's power supply is relatively weak and the Explore 100 board can draw quite a bit of current, so we would expect there to be some voltage sag on the +3.3V supply. If it sags enough, it could trigger the MCP120 to pull $\overline{\text{MCLR}}$ low, which could interfere with programming.

Try powering the Explore 100 from USB with JP1 fitted, or via CON1, depending on whatever is easier. That should solve the sag problem. You should turn off the option to power the target device from the PICkit while you are providing power from elsewhere, although it's unlikely to cause any real problems if you forget to do that.

Charging caravan batteries

I have two 105Ah deep cycle batteries in my caravan which are charged by an onboard 230V AC/12V DC three-stage charger, connected from the tow vehicle alternator via an Anderson plug. These batteries power the van electricals, fridge etc as well as a 2000W inverter I use for the microwave occasionally while off-road.

The charging rate for these batteries is slow; they take many hours to recharge while driving. I strongly suspect a voltage drop as the cause of the delay. I vaguely remember a booster charging circuit published by SILICON CHIP but cannot find any reference to it. Failing that, would it be possible to beef up your SC 12V 100W Inverter project from May 2011 (**siliconchip.com.au/Article/1009**) to a 200W version?

I note the low-end boost output of that project is 7A @ 15V. A 15V, 15A version might be just the ticket to boost the charging rate in my application. I can see R1 would probably need reducing to 0.02Ω while all the other components appear more than robust. Also, would you be able to advise the merits of the location for the inverter, ie, near the alternator or at the onboard charger end? (C. O., Adelaide, SA.)

● That project would require substantial changes to be able to deliver 15A at 15V. The toroidal transformer would need to be considerably larger for a start, and more/larger capacitors would be required.

We're a bit mystified that your charger doesn't already have a boost function; if it's a lead-acid charger with a 12V DC input, we would have thought it would need to boost the voltage to provide the three-stage charging function.

Check this; if it doesn't, we think the best solution is for you to replace it with a Jaycar Cat MB3683 20A DC/DC charger, which can operate with an input supply as low as 9V DC: siliconchip.com.au/link/ab0m

It should be located near the batteries being charged.

Help with Digital Pulse Adjuster

I've recently built the Digital Pulse Adjuster from your Performance Electronics for Cars book (siliconchip.com.au/Article/8644). When I power it on, all three LEDs come on together. I don't think that is right, shouldn't it just be the power LED on initially? I have all links set to negative. I'm reluctant to hook it up to my car as I believe it may be faulty.

Also, how do I connect the Peak-Hold Injector Adaptor (siliconchip.com.au/Article/8646) from the same book to the Digital Pulse Adjuster? I'm trying to control a solenoid that uses peak-hold as the control.

If I use the Adaptor, I can measure the pulse width with a simulated solenoid resistive load for the Pulse Adjuster. But I need to drive a peak and hold output to control the solenoid. Am I on the right track? (M. D., Emerald, Qld)

● It is correct for all three LEDs to light up. The Peak-Hold Adaptor output, shown as a green wire in Fig.1, connects to the pulse input of the Digital Pulse Adjuster. When using the Peak-Hold Adaptor, follow the Fig.3 diagram to add an extra injector.

The Peak-Hold Adaptor is intended to square up a peak-and-hold drive. We haven't published a circuit to drive a solenoid using the peak-and-hold method. The Texas instruments DRV110 IC is designed for that purpose. See: siliconchip.com.au/link/ab0n

Microphone preamp for recording birds

I am looking for a low-noise microphone preamplifier for an electret microphone, to be used for recording bird songs. I am seriously considering building a parabolic dish along the lines of the one described in *Electronics Australia*, November 1983 (83ma11). I built two of these in the past, but they were lost in a house fire back in 2017.

My guess is that the LF351 op amp IC is no longer available, and there are probably better ways of amplifying things 27 years later. The Sooper Snooper (September 2001; siliconchip.com.au/Article/4152) is interesting, but the PCB looks to be proprietary to Oatley Electronics, and it is no longer on their website, so that is probably a bit of a dead-end. Do you have any suggestions? (D. H., Lower Pappinbarra, NSW)

● It is still possible to obtain LF351 op amps (they are very similar to the TL071) but instead, we suggest that you build the Champion Preamp (June 2015; siliconchip.com.au/Article/8609).

This is available as a Jaycar kit, Cat KC5531, or you can order the PCB from our website at: siliconchip.com.au/Shop/8/1033

Power transformer sizing question

I am considering using an Altronics M6014 outdoor transformer (generally used to power small pump motors, lights etc) to power a contactor and several irrigation solenoids. The loads add up to 2.27A, while that transformer is rated at 24V, 3A.

The surge current of contactor and solenoids totals 4.05A, which exceeds the rating of the transformer. Is this safe, or should I choose a transformer with a higher amperage? Is there a rough rule regarding how much the rated amp rating can be exceeded for surge currents? (P. B., Cooloongup, WA)

● It depends on whether the solenoids and contactor are AC or DC types. The surge current can be averaged out for a DC load if the bypass capacitor is large enough. For AC loads, the full surge current is drawn from the transformer.

It probably would be preferable to use a larger transformer that can handle the extra current. However, transformers can generally supply somewhat more than their rated current for a short time, as long as the loads will not be negatively affected by voltage sag during that period.

If you exceed the transformer rating, along with the voltage dropping, the transformer will generate more heat than it is designed to handle. That can be detrimental if it is sustained. The internal thermal fuse may also blow, depending on how long the overload lasts.

X2 capacitor replacement

I need some advice. I have an ultrasonic cleaner in my workshop that has several blown components, including the two main Mosfets.

The unit was made in Germany, so I assume it is of reasonable quality. I replaced all the blown components, and the unit seems to be running how it should. The X2 series capacitor in the mains power supply tested OK, but I replaced it anyway.

The data sheet for this X2 capacitor I bought says it is a 'suppression' capacitor, and should not be used in a pulse circuit. I have fitted it anyway (for the time being, if nothing else). I can get a 'pulse' X2 capacitor, and I suspect that is what I should have used.

However, I checked the specifications of the original X2 capacitor (B81130 X2 MKP/SH 40/100/21/B 680nF, 275V) and they suggest that it was a 'suppression' capacitor too.

The capacitor I bought from RS Components, Cat 874-0822, is a Vishay F1772 series type. Can you advise me whether this is suitable as the mains series 'dropping' capacitor in this unit? (P. W., Auckland, NZ)

● Either a polypropylene or polyester X2 class capacitor is suitable for your application. The polyester types are generally smaller. There is no need to use a special type for a dropping capacitor in this role, as it only charges and discharges at 50Hz. For more information, see the PDF file at: siliconchip.com.au/link/ab0o

Continued page 112

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Coming up in Silicon Chip

Anodising aluminium
Professionally-made aluminium pieces are often anodised, for protection against damage and corrosion, or to change their colour. Sometimes you don't have that option, though, especially when you are making aluminium panels at home. But the anodising process is not that complicated and you can do it at home with just a few basic tools and chemicals. We'll explain how.

DIY solder reflow oven with PID temperature control
We've previously described how you can use a toaster oven to reflow solder paste. This is a great way to solder many SMDs at once, but it's a bit "hit and miss". By adding this PID temperature controller, you can get the oven to follow the correct soldering temperature profile, and get good results every time! It's also great for curing glues and paints at lower temperatures.

Mono & stereo 7-band equalisers
These two equalisers use rotary pots, so they can easily be installed in pre-existing equipment like amplifiers or preamplifiers. They are simple to build and have stellar performance. They're ideal for compensating for uneven loudspeaker or room responses, or just tweaking the sound profile to your liking.

Stealth Technology
Making giant metallic objects like aircraft or ships vanish from radar (and other sensors) may seem like witchcraft, but it's actually a feat of science and engineering. The full details are naturally kept secret, but in this article, Dr David Maddison presents what is known about the various technologies used to absorb and deflect radar signals. We also describe other 'low observable' techniques to reduce the visible, infrared and audible signals of various vehicles and even people.

Note: these features are planned or are in preparation and should appear within the next few issues of Silicon Chip.

The April 2020 issue is due on sale in newsagents by Thursday, March 26th. Expect postal delivery of subscription copies in Australia between March 24th and April 10th.

Notes & Errata

AM/FM/CW Scanning HF/VHF RF Signal Generator, June & July 2019: some constructors have described erratic operation of the rotary encoder. The designer has tracked this down to variations in the internal RC oscillator frequency of the ATmega328P microcontroller (IC1). Revised software (V11) is available for download from the Silicon Chip website which fixes this. This new version will also be used to program any chips ordered from now on.

Advertising Index

Battery booster wanted

I am putting a second battery in my vehicle to keep my fridge running when the engine is stopped. I am going to use a 36Ah sealed lead-acid (SLA) battery, also known as a gel cell. I have the necessary dual battery switching, but this will only charge the SLA to the flooded battery voltage, where the SLA full charge voltage is specified as 14.4-15V.

Have you ever described anything that will boost the car's output voltage up so that it will charge the SLA correctly? (P. C., Balgal Beach, Qld)

● We spent some time working on such a design about ten years ago, but found that the parts to build a decently powerful 'caravan booster' cost more than a commercial off-the-shelf unit.

Hence, we have never published such a design. However, you may like to look at our July 2019 article on building a Dual Battery Isolator (siliconchip.com.au/Article/11699) as it is related to your situation.

While it would be better to charge the SLA battery according to specifications, it should charge sufficiently at the flooded battery charge voltage to provide for running the fridge. Just make sure to minimise losses between the vehicle's alternator regulator output and the secondary battery, eg, use thick cables etc. Any loss along the way will only lead to a lower final charge on the added battery. SC