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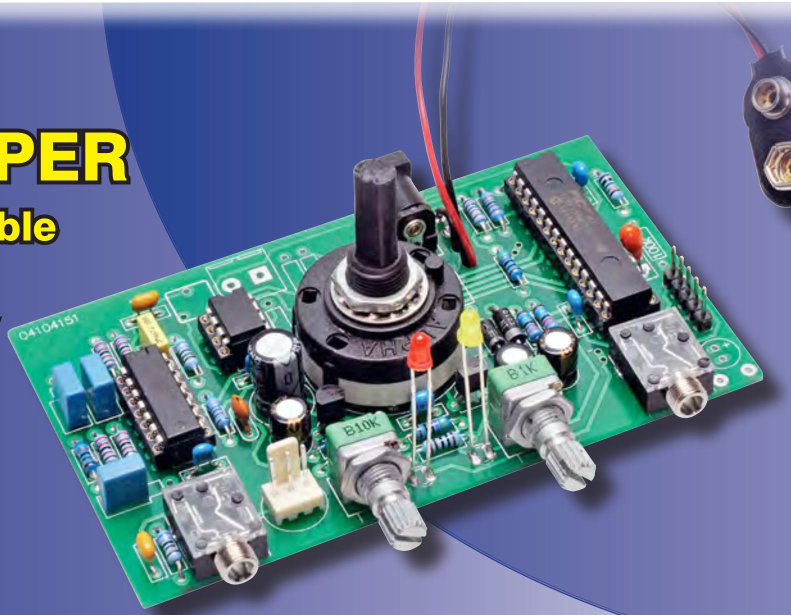

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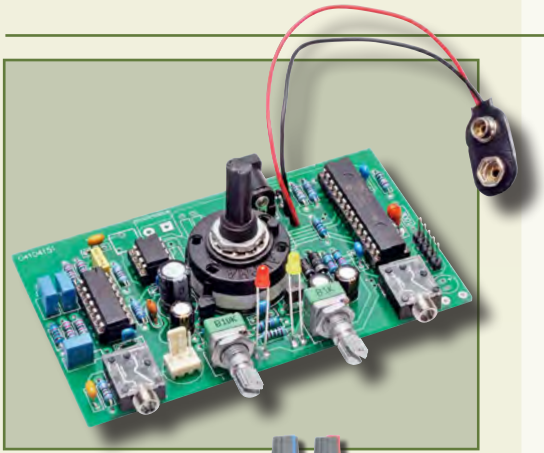

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Our July 2016 issue will be published on Thursday 2 June 2016, see page 80 for details.

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*Kit Order Code: 8157KT - **£49.95***
*Assembled Order Code: AS8157 - **£54.95***

Computer Temperature Data Logger

Serial port 4-channel temperature logger. °C or °F. Continuously logs up to 4 separate sensors located 200m+ from board. Wide range of free software applications for storing/using data. PCB just 45x45mm. Powered by PC. Includes one DS1820 sensor.
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*Assembled Order Code: AS3145 - **£26.95***
*Additional DS1820 Sensors - **£4.95 each***

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

4-Ch DTMF Telephone Relay Switcher

Call your phone number using a DTMF phone from anywhere in the world and remotely turn on/off any of the 4 relays as desired. User settable Security Password, Anti-Tamper, **Rings** to Answer, Auto Hang-up and Lockout. Includes plastic case. 130 x 110 x 30mm. Power: 12Vdc.
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Here are a few of the most recent products added to our range. See website or join our email Newsletter for all the latest news.

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Get better performance from your stepper motors with this dual full bridge motor driver based on SGS Thompson chips L297 & L298. Motor current for each phase set using on-board potentiometer. Rated to handle motor winding currents up to 2 Amps per phase. Operates on 9-36Vdc supply voltage. Provides all basic motor controls including full or half stepping of bipolar steppers and direction control. Allows multiple driver synchronisation. Perfect for desktop CNC applications.
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*Assembled Order Code: AS3187 - **£49.95***

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*Assembled Order Code: AS3067 - **£27.95***

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Control the speed of most common DC motors (rated up to 32Vdc/10A) in both the forward and reverse direction. The range of control is from fully OFF to fully ON in both directions. The direction and speed are controlled using a single potentiometer. Screw terminal block for connections.
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*Assembled Order Code: AS3166v2 - **£33.95***

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Drives any 5-35Vdc 5, 6 or 8-lead unipolar stepper motor rated up to 6 Amps. Provides speed and direction control. Operates in stand-alone or PC-controlled mode for CNC use. Connect up to six 3179 driver boards to a single parallel port. Board supply: 9Vdc. PCB: 80x50mm.
*Kit Order Code: 3179KT - **£17.95***
*Assembled Order Code: AS3179 - **£24.95***

Computer Controlled Bi-Polar Stepper Motor Driver

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*Kit Order Code: 3158KT - **£24.95***
*Assembled Order Code: AS3158 - **£34.95***

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See website for lots more DC, AC and stepper motor drivers!

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40 MHz sampling rate, 12 MHz analog bandwith, 0.1 mV sensitivity, 5mV to 20V/div in 12 steps, 50ns to 1 hour/div time base in 34 steps, ultra fast full auto set up option, adjustable trigger level, X and Y position signal shift, DVM readout and more...
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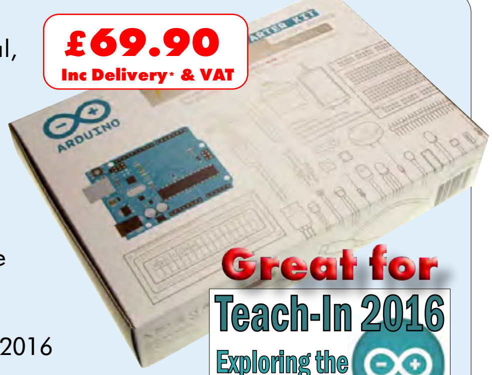
Arduino Starter Kit

Genuine Arduino Starter kit which comprises of a 170 page instruction manual, Arduino UNO Board, Breadboard, components & more.

£69.90 Inc Delivery* & VAT



The kit walks you through the Arduino programming and basic electronics in a hands on way. You will be able to build 15 projects using the components supplied. They allow you to control the physical world through different kinds of sensors and actuators. Once you have mastered this knowledge, you will have the ability and circuits to create something beautiful, and make someone smile with what you invent. So build, hack and share!

Great for Teach-In 2016 Exploring the Arduino

The Arduino Starter kit is the ideal partner for anyone following the Teach-In 2016 which started in the February 2016 issue of EPE Everyday Practical Electronics.

This Starter kit is supplied with a Wood base, USB & Interconnect leads, Electric motor, Piezo sounder, Movement and Temperature sensors, Switches, LCD, Breadboard & Servo motor. The kit also includes over 100 electronic components:- Diodes, Transistors, Capacitors, h-Bridge, Resistors, LED's, Switches and Trimmers. Quote: EPEARDSK

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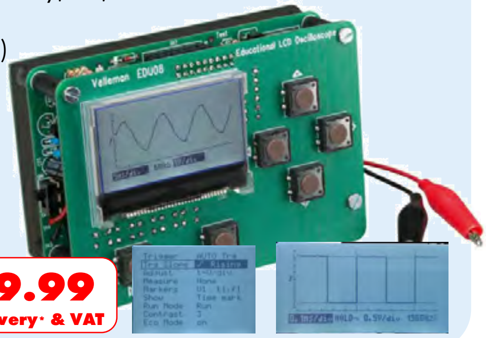

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VOL. 45 No. 06 JUNE 2016

EVERYDAY PRACTICAL ELECTRONICS

Now is the time to learn about PICs

Spring is finally here and with it a warm welcome to the June issue of *EPE*. We have a cornucopia of exciting, informative and useful material for you this month; but top of my list is the start of a *PIC n' Mix* mini-series on the basics of designing and building PIC-based circuits. If you've never dabbled in this important area of electronics then now is the time to start.

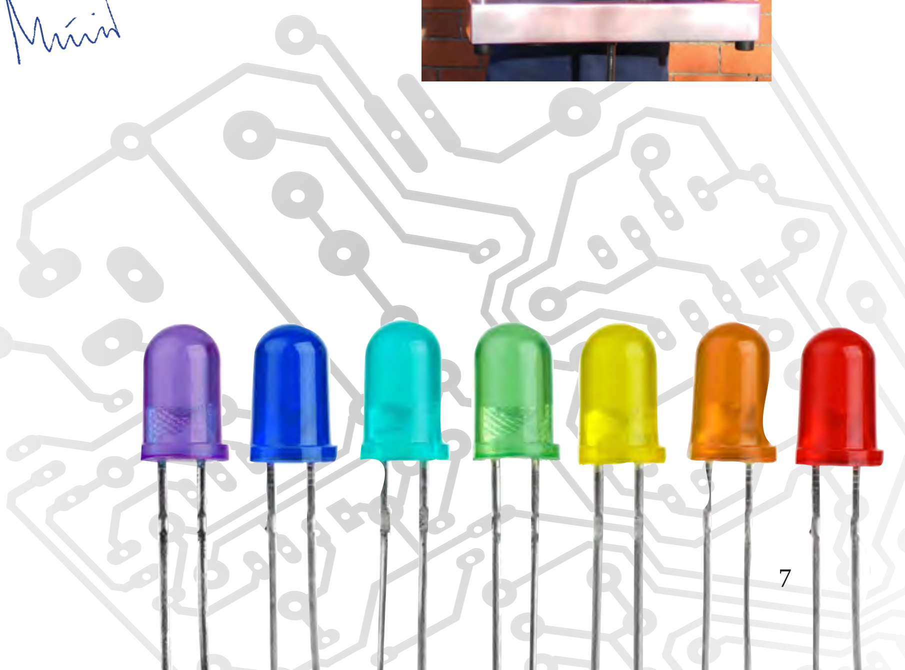
Troubleshooting...

I enjoy just about every aspect of electronics: design is an ever-fascinating intellectual challenge; construction is a combination of skill, dexterity and arranging components in a neat, logical and satisfying manner; and even sourcing components has its pleasant challenges. However, there is one area that can drive me to distraction – fault finding and troubleshooting a problem. We've all been there, you check, check and check again, but your carefully designed, meticulously constructed circuit just refuses to behave. You go round in ever decreasing circles, hunting for errors, solder bridges, loose power connections… till you start to doubt your ability, or even your sanity.

Anything that can reduce this pain is to be welcomed, which is why all serious constructors of analogue or AM radio circuits should be pleased to see the publication this month of our *Audio Signal Injector/Tracer project.* It won't solve all your problems, but it might just give you the head-start you need to stay sane!

EPE's got talent!

Or rather I should say Jake does… I'm not normally a follower of ITV's 'Britain's Got Talent', but the show on Saturday, 16 April was an exception. Appearing live before a huge audience and a quartet of formidable judges was *EPE's* very own audio electronics guru – Jake Rothman. Performing with a 1996 version of his famous *EPE* Theremin design, Jake may not have exactly wowed the crowd, but he gets my vote simply for being one of the few (if not only) performer who actually designed and made the instrument used live on stage.



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NEWS

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

Portable jump start and screen burn – *report by Barry Fox*

Phone/tablet/camera charger and autmotive jump starter

The Cobra CPP 8000 JumPack costs £80, is around the size of a pack of cards and weighs 300g, with an internal 7500mAh lithium-cobalt battery. The battery is conventionally charged either by a 5V USB or car socket connector, and delivers 5V at 2.1A for rapid charging of portable devices such as mobile phones, tablets and digital cameras. Unconventionally, JumPack also has a shuttered, twin-pin socket that takes short, fused leads with crocodile clips. These connect to a car battery and deliver bursts of 12V at around 200A. The makers say this is enough to 'jump start most vehicles'.

Normally, it would take a fully charged, big and heavy lead acid battery to deliver enough current to start a car engine. I was, therefore, a little wary, and put the device to a real-world test, deliberately draining the battery of a VW Polo with 1.4 litre petrol engine by leaving the headlights on, and then trying to start it with the JumPack.

Close, but...

The JumPack delivered enough power to turn over the engine, several times, but not with enough speed and torque to start the engine running. I followed the instructions and tried several times with short bursts. The JumPack got pretty hot, but could not start the car engine.

I repeated the test with a different sample, in case the first unit had been faulty.

After again deliberately draining the car battery again I tried the 100% charged replacement JumPack. The result was the same; the engine turned over but would not start.

As a final test I tried connecting both JumPacks to the car battery, in parallel, and the car started.

So one JumPack will be a life-saver when an engine just fails to start because the car battery is low or failing; but two JumPacks may be needed when the car battery is fully flat.

Two JumPacks will cost more than most car batteries but are a lot more convenient to carry – and also serve as very gutsy mobile phone, tablet and camera chargers.

Return of the burn

Welcome (not) to the return of an old bugbear – screen burn, otherwise known as 'image retention' or 'image sticking'.

Cathode ray tubes (CRT) and plasma screens, which emit light, can physically change when used at high brightness for long periods. If the light is in a stationary pattern, the pattern imprints on the screen.

Old arcade games, where a games grid remained stationary for months or even years, showed the grid even when turned off. The same thing happened on TVs and computers – to a lesser extent – with wordpro templates, logos, test patterns and TV station ID 'bugs' sticking to the screen.

That's how screen savers were born. Later, when LCD screens took over from CRTs and plasmas, the screen savers became totally unnecessary 'brain savers'. LCDs 'light gate' a backlight, so they do not suffer from burn.

OLEDs emit light so are at similar risk to CRT and Plasma displays. This is not an unfounded scare story. At a recent technical seminar held by Panasonic in Germany, Eric Gemmer, Director of Imaging Technology at THX in California, was noticeably careful about leaving a static test pattern on the OLED screen he was using to demonstrate the contrast difference between LCD and OLED displays.

'As with CRTs and plasmas' he explained, 'it starts as a temporary residual effect which disappears in around two hours, but can become permanent.'

Remember this? Screen burn on a gaming CRT display; this issue may be about to return with the rise of OLED displays

DNA data storage breakthrough

Companies such as Google routinely build huge data centres to store all the kitten pictures and emails its users generate – and keep.

However, a new technique developed by the University of Washington (UW) and Microsoft researchers could shrink the space needed to store digital data that today would fill a factory-sized supercenter down to the size of a sugar cube.

The team of scientists and bio-engineers has created one of the first complete systems to encode, store and retrieve digital data using DNA molecules, which can store information millions of times more compactly than current archival technologies.

Encode and retrieve data

In one experiment, the team successfully encoded digital data from four image files into the nucleotide sequences of synthetic DNA snippets. More significantly, they were also able to reverse that process – retrieving the correct sequences from a larger pool of DNA and reconstructing the images without losing a single byte of information.

'Life has produced this fantastic molecule called DNA that efficiently stores all kinds of information about your genes and how a living system works – it's very, very compact and very durable,' said co-author Luis Ceze, UW associate professor of computer science and engineering.

Data explosion

The digital universe – all the data contained in computer files, archives, movies, photo collections and created by businesses – is expected to hit 44 trillion gigabytes by 2020.

That's a tenfold increase from 2013, and will represent enough data to fill more than six stacks of computer tablets stretching to the moon. While not all of that information needs to be saved, the world is producing data faster than the capacity to store it.

DNA molecules can store information many millions of times more densely than existing technologies, such as flash drives, hard drives, magnetic and optical media. Those systems also degrade after a few years or decades, while DNA can reliably preserve information for centuries. DNA is best suited for archival applications, rather than instances where files need to be accessed immediately.

From bits to DNA

The researchers have developed a novel approach to convert the long strings of ones and zeroes in digital data into the four basic building blocks of DNA sequences – adenine, guanine, cytosine and thymine.

'How you go from ones and zeroes to As, Gs, Cs and Ts really matters because if you use a smart approach, you can make it very dense and you don't get a lot of errors,' said co-author Georg Seelig, a UW associate professor. 'If you do it wrong, you get a lot of mistakes.'

The data is chopped into pieces and stored by synthesising a massive number of tiny DNA molecules, which can be dehydrated or otherwise preserved for long-term storage.

The UW and Microsoft researchers are one of two teams nationwide that have also demonstrated the ability to perform 'random access' – to identify and retrieve the correct sequences from this large pool of random DNA molecules, which is a task similar to reassembling one chapter of a story from a library of torn books.

Currently, the largest barrier to viable DNA storage is the cost and efficiency with which DNA can be manufactured and sequenced (or read) on a large scale. But researchers say there's no technical barrier to achieving those gains if the right commercial incentives are in place.

UK's first commercial computer

More than 60 years after it was first revealed to the public, Britain's first mass-produced business computer, the Hollerith Electronic Computer (HEC), is now on display at The National Museum of Computing (TNMOC) at Bletchley Park.

The HEC was the prototype for the range of computers that were to become Britain's best-selling first-generation computer and, as the first computer installed in many countries including India, New Zealand and East Africa, the machine played a key role in starting the global computer revolution.

The first version of the 2m x 3m HEC with its highly innovative magnetic drum store can be seen by visitors to the First Generation Gallery at TNMOC where it stands alongside other machines of the period: the ongoing reconstruction of the 1949 EDSAC computer and the original 1951 Harwell Dekatron / WITCH computer.

The HEC was commissioned by the British Tabulating Machine Company (BTM). Dr Raymond Bird, a skilled and enthusiastic electronics engineer, was tasked with its development.

Dr Bird explained the development process: 'BTM was one of Britain's largest suppliers of pre-computing punch-card systems and the company realised that computing was the company's future. BTM had been approached by Professor Andrew Booth of Birkbeck College, London, who needed input and output technologies – punch cards – for a computer he was designing. A deal was struck and I was sent to make copies of Booth's computer design.'

Dr Raymond Bird demonstrates the HEC at the 1953 Business Efficiency Exhibition. Photo courtesy Dr Raymond Bird.

Smart contact lens

Samsung has been granted a patent for a smart contact lens that projects images directly into the wearer's eye with a built-in camera that is controlled by blinking.

The patent shows that Samsung has been developing a contact lens with a tiny display, a camera, an antenna, and several sensors. It's designed to be paired with an external device, such as a smartphone for image processing and data storage.

Samsung claim their smart contact lenses provide superior image quality than off-eye solutions such as Google Glass. Like Google Glass, however, these contact lenses will undoubtedly come under intense scrutiny over its privacy-eroding implications — they're essentially hard-to-detect cameras that can be taken and used anywhere a person goes and on anything a person can see.

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Proof at last!

TechnoTalk

Mark Nelson

People who have long suffered pain and other ailments that they blamed on 'electronic smog' can finally refute the sceptics. New academic proof that these effects are not imaginary is Mark Nelson's subject this month.

ELECTRONIC SMOG – DESCRIBED as 'an unprecedented dense mesh of artificial magnetic, electrical and electromagnetic fields' – has been blamed for many ills. In 2008, radiation from mobile phone towers and power lines was cited as causing the collapse of bee colonies and declining sparrow populations by upsetting their migration paths. Even more disturbing were the allegations that humans were affected too, suffering symptoms of weakness and dizziness, or worse – death from brain tumours or throat and breast cancer. The Bioinitiative Working Group, an international study group of respected scientists and public health policy experts, stated in 2007: 'Chronic exposure to even low-level radiation (like that from cellphones), can cause a variety of cancers, impair immunity, and contribute to Alzheimer's disease and dementia, heart disease, and many other ailments. We now have a critical mass of evidence, and it gets stronger every day.'

EHS

An allied ailment is EHS (electrical hypersensitivity), which is becoming more widespread, Some experts say up to three per cent of all people may be clinically hypersensitive and up to 30 per cent to a lesser degree. Symptoms attributed to EHS include fatigue, facial irritation, tinnitus, dizziness, and digestive disturbance. Exposure to computer screens, mobile phones and other everyday electronic equipment, as well as to Wi-Fi in the home or workplace, is the alleged culprit.

The final truth?

Up to now, these allegations have been refuted time after time, with no definite medical evidence confirmed. Now, researchers at The University of Texas at Dallas in the US have provided scientific evidence to back up the anecdotal stories of people who reported abnormal sensations and neuropathic pain around cellphone towers and other devices that produce radio-frequency electromagnetic fields. 'Our study provides evidence, for the first time, that subjects exposed to cellphone towers at low, regular levels can actually perceive pain,' says Dr Mario Romero-Ortega, an associate professor of bioengineering at the university. 'Our study also points to a specific nerve pathway that may contribute to our main finding.'

Pain response in rats

Rats were exposed to a 915MHz radio signal (close to frequencies used by many cellphones) for ten minutes, once per week for eight weeks. The antenna delivered a power density equal to that measured at 39m from a local cellphone tower – a power density that a person might encounter outside of occupational settings. By the fourth week, 88 per cent of subjects in the nerve-injured group demonstrated a behavioural pain response, while only one subject in the sham group exhibited pain at a single time point, and that was during the first week. After remedial treatment the pain responses persisted. Professor Romero-Ortega concludes: 'In our study, the subjects with nerve injury were not capable of complex psychosomatic behaviour. Their pain was a direct response to man-made radio frequency electromagnetic energy.'

Phase difference

Until recently, most electrical and electronic gadgets bought in North America would not work well or at all in Europe. It was not just the AC voltage that was different; but also the mains or line frequency. Today, many appliances use switch-mode power supplies and are frequency and voltage-agnostic, for which we can be truly thankful; but have you ever wondered why the Americans perversely chose 60Hz, at a time when 50Hz was used in (most of) the rest of the world? I wanted to know who made that strange choice and why.

The most plausible answer I found was given by Robert Frost, an instructor and flight controller at NASA, on the **Quora.com** website. He states: 'In 1891, Westinghouse selected 60Hz while at the same time, in Germany [and all of Europe in fact] they were selecting 50Hz. Westinghouse chose 60Hz because the arc-light carbons that were popular at that time worked better at 60Hz than at 50Hz. Either 50 or 60 works today, obviously, but they are both trade-offs. At lower frequencies more copper and iron are needed (in motors and transformers) but at higher frequencies, more expensive plates are needed to prevent eddy losses.'

Impractical everyday electronics

Today, using satellites for receiving TV ('200 channels and nothing on' as the cynics say) and calculating your location by GPS is commonplace. But who had the idea first?

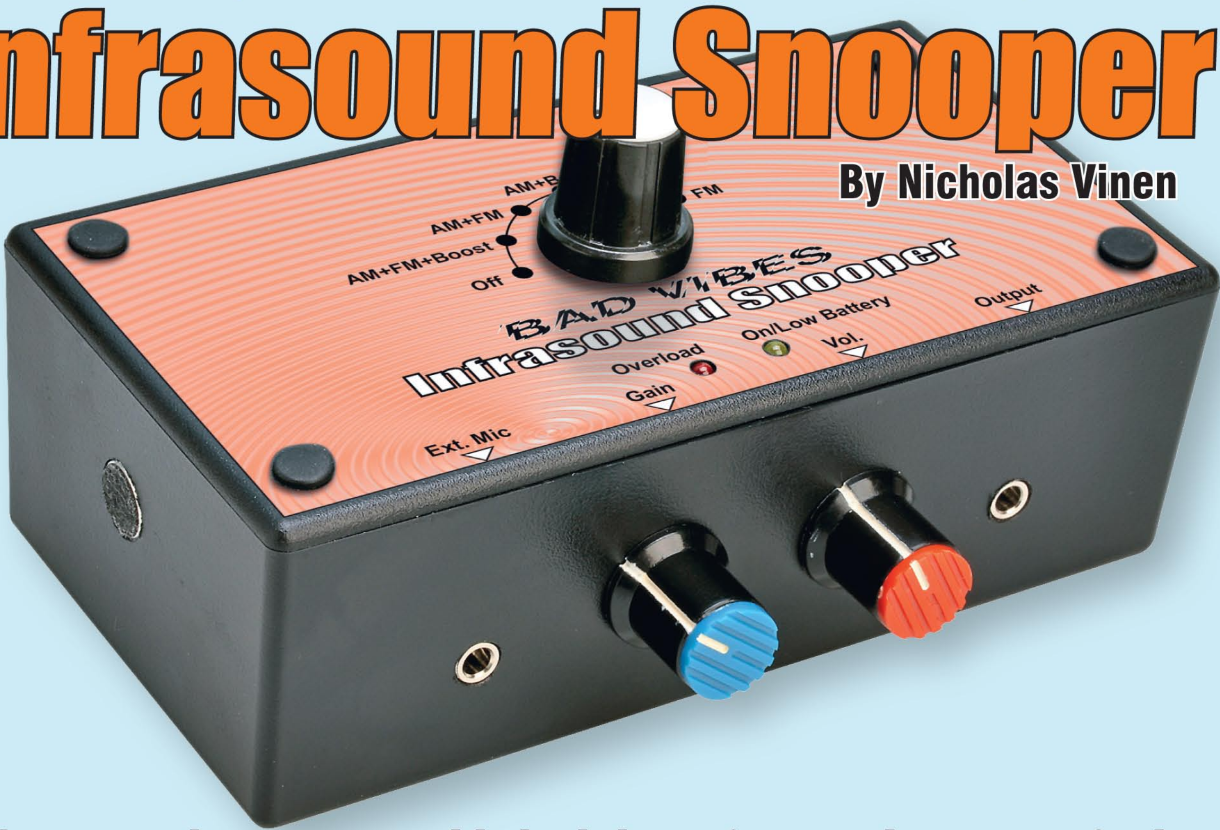
Did you say Sir Arthur C. Clarke? 'Twas indeed he who proposed the use of geostationary satellites for communication purposes in the February 1945 issue of *Wireless World* magazine. He followed up this letter with a fully worked-out article in October of that year (**http://lakdiva.org/clarke/1945ww**). But, five years previously someone else beat him to it. This was another Brit by the name of John Bray, who later became Director of Research for Post Office Telecommunications (a little before it became British Telecom). His proposal was considered 'moonshine' at the time by his superiors, but he was unperturbed and went on to play a key role in global satellite communications. His prophetic words follow.

'Sitting in an armchair on the lawn at home in that summer of 1940, I began to consider the possibility of using the Moon as a passive communication satellite by beaming radio waves at its surface and picking up the scattered waves at any other location on Earth from which the Moon was visible. It might thus serve as a means of telegraph or telephone communication — for example, of encoded signals for military purposes.

'Calculations showed that, with microwave powers of about 1kW and dish aerials some three metres in diameter, the radiated energy could be concentrated in a beam about 0.5 degree wide that could illuminate the Moon at a distance of 250,000 miles and produce a scattered signal energy at the receiver adequate for a telephone channel of usable quality. However, the two-way transmission delay due to the finite velocity of radio waves, 186,000 miles per second, was about 2.5 seconds — unimportant for telegraph communication but a handicap for normal telephone conversation.'

The Bad Vibes Infrasound Snooper

By Nicholas Vinen



Back in March 2014 we published the *Infrasound Detector* for low frequency measurements. Now you can 'listen' to low frequency vibrations with our *Infrasound Snooper*. It frequency shifts and amplitude modulates a frequency range of about 1Hz to 20Hz by about five or six octaves so that you can listen directly to wind turbines or elephants, crocodiles and other animals that communicate with infrasound.

OUR *Inftasound Snooper* uses digital signal processing (DSP) techniques in a PIC32MX170 microcontroller, an electret microphone, a DAC chip, a TL074 quad op amp and very little else, to drive a pair of headphones.

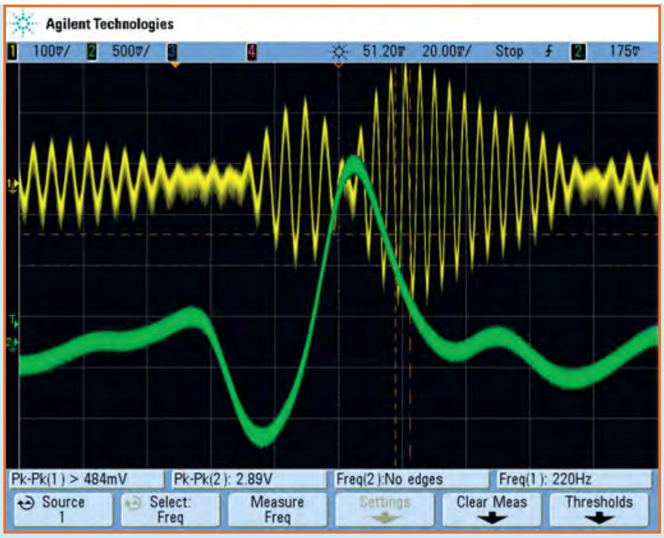
High levels of infrasound may have a negative impact on your health but you might not even know when you are being exposed to low frequency vibrations unless they excite harmonics by rattling window panes and similar, because they're otherwise inaudible.

In January last year, a study by Steven Cooper of Bridgewater Acoustics attracted a great deal of controversy over its findings which support the notion that infrasound from wind turbines can cause negative health impacts on people some distance away.

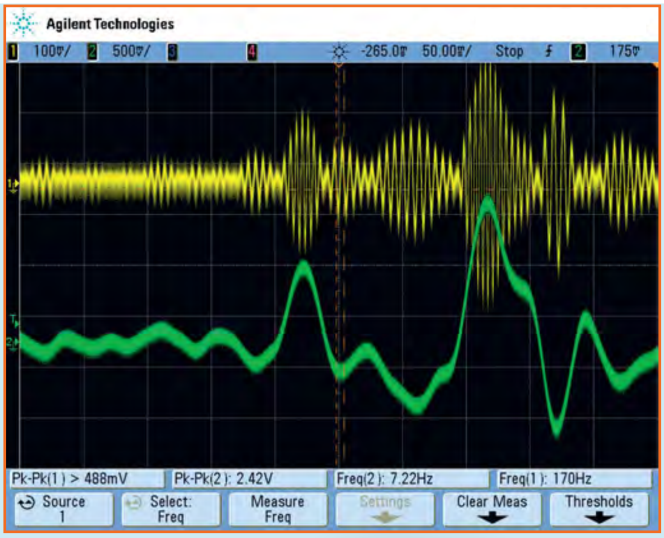
At the author's offices, some staff recently experienced ill effects, including headaches and nausea, when a ground compacting machine was operating on a nearby building site. It evidently set up all sorts of standing waves in our building, as it moved around the construction site. Some 'nodes' in our building were quite unpleasant places to be.

So if you are living or working near potential sources of infrasound and are suffering from some of the potential symptoms, our *Infrasound Snooper* can certainly help.

Our *Infrasound Detector* (*EPE*, March 2014) allows you to measure the amplitude and frequency of infrasonic sound waves, but the results can be somewhat difficult to interpret since you cannot hear the phenomenon. The *Infrasound Snooper* lets you assess the amplitude and frequency of the waves but importantly, you can also hear the details – whether they



Scope1: amplified infrasound output from IC2c (green) and the modulated signal to the headphones (yellow) for a low-frequency impulse of about 10Hz. The mode is AM+FM with low-frequency boost and you can see the output frequency shifting for the positive/negative infrasound signal as well as the delay from the low-frequency boosting filter.



Scope2: a similar impulse at a longer timebase than Scope1 (50ms/div rather than 20ms/div). The mode is AM+FM without low-frequency boost and thus the output waveform modulation corresponds very closely to the green input signal excursions. As before, positive excursions produce higher modulated frequencies than negative excursions.

are short, repetitive bursts, continuous waves or somewhere in between.

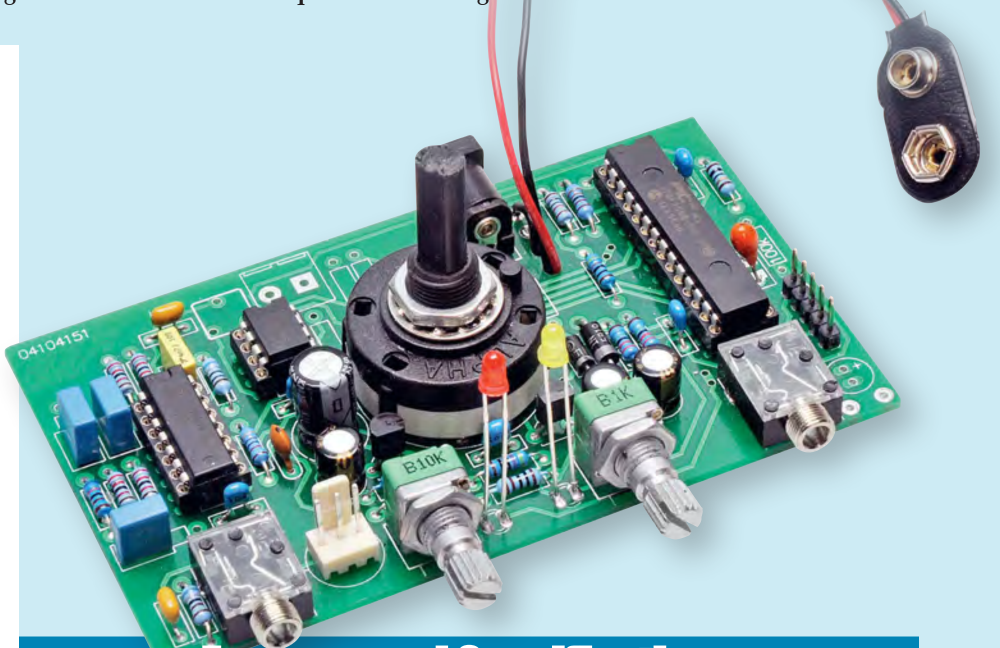
Our *Infrasound Snooper* is housed in a small plastic box and uses a double-sided PCB, which is available from the *EPE PCB Service*, (code 04104151) measuring 104 × 60.5mm. An electret microphone is mounted at one end of the case and a rotary switch on the lid offers a number of different listening modes.

Circuit description

Fig.1 shows the circuit details. Infrasonic sound waves are sensed with the electret microphone (MIC1) or an external microphone plugged into CON4. A 6.8kΩ pull-up resistor from the 5V regulated rail provides the electret's operating current.

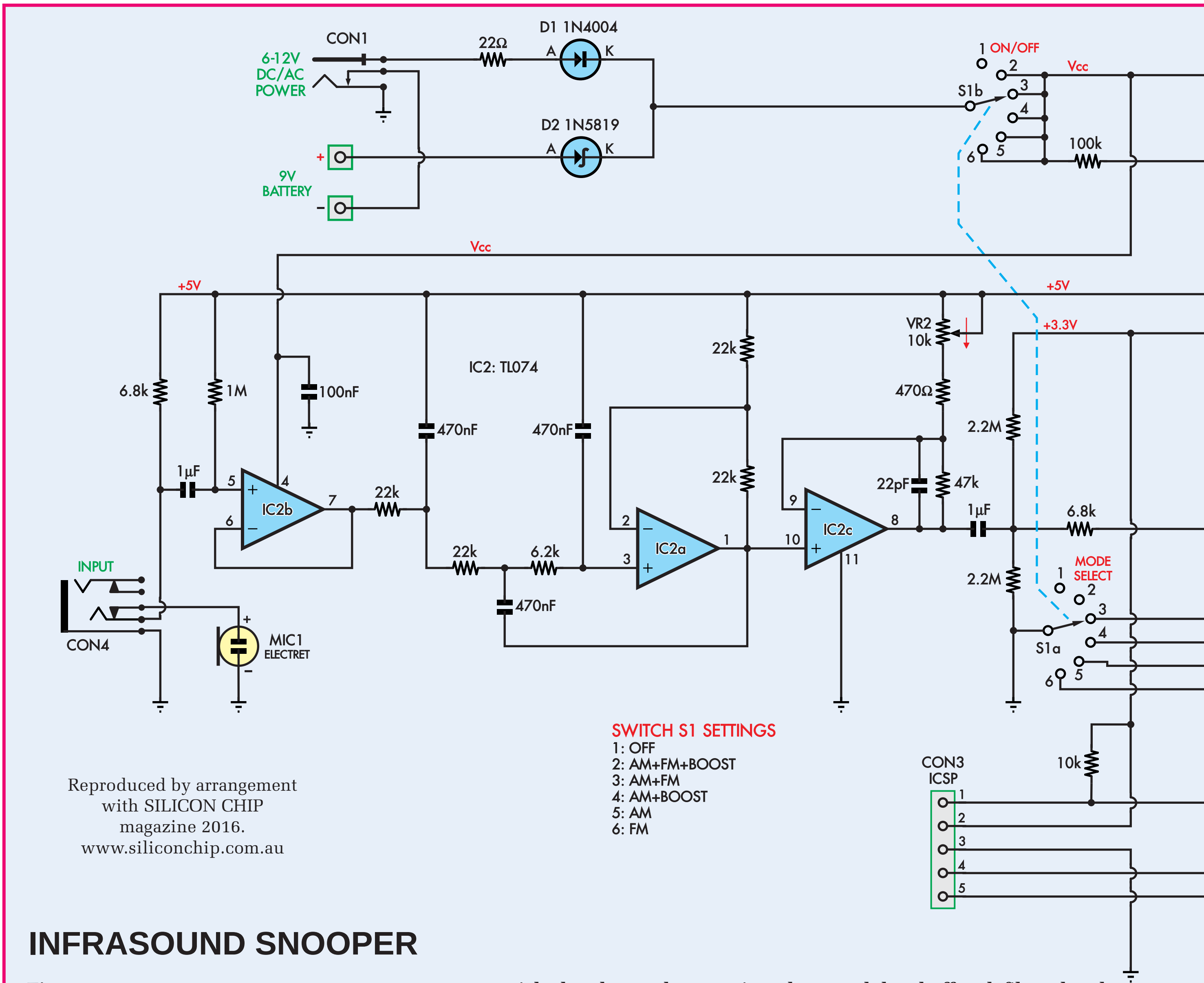
The electret signal is AC-coupled via a 1µF capacitor to the non-inverting input of op amp IC2b, one section of a TL074 quad JFET-input op amp. In conjunction with the 1MΩ resistor, this capacitor forms a low pass filter with a –3dB corner frequency at 0.2Hz. Thus, signals above 0.5Hz pass through with little or no attenuation. The 5V rail is used as a convenient DC bias point to bring the signal within IC2's supply rails, ie, roughly half-way between 0V and V_{CC} which is typically 8.7V.

IC2b operates as a simple buffer, feeding the following third-order active low-pass filter based around op amp stage IC2a, which has a gain of



Features and Specifications

- Converts infrasonic sound waves to audible waves via frequency shift modulation
- Minimal delay between detection of infrasound and audible response; operates essentially in real time
- Output volume proportional to infrasonic wave amplitude
- Output pitch deviation indicates infrasonic wave polarity
- Optional digital filter to compensate for typical low-frequency microphone roll-off
- Quick response time allows listener to determine nature of infrasound (pulsed, continuous) as well as frequency and amplitude
- Operating input frequency range: approximately 1-20Hz
- Power supply: 9V battery, ~60mA current drain (9-15V DC plugpack can also be used)
- Five modes: AM+FM with or without microphone response compensation, AM only with or without microphone response compensation, FM only (fixed amplitude)



INFRASOUND SNOOPER

Fig.1: the complete circuit diagram. The infrasound is picked up by an electret microphone and then buffered, filtered and amplified by IC2b-IC2a before being fed to microcontroller IC1. IC1 digitises the signal and carries out the necessary signal processing before feeding it to DAC IC3. IC3 then feeds gain stage IC2d, which in turn drives the output socket (CON5).

two (set by the pair of 22kΩ resistors at its pin 2). The filter is a Butterworth type, which is pretty much flat from DC up to 20Hz, with gain rapidly falling off at higher frequencies.

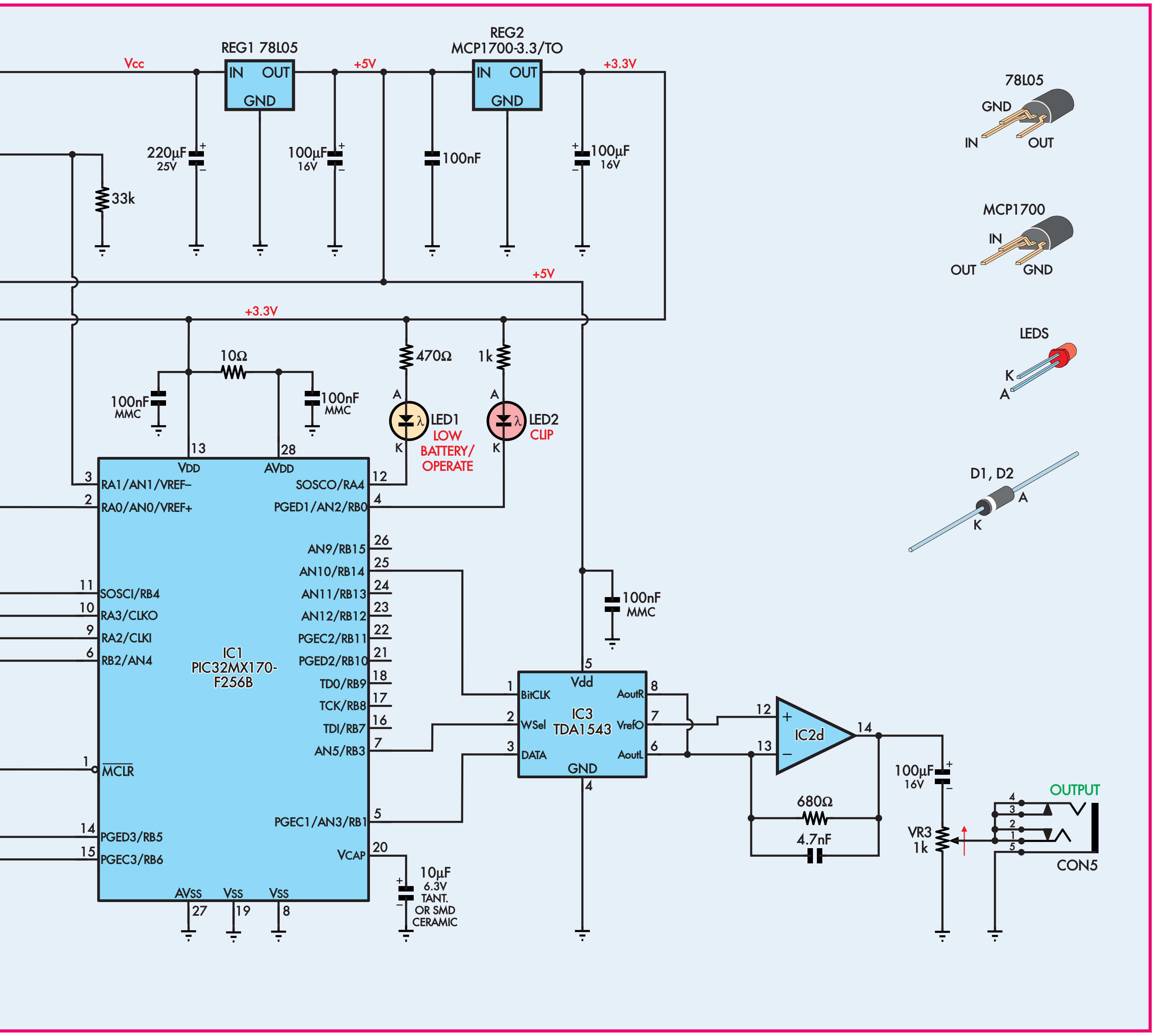
This is important because we need to apply a fair bit of gain to the infrasonic signals to scale them to an appropriate level for the microcontroller's ADC (~1V RMS). Op amp IC2c provides the requisite gain, which is variable using VR2. So the gain ranges from a minimum of 6 (47kΩ ÷ (10kΩ + 470Ω) + 1) to a maximum of around 100 (47kΩ ÷ (470Ω + W) + 1, where W is VR2's wiper resistance). Thus, VR2 acts as the unit's sensitivity adjustment.

The signal must then have its DC bias shifted to suit the ADC of the PIC32MX microcontroller, which runs from a 3.3V regulated rail. Therefore, it is AC-coupled with a 1μF capacitor and biased with a pair of 2.2MΩ resistors forming a voltage divider between the 3.3V rail and ground. This sets the DC level at pin 2 of IC1 at around 1.65V. The 6.8kΩ resistor protects IC1 from high voltages from IC2 during power-up, power-down and high signal excursions.

IC1 digitises the signal and then applies some DSP-based filtering to correct for low-frequency roll-off due to the two coupling stages and the microphone's response. To create an audible signal, the infrasound signal is rectified and then used to amplitude modulate a sinewave at about 200Hz.

Some frequency modulation is normally also applied to this waveform, based on the pre-rectification signal. This allows the polarity of infrasonic excursions to be distinguished, based on the difference in resulting signal frequency.

This modulated signal appears in digital (I^2S) format at pins 5, 7 and 25 of IC1. The serial audio data is produced at pin 5 (RB1) which is mapped to one of the two internal SPI peripherals so



that the data stream is uninterrupted. This data is clocked by a signal from pin 25 (RB14/SCK1). The left/right 'word' clock is produced at pin 7 (RB3), also by the SPI peripheral, using its audio framing feature.

These three signals pass to IC3, a TDA1543 16-bit oversampling DAC. We've used this chip for a number of reasons: it's available in an 8-pin DIL package that is easy to solder; it runs from a single 5V rail; it's quite cheap; it's easy to interface to and its audio performance is respectable.

Its outputs at pins 6 and 8 are current sink stages and since we only need a mono signal, they are simply connected together, filtered (to remove the digital aliasing artefacts) and converted to a voltage by remaining op amp IC2d. The 680Ω resistor sets the output voltage swing.

IC2d's pin 12 non-inverting input is connected to the 2.2V reference voltage which sets the DC level of the resulting signal. The Vref (pin 7) of IC3 has a dual purpose; the current drawn from this pin is internally amplified and added to the current sink by the left and right output pins. However, in this case, the circuit works best with no extra current sink, hence there is no load on the Vref pin.

The DC in IC2d's output is blocked by a 100µF electrolytic capacitor and biased to ground by the track of VR3, the volume potentiometer. The headphones or earphones are connected to its wiper via CON5 with no extra buffering. This is a relatively crude system, but it works well enough. The main purpose is to allow the user to reduce the output to a comfortable level when used in conjunction with sensitive earphones.

Power supply

The *Infrasound Snooper* is designed to run off a 9V battery, but a 9-15V DC plugpack can be used. The supply current therefore flows through one of two

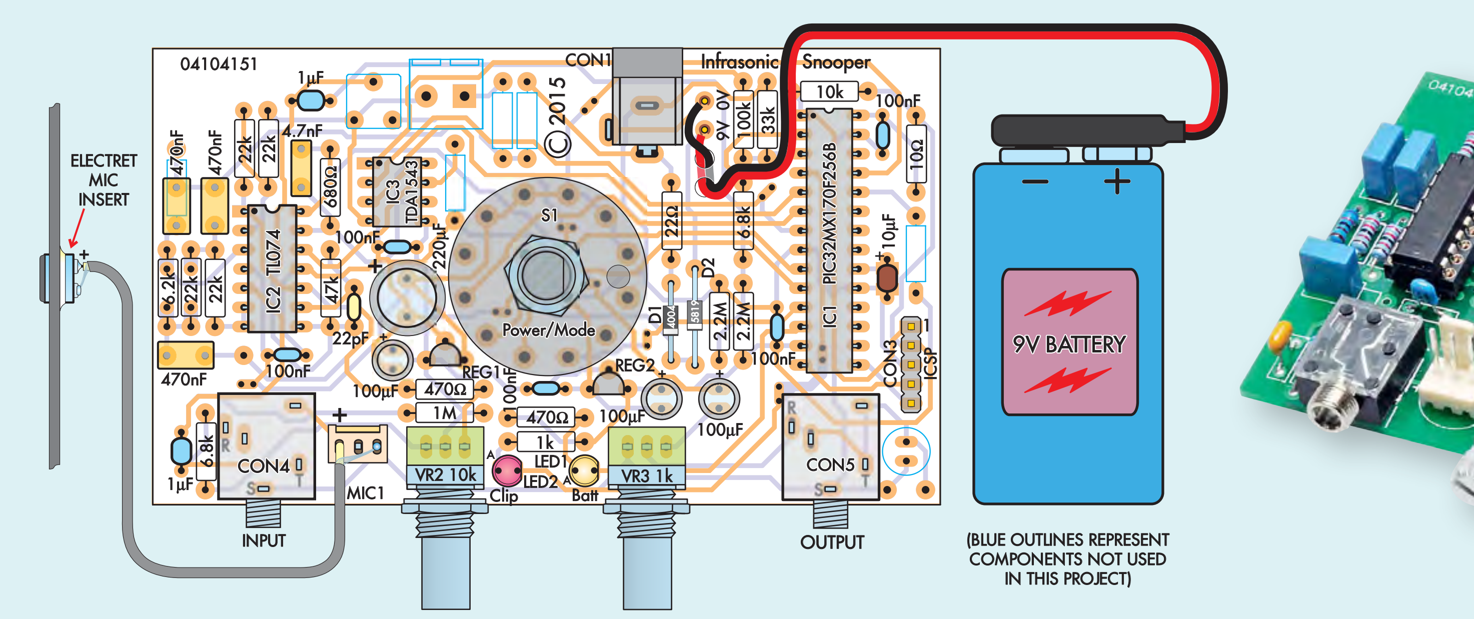


Fig.2: follow this parts layout diagram to build the PCB. Take care to ensure that all polarised parts are correctly oriented and use a socket for microcontroller IC1. Sockets are optional for IC2 and IC3.

reverse-polarity protection diodes, D1 for the plugpack or D2 for the battery. D2 is a Schottky diode to minimise voltage drop and hence extend battery life.

Rotary switch S1 acts as both the power and mode switch. One pole connects the power supply directly to IC2 as well as to the input of REG1. This regulator provides the 5V rail for DAC IC3, the electret supply and for signal biasing in the input filter. It also feeds REG2, a 3.3V low-dropout regulator that powers microcontroller IC1.

The other pole of S1 is connected to pins 6, 9, 10 and 11 of IC1, which are configured as inputs with internal pull-up currents enabled. Thus, IC1 can sense which position S1 is in by determining which of these inputs is pulled low. If none are, then the switch must be in the second position, as the circuit is not powered in the first position.

IC1 monitors the battery voltage via a 4:1 divider (100kΩ/33kΩ), digitising the resulting voltage at its AN1 analogue input (pin 3). If the battery voltage is low (<7V), it illuminates the low-battery LED (LED2) via its pin 12 output (RA4). The 470Ω current-limiting resistor sets the LED current to around 2-3mA.

Similarly, IC1 can light LED1 if there is an input signal overload, using its pin 4 output. The red LED is a little more efficient, so it operates at a lower current with a 1kΩ current-limiting resistor, resulting in around 1-1.5mA flowing.

CON3 is a programming header for IC1 (if required) with a 10kΩ pull-up resistor on its MCLR pin (pin 1) preventing unexpected reset events. IC1's analogue supply at pin 28 is low-pass filtered with a 10Ω resistor and 100nF bypass capacitor, while a 10µF capacitor at pin 20 is required for its internal core regulator.

Construction

All the parts except for the electret microphone are mounted on a double-sided PCB, which is available from the *EPE PCB Service*, coded 04104151 (104 × 60.5mm). This can be clipped into a standard UB3 jiffy box.

Fig.2 shows the parts layout on the PCB. Start by fitting the fixed resistors. Table 1 shows the resistor colour codes, although it's better to check the values using a DMM. Note that since the same PCB was used for the *Low Frequency Distortion Analyser* (*EPE*, April 2016) there are a number of component positions which are not populated (including some resistor locations).

Diodes D1 and D2 can go in next, noting that D1 is a 1N4004 while D2 is a 1N5819. Be sure to orient them correctly, with their striped cathode ends towards the bottom edge of the PCB.

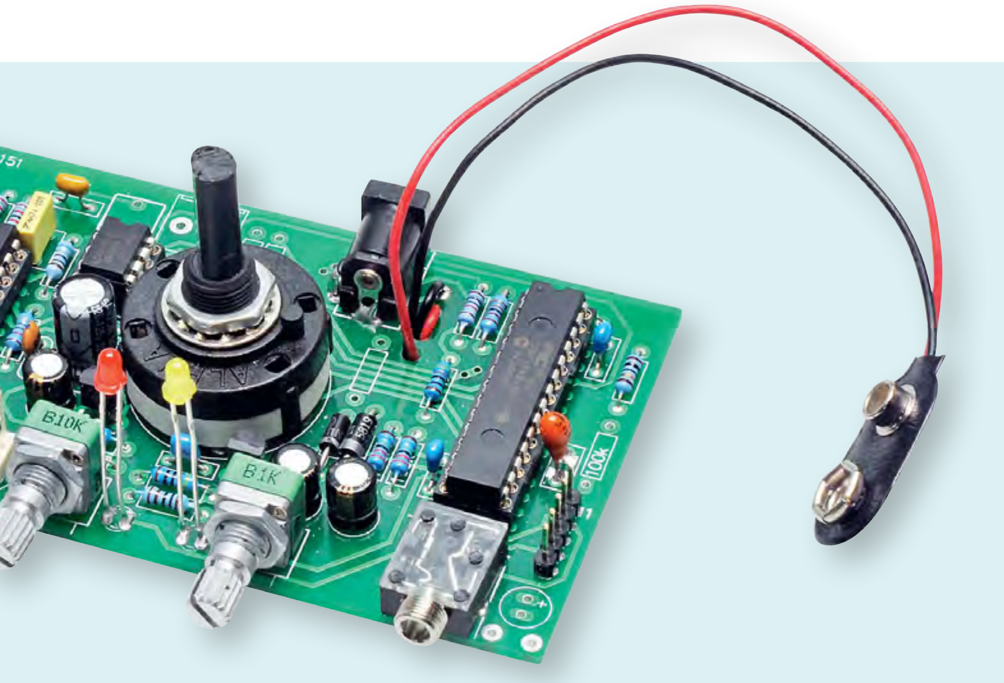
Follow with the IC socket(s). It's a good idea to use a socket for microcontroller IC1, but they are not really necessary for IC2 and IC3. Instead, IC2 and IC3 can be soldered directly to the PCB for greater long-term reliability. Either way, make sure that the pin 1 notch/dot of each IC goes towards the top of the board. This is vital if soldering the ICs in without sockets, since you can't easily remove them once they're in!

The two jack sockets are next on the list, followed by the ceramic and MKT capacitors. REG1 and REG2 can then go in, but be careful not to get them mixed up as they look similar. Their leads will need to be cranked out using needle nose pliers to suit the pad spacing on the PCB.

Now solder the DC socket in place, followed by the electrolytic capacitors. Be sure to orient them correctly, with the longer (positive) leads towards the top edge of the PCB (see Fig.2). If using a tantalum type rather than an SMD ceramic for the 10µF capacitor, it too is polarised and can go in now.

Now fit the two 9mm potentiometers. They're different values so don't get them mixed up (the 1kΩ pot may be marked '102' and the 10kΩ pot '103'). The polarised 3-pin header (for the microphone) can then be fitted with its keyway tab oriented as shown.

The battery snap is next. Pass its leads through the two strain relief holes before soldering its leads to their respective pads on the top of the PCB, as shown in Fig.2. You can then pull the leads back through the holes to reduce the slack. Note that they will probably be a tight fit, to provide the necessary strain relief.



This view shows the completed PCB assembly. Note how the battery snap leads are looped through strain relief holes before being soldered to the top of the PCB.

Table 2: Capacitor Codes

Value	µF Value	IEC Code	EIA Code
1µF	1µF	1u0	105
470nF	0.47µF	470n	474
100nF	0.1µF	100n	104
4.7nF	.0047µF	4n7	472
22pF	NA	22p	22

The two 3.5mm switched jack sockets (CON4 and CON5) can now be mounted. Check that they sit flush against the PCB before soldering their pins. CON3, the ICSP header, can then go in – but can be omitted if you're using a pre-programmed microcontroller.

Rotary switch S1 is mounted after first cutting its shaft so that it's 30mm long, as measured from the top surface of the main body. This can be done using a hacksaw and the end of the shaft then cleaned up with a file to remove any burrs. It must be installed with its polarity-indicating plastic post oriented as shown on Fig.2 (ie, at the three o'clock position). Again, make sure it's pushed down flat against the board before soldering its pins.

Finally, solder the two LEDs in place. The longer leads are the anodes and go into the pads indicated with 'A' on Fig.2. Tack solder these in place at full lead length; you can adjust the height and solder them properly once the box has been prepared.

Microphone cable

The next job is to make up a cable to connect the microphone. That's done using a 70mm length of light-duty Fig.8 cable that is terminated at one end in a 2-way polarised header.

Begin by removing about 3mm of insulation from the leads at each end of the cable, then carefully solder and crimp the leads at one end to the header crimp pins. That done, the crimp pins can be slid into the header (the tang goes into the narrow channel) until they lock into position.

The next step is to determine which lead on the electret microphone is the positive and which is the negative. This may be marked, but if not, use your DMM (set to ohms) to determine which lead is connected to the case – this is the negative (ground) lead.

Next, slip 5mm-lengths of 3mm-diameter heatshrink over the insulation at the end of the cable leads, then solder these two leads to the microphone. Make sure that the positive lead from the header goes to the electret positive (the positive side is marked on the PCB, adjacent to CON4).

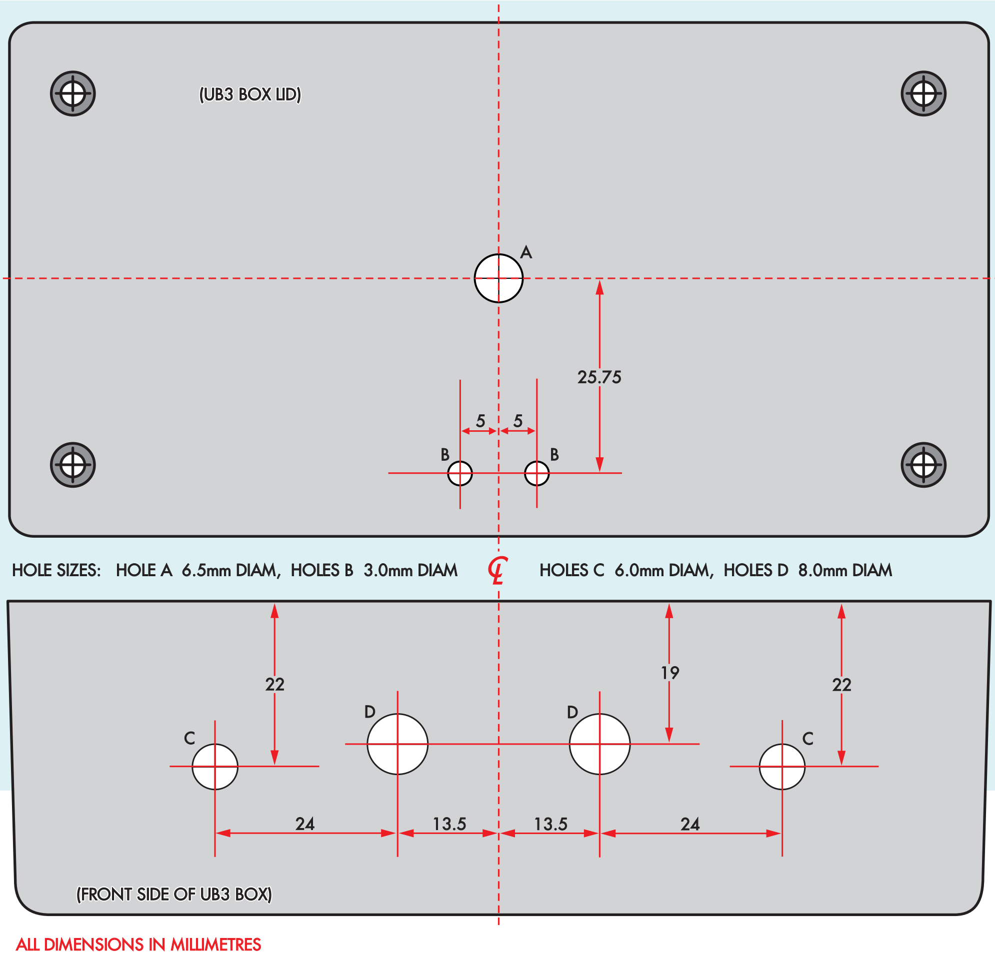
Once the two leads have been soldered, slip the heatshrink sleeves over the solder connections and shrink them down to provide strain relief (see photo).

Testing

If using sockets, plug in the ICs, with their pin 1 dot or notch aligned as shown in Fig.2. If IC1 hasn't already

Table 1: Resistor Colour Codes

❏	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❏	2	2.2MΩ	red red green brown	red red black yellow brown
❏	1	1MΩ	brown black green brown	brown black black yellow brown
❏	1	100kΩ	brown black yellow brown	brown black black orange brown
❏	1	47kΩ	yellow violet orange brown	yellow violet black red brown
❏	1	33kΩ	orange orange orange brown	orange orange black red brown
❏	4	22kΩ	red red orange brown	red red black red brown
❏	1	10kΩ	brown black orange brown	brown black black red brown
❏	2	6.8kΩ	blue grey red brown	blue grey 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
❏	1	680Ω	blue grey brown brown	blue grey black black brown
❏	2	470Ω	yellow violet brown brown	yellow violet black black brown
❏	1	22Ω	red red black brown	red red black gold brown
❏	1	10Ω	brown black black brown	brown black black gold brown



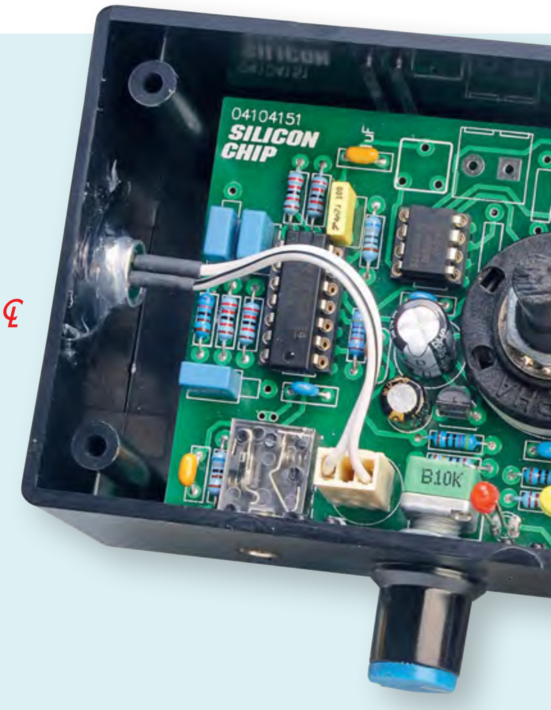


Fig.3 (left): use this full-size template to drill the holes in the lid and front side of the UB3 case.

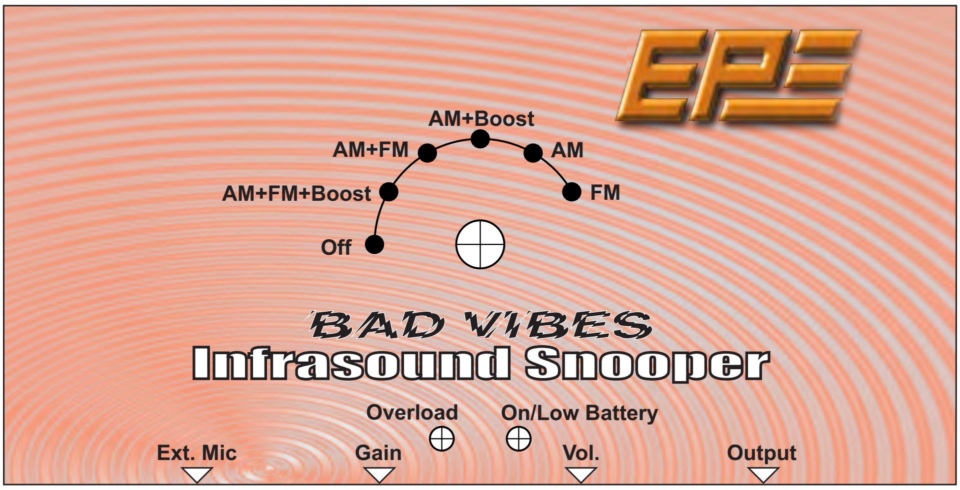


Fig.4: this front panel artwork can be copied and used direct or a PDF version can be downloaded from the *EPE* website and printed onto photo paper or onto Datapol/Dataflex label paper.

been programmed (you can buy a programmed micro from the SILICON CHIP Online Shop), do it now via CON3. External power can be supplied from the programmer (eg, a PICkit 3).

Once all the ICs are in place, you can test the unit as follows:

1) Rotate S1 to the off position (fully anti-clockwise), then connect the battery.
2) Rotate S1 one step clockwise and check that the yellow LED flashes briefly, then periodically.
3) Turn VR2 and VR3 all the way down and connect a pair of headphones or earphones to the unit.
4) Turn VR2 and VR3 up slowly and blow on the microphone insert. After turning the potentiometers up sufficiently, you should hear the modulated signal from the low frequency components of this sound. With the gain up high, if you blow hard enough, the overload (red) LED may light.
5) Switch S1 to the other positions and check that the sound produced by the unit changes.
6) Switch the unit off and remove the battery.

If it doesn't work as expected, carefully inspect the solder joints under magnification. Also check that the components are all in their correct positions and that the polarised parts (diodes, ICs, electrolytic capacitors) are oriented correctly.

Case preparation

If fitting the PCB into a UB3 jiffy box, you will need to drill four holes in the side of the case for the microphone input and headphone output sockets, plus the gain and volume adjustment knobs. The bottom section of Fig.3 shows the relevant drilling template – this can be copied (or downloaded from the *EPE* website and printed out) and temporarily stuck to the side of the case (eg, using double-sided tape).

Note that the top edge of the template must be aligned with the top edge of the box and centred horizontally.

The holes must be accurately placed. Start by drilling pilot holes (eg, 3mm) in each location and then enlarge them using larger drill bits, a stepped drill

Above: the PCB is a snapfit inside the case; the battery sits on a piece of non-conductive foam (see text).

bit or a tapered reamer. Clean up any burrs, then remove the nuts from the two jack connectors, screw the nuts and washers all the way onto the potentiometers and check that the connectors and pots fit through the holes.

If you want to be able to run the unit from a plugpack, you will also need to drill a 5.5mm hole in the other side, to allow access to the connector. The same template can be used; simply drill the hole for the power jack centred on the same location as that used for the volume control pot on the opposite side. If in doubt, check the location of the power socket on the board before drilling.

Fitting the microphone

A hole also has to be drilled in the lefthand end of the case for the electret microphone. The hole should be positioned about 16mm down from the top of the case and centred horizontally. Start by drilling a small pilot hole, then carefully ream the hole out until the microphone is a tight fit.

Once the mic fits, adjust it so that its face is flush with the outside of the case. It can then be secured inside the case using a small amount of neutral-cure silicone adhesive and the assembly placed aside to cure while the case lid is drilled.

Front panel drilling

Three holes are required in the case lid, for the two LEDs and switch S1. The drilling template is at the top of Fig.3 and it's just a matter of drilling the holes to size and checking that the LEDs and switch shaft fit.

The next step is to make and attach the panel label (Fig.4). This can be copied or downloaded and printed onto photo paper and affixed to the panel using silicone adhesive. Alternatively it can be printed onto Datapol/Dataflex label paper and stuck onto the lid. The three holes are then cut out using a sharp hobby knife.

Final assembly

Assuming that the silicone around the microphone has cured, the PCB can now be installed in the case, it's just a matter of angling the front of the board down so that the sockets and pot shafts go into their respective holes, then pushing down on the back of the board until it snaps into the integral side-rails. If it won't go in, you may need to enlarge the holes slightly.

Now trial fit the lid. If the LED heights are wrong, you will need to remove the PCB and adjust them accordingly. Once they fit properly, re-solder their leads and re-install the board in the case. The potentiometer nuts can then be wound forwards until they're against the inside face of the case.

Next, rotate S1 to off (fully anticlockwise), then connect the battery and place it on top of the PCB with a piece of non-conductive foam sandwiched in between. This will prevent

Parts List

- 1 double-sided PCB, available from the *EPE PCB Service*, coded 04104151, 104 × 60.5mm
- 1 UB3 jiffy box (optional)
- 1 10kΩ 9mm single-gang potentiometer (VR2)
- 1 1kΩ 9mm single-gang potentiometer (VR3)
- 1 28-pin narrow DIL IC socket
- 1 14-pin DIL IC socket (optional)
- 1 8-pin DIL IC socket (optional)
- 1 piece non-conductive foam, approximately 65 × 40 × 8mm
- 1 PCB-mount DC socket (CON1)
- 2 3.5mm switched jack sockets (CON4,CON5)
- 1 2-pole 6-position rotary switch (S1)
- 1 medium-sized knob, to suit S1
- 2 small knobs, to suit VR2 and VR3
- 1 9V battery snap (BAT1)
- 1 9V alkaline battery (BAT1)
- 1 pair headphones or earphones
- 1 5-pin header, 2.54mm pitch (CON3) (optional – see text)
- 1 PCB-mount electret microphone insert
- 1 3-pin polarised header, 2.54mm pitch (CON6)
- 1 3-way polarised header plug
- 1 70mm-length light duty figure-8 cable
- 1 10mm length 3mm-diameter heatshrink

Semiconductors

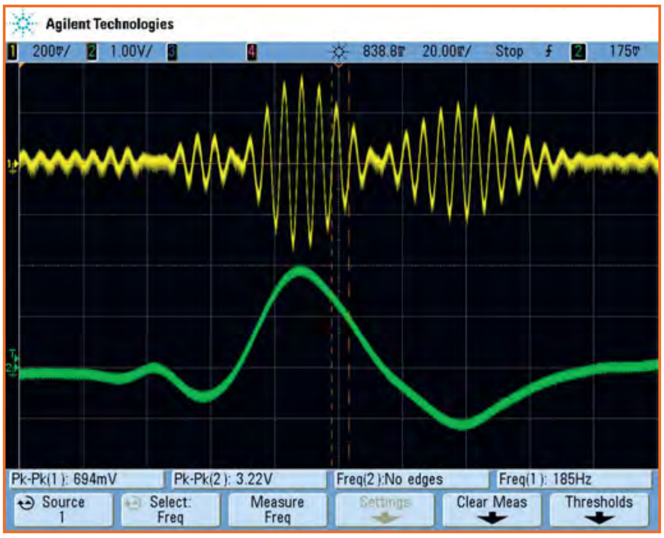
- 1 PIC32MX170F256B-I/SP 32-bit microcontroller programmed with 0420415A.HEX (IC1)
- 1 TL074 quad JFET-input op amp (IC2)
- 1 TDA1543 oversampling DAC (IC3)
- 1 78L05 5V regulator (REG1)
- 1 MCP1700-3.3/TO 250mA 3.3V LDO regulator (REG2)
- 1 red 3mm LED (LED1)
- 1 yellow/orange 3mm LED (LED2)
- 1 1N4004 1A diode (D1)
- 1 1N5819 1A Schottky diode (D2)

Capacitors

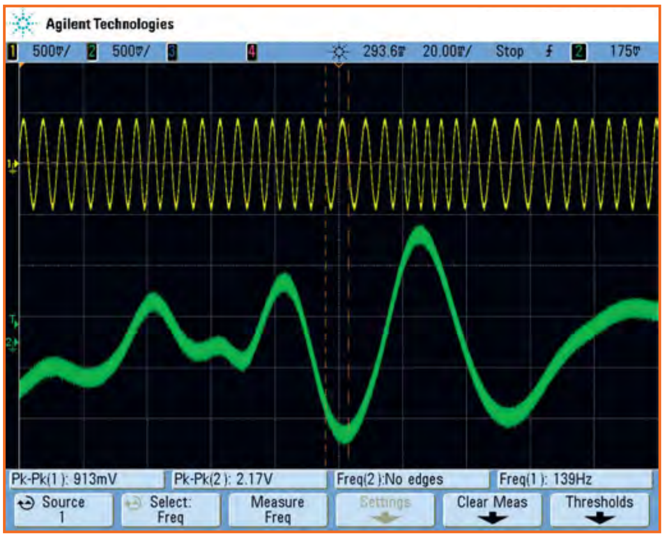
- 1 220µF 25V electrolytic
- 3 100µF 16V electrolytic
- 1 10µF 6V tantalum or SMD ceramic (1210/1206/0805)
- 2 1µF 50V multi-layer ceramic
- 3 470nF 63V/100V MKT
- 5 100nF 50V multi-layer ceramic
- 1 4.7nF 63V/100V MKT
- 1 22pF disc ceramic

Resistors (0.25W, 1%)

2 2.2MΩ	2 6.8kΩ
1 1MΩ	1 6.2kΩ
1 100kΩ	1 1kΩ
1 47kΩ	1 680Ω
1 33kΩ	2 470Ω
4 22kΩ	1 22Ω
1 10kΩ	1 10Ω



Scope3: amplitude modulation-only mode. The output frequency is fixed at around 185Hz and only its amplitude varies, increasing for either polarity of infrasound pressure wave excursion. Each waveform shown here is at maximum sensitivity and this is how the unit should be used unless it is overloading due to intense infrasound.



Scope4: frequency modulation mode. The signal amplitude is constant and high (generally the output volume should be turned down in this mode) and only the frequency changes in response to infrasonic waves picked up by the microphone. As before, the frequency increases for one polarity of wave and decreases for the other.

shorts and also stop the battery from rattling around inside the case.

Finally, screw the lid in place, then attach the knobs for S1, VR2 and VR3 (the jack socket nuts aren't required).

Using it

Typically, you would use the device with the gain somewhere near maximum and the volume adjusted to a level which is not excessive for the headphones or earphones being used. Due to the way the volume control works, this is likely to be somewhere near maximum too, although lower settings may be necessary for 'in-ear' earphones.

Sealed headphones or in-ear phones have the advantage that you can more easily determine the level of infrasound emitted from sources that also produce audible frequencies. That's because they will do a better job of blocking those audible frequencies out and allow you to more clearly hear the output of the device.

An example of this would be a door slamming shut. This can generate quite a significant infrasonic pulse, but it may be difficult to hear the unit's response against the audible noise of the door slamming. Other sources which can be used to test the unit include large air-conditioning units, passing trucks and large idling engines.

When using one of the frequency modulation (FM) modes, it is possible to determine the polarity of an infrasonic pulse. One polarity will produce a sound which increases in frequency while the other will produce a sound that decreases in frequency. Regular pulses from the same source will normally have a consistent polarity. Typically, a compression wave will precede an expansion wave.

Finally, note that a wind shield may be necessary for the microphone if the unit is used outdoors. As with the March 2014 *Infrasound Detector*, the windshield from a dynamic microphone could be used.

Alternatively, a separate external electret microphone (plugged into CON4) could be used instead of the inbuilt electret. Just make sure it has the required high sensitivity, a good low-frequency response and is able to operate from the ~0.5mA bias current supplied by the unit.

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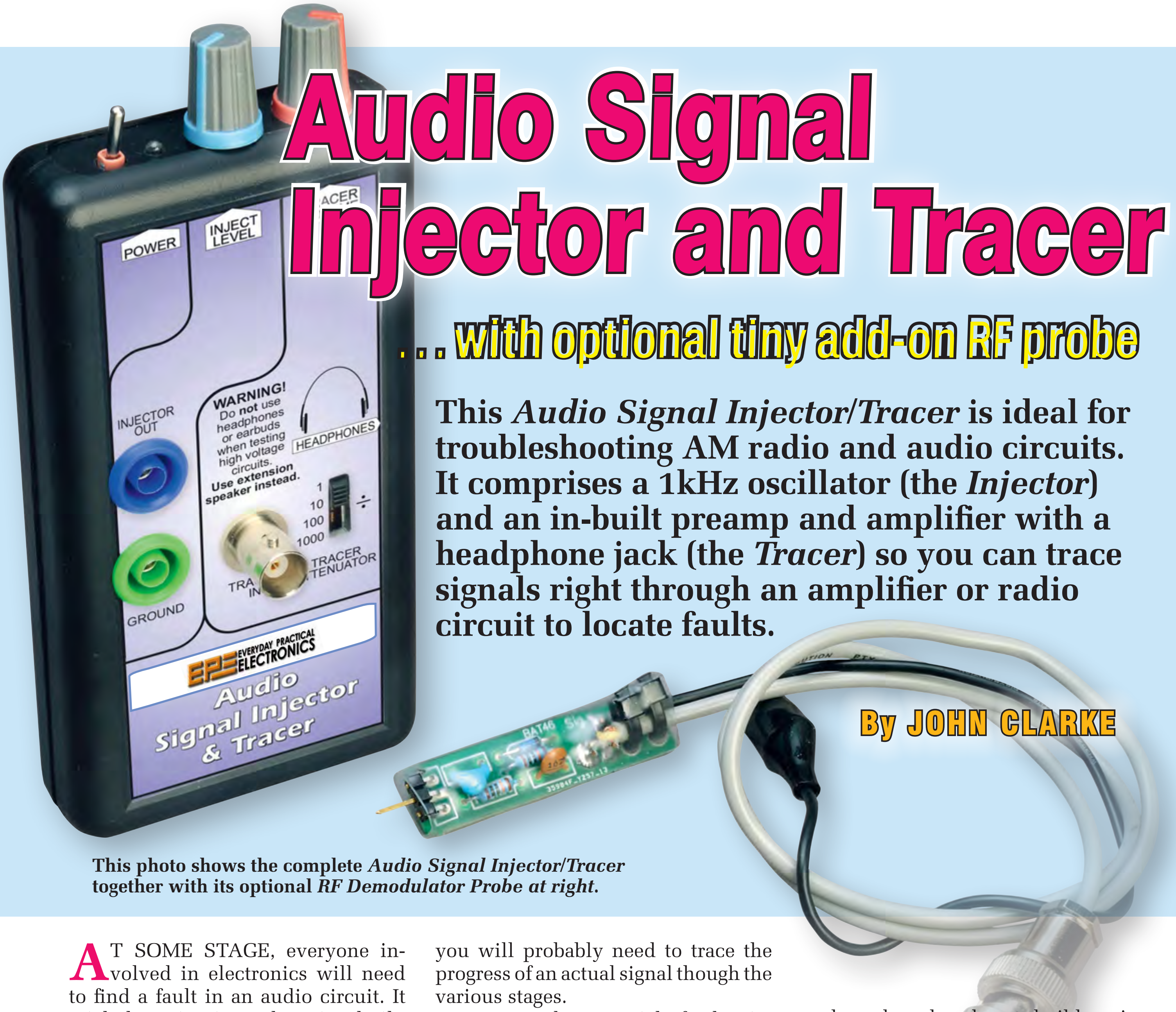
Audio Signal Injector and Tracer

...with optional tiny add-on RF probe

This *Audio Signal Injector/Tracer* is ideal for troubleshooting AM radio and audio circuits. It comprises a 1kHz oscillator (the *Injector*) and an in-built preamp and amplifier with a headphone jack (the *Tracer*) so you can trace signals right through an amplifier or radio circuit to locate faults.

By JOHN CLARKE



This photo shows the complete *Audio Signal Injector/Tracer* together with its optional *RF Demodulator Probe at right*.

AT SOME STAGE, everyone involved in electronics will need to find a fault in an audio circuit. It might be a circuit you have just built, a repair job for a friend or a job to be done in your workplace. And while you can often check voltages if you have a circuit diagram, sooner or later you will probably need to trace the progress of an actual signal though the various stages.

For example, you might feed a signal into the input and then find that it disappears as it feeds through a capacitor. The obvious conclusion would be that the capacitor is faulty (open) or it has not been properly soldered into circuit.

To do this sort of fault-finding, you need a suitable signal (one you can hear) and a small amplifier so you can listen to the signal at various stages in the amplifier or AM radio being tested. So, our *Audio Signal Injector/Tracer* has a 1kHz oscillator as the *Injector* and a small amplifier as the *Tracer*.

AM radio adds an extra complication because you need to listen to a modulated radio signal as it goes from stage to stage in the circuit. For that you need an optional RF demodulator probe and we show how to build one in the next article of this issue – it's tiny!

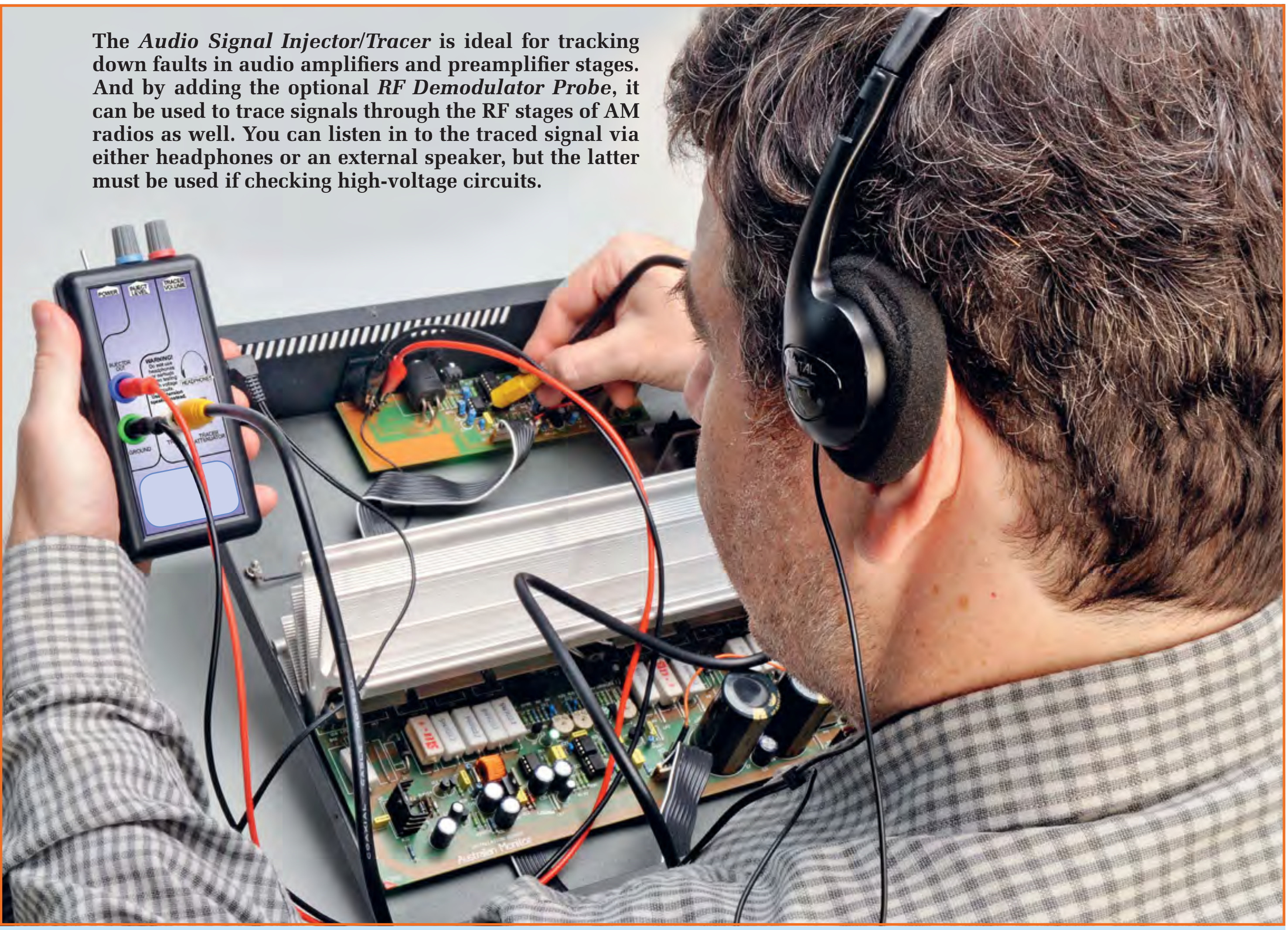
Mind you, if you are repairing an amplifier, you may not need the *Injector's* audio signal, provided you have a CD player or even a smart phone which has music tracks.

On the other hand, a music signal is not always ideal if you are using an oscilloscope and want to see if the signal becomes distorted at a particular stage in the circuit. In that case, you might find the *Injector* more convenient as you trace a signal of known shape through the circuit.

As mentioned, our *Injector* is a 1kHz oscillator and you can see the shape in the scope grab designated 'Scope 1'. It looks a bit like a sinewave, but is actually a somewhat 'rounded' square wave. It has a maximum amplitude of

Main Features

- Hand held and battery powered
- 1kHz injector output
- Adjustable injector level
- Tracer input attenuator
- Tracer volume control
- Audio output to headphones or small speaker
- Low battery indication
- Optional RF probe for AM modulation detection



The *Audio Signal Injector/Tracer* is ideal for tracking down faults in audio amplifiers and preamplifier stages. And by adding the optional *RF Demodulator Probe*, it can be used to trace signals through the RF stages of AM radios as well. You can listen in to the traced signal via either headphones or an external speaker, but the latter must be used if checking high-voltage circuits.

about 2V RMS but it can be adjusted down to just few millivolts.

This means it will cover virtually all signal tracing situations, from sensitive audio preamplifiers and the audio sections of AM/FM radios, right up to high-powered guitar and public address amplifiers.

Then we come to the *Signal Tracer*. It needs a small amplifier to listen to small signals in sensitive circuits, but it also needs an input attenuator so that it is not overloaded by the much larger signals, perhaps 50V or more, that you might find in a high-power amplifier. You also need a volume control so that your ears are not blasted as you step through a circuit.

Finally, both the *Injector* and *Signal Tracer* need to be protected from any high voltages that may be present in a solid-state or valve circuit. If you feed the *Injector* into a circuit operating at 300V DC, for example, you don't want it to be blown to shreds and by the same token, if you touch the *Tracer* probe onto a similar high-voltage point, you don't want it to be 'cooked'. Our circuit takes care of those possibilities.

Specifications

Power: 9V at 2.3mA

Tracer input impedance: ~6.45MΩ to 10MΩ, depending on attenuator setting

Tracer signal gain: adjustable from 2x to 20x

Tracer attenuator: 1:1, 1:10, 1:100 and 1:1000

Tracer signal frequency response: 70Hz to 3kHz

Injector signal: 1kHz rounded square-wave

Injector signal level: adjustable from 0-2V RMS (5.6V peak-peak) with a 9V supply

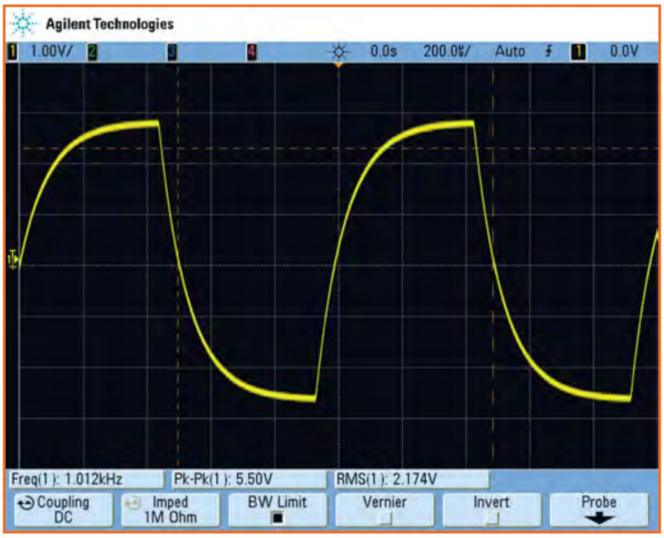
Headphone output: 6.6V peak-peak maximum into 16Ω with a 9V supply

Test circuit DC voltage: ±300V DC maximum recommended

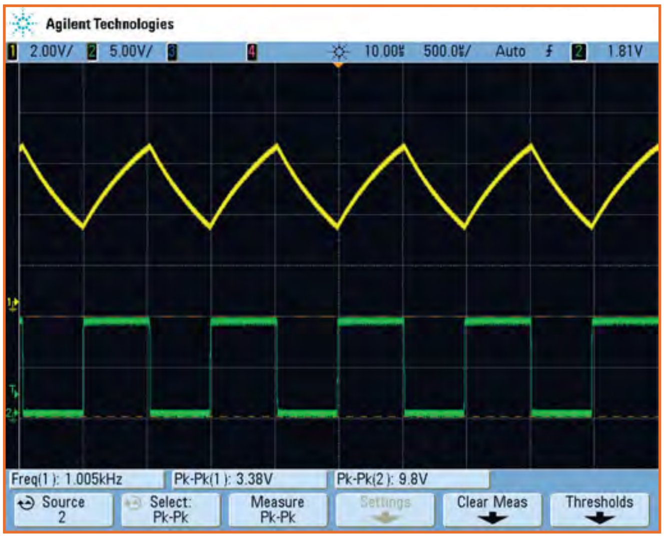
Our *Injector/Tracer* is housed in a compact plastic case with an internal battery compartment. It has a pair of jack sockets for the output of the *Injector* and a BNC socket for the input to the *Tracer*. Next to that socket lies a 4-position slide switch for the Attenuator, which has settings of 1:1, 1:10, 1:100 and 1:1000.

Input impedance

The input impedance of the *Tracer* is rather high, varying between about 10MΩ and 6.45MΩ, depending on the setting of the input attenuator. This means that the impedance of the



Scope 1: the 1kHz waveform generated by the oscillator looks a bit like a sinewave but is actually a 'rounded' square wave. It has a maximum amplitude of about 2V RMS but can be adjusted down to just a few millivolts.



Scope 2: this scope grab shows the Schmitt trigger operation of IC1a. The yellow trace shows the charging and discharging of the 6.8nF capacitor from 3V to 6V, while the green trace shows the resultant square-wave output at pin 1.

Tracer will not load down or affect the operation of the circuit being tested. The high-impedance input also means that the *Tracer* probe can be used to directly test ceramic (crystal) phono cartridges or piezoelectric pick-ups on musical instruments such as a violins.

To connect a signal to the *Tracer* you can use a 1:1 oscilloscope probe or any shielded cable with a BNC plug at one end and a suitable connector at the other, such as an RCA plug or a pair of alligator clips. More about this later in the article.

The on/off switch, a power LED and the two knobs for the *Injector* level and *Tracer* volume controls are at one end of the case, while the 3.5mm headphone jack is on the side, adjacent to the 4-position Attenuator switch.

Warning!

When using the *Audio Signal Injector/Tracer* with high-voltage circuitry (eg, in a valve radio), take care not to touch any part of the circuit with your hand. Always treat the circuit as though it has mains voltage present.

As stated in the article, use a small extension speaker rather than headphones when using the unit with high-voltage circuitry. Small non-powered extension speakers are available for use with iPods and similar MP3/MP4 players.

The use of a small speaker will remove the possibility of deafening clicks or even a high-voltage shock should there be a fault within the *Audio Signal Injector/Tracer* or if the earth lead becomes disconnected.

Circuit description

Let's now take a look at the circuit of the *Audio Signal Injector/Tracer* – see Fig.1.

As shown, it's based on an LMC6482AIN CMOS dual rail-to-rail op amp and a handful of other components. One op amp is used for the *Signal Injector* while the other is used for the *Tracer*. The output frequency of 1kHz is set by the 100kΩ resistor and 6.8nF capacitor connected to pin 2, the non-inverting input.

The three resistors connected to the pin 3 inverting input set the threshold voltage (at pin 3) at 1/3Vcc or 2/3Vcc, depending on whether the output of IC1a is high or low. So with Vcc = 9V, the input (threshold) voltage at pin 3 will be either +3V or +6V.

When power is applied to the circuit, the 6.8nF capacitor at pin 2 will be discharged (ie, 0V), so pin 2 will be lower than pin 3. Therefore, the output at pin 1 will be high (+9V) and this charges the 6.8nF capacitor via the 100kΩ resistor between pins 1 and 2. When the capacitor voltage rises just above 6V, pin 2 becomes higher than pin 3 and so the op amp's pin 1 output switches low, to 0V (remember, this is a 'rail-to-rail' op amp).

So now pin 3 is at 3V and the capacitor discharges via its 100kΩ resistor until pin 2 is just below pin 3, whereupon the pin 1 output goes high again to recharge the capacitor. This continuing cycle generates a 1kHz square wave that is filtered using a 6.8kΩ resistor and 22nF capacitor to give a 'rounded' waveform, as shown in Scope 1.

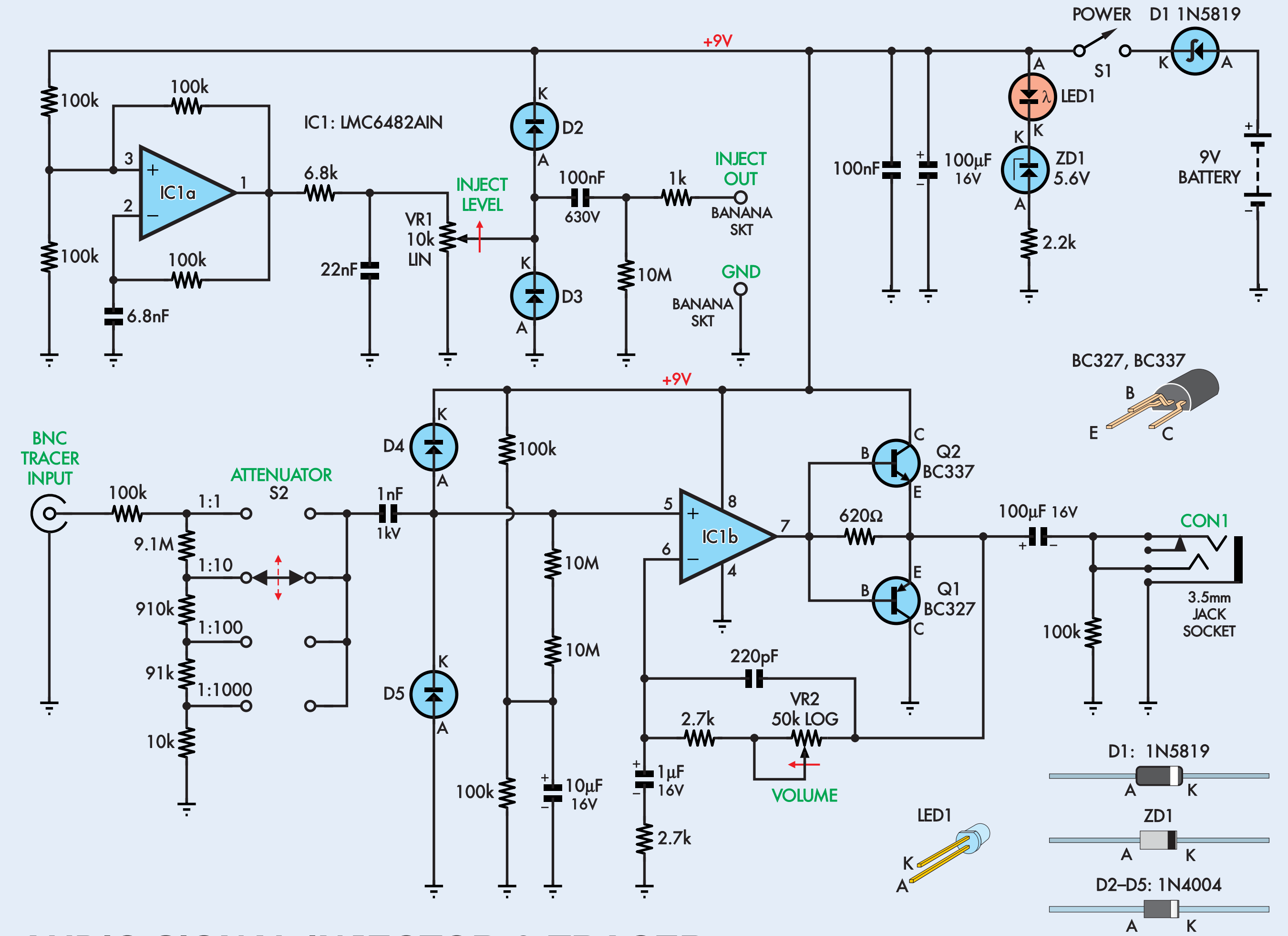
The Schmitt trigger operation of IC1a is demonstrated in Scope 2, which shows the charging and discharging of the 6.8nF capacitor from 3V to 6V in the yellow trace. The lower green trace shows the resultant square-wave output at pin 1. Note that the amplitude of the square-wave is shown as 9.8V – we used a fresh 9V battery.

Potentiometer VR1 connects across the 22nF capacitor to provide the *Injector* level control. This is AC-coupled to the output terminal via a 100nF 630V capacitor. We specified a high voltage rating for this capacitor so that the *Injector* output can be connected to a high voltage on the circuit under test without damage.

For the same reason, diodes D2 and D3 clamp any high voltage from an external circuit (eg, a valve radio being tested) at the wiper of VR1 to 0.7V above or below the 9V and 0V supply rails. The 10MΩ resistor across the 100nF capacitor is there to discharge the capacitor when it is disconnected from the circuit under test. The 1kΩ resistor in series with the *Injector* output limits peak current to the clamping diodes.

Tracer circuit

The input signal from the BNC socket is fed to 4-way slider switch, S2 and the attenuator resistors. The resistors



AUDIO SIGNAL INJECTOR & TRACER

Fig.1: the circuit is based on dual op amp IC1. IC1a operates as a Schmitt trigger oscillator and this generates the injector signal, with VR1 setting the output level. The traced signal is fed in via a switched attenuator and then fed to op amp IC1b. Its output signal is then buffered by Q1 and Q2 and fed to CON 1, while VR2 sets the op amp gain.

provide four division ratios of 1:1, 1:10, 1:100 and 1:1000.

Following S2, the signal is coupled via a 1nF 1kV ceramic capacitor to the pin 5 non-inverting input of IC1b. This is tied via two series-connected 10MΩ resistors to a voltage divider (two 100kΩ resistors) which provides a reference at 4.5V – ie, half the 9V supply.

Diodes D4 and D5 clamp any high voltage input signals to 0.6V above or below the 9V supply rails.

IC1b is connected as a non-inverting amplifier and its pin 7 output drives a complementary emitter-follower stage using transistors Q1 and Q2. These provide a buffered output to the headphone socket via a 100µF coupling capacitor.

Note that the emitter follower output stage is operated with no quiescent current, but is within the negative feedback loop of the op amp to minimise crossover distortion.

The 50kΩ volume control (VR2) is also in the op amp's feedback loop, connected in series with a 2.7kΩ resistor. In conjunction with the 1µF capacitor and series 2.7kΩ resistor from pin 6 to 0V, this allows the AC gain to be varied from between two and 20. The DC gain is unity, by virtue of the 1µF capacitor.

Note that while the amplifier is mainly intended to drive headphones, it can also be used to drive a small speaker and we recommend this if you are doing signal tracing in a high-voltage circuit which might cause deafening clicks when you touch the probe on high voltage points.

Power supply

As already noted, the circuit operates from a 9V battery, fed in via toggle switch S1. Diode D1 gives protection if the battery is inadvertently connected the wrong way around. A high-intensity red LED is used for power indication. It is bright when the supply is at 9V, but drops to a dim glow when the battery is flat, by virtue of ZD1, a 5.6V zener diode in series with the LED.

When the battery is fresh, ie, putting out 9V or maybe as much as 10V, we will have 1.8V across the red LED, 5.6V across ZD1 and 1.6V or more across the 1kΩ resistor, so that 1.6mA or more flows through LED1. As the voltage falls, the voltage across the 1kΩ resistor also falls. At a battery voltage of 7.4V or less, there is very little voltage across the 1kΩ resistor and so LED1 will be dim.

RF demodulator probe

As previously noted, if you want to troubleshoot an AM radio with the *Tracer*, you need to have an additional

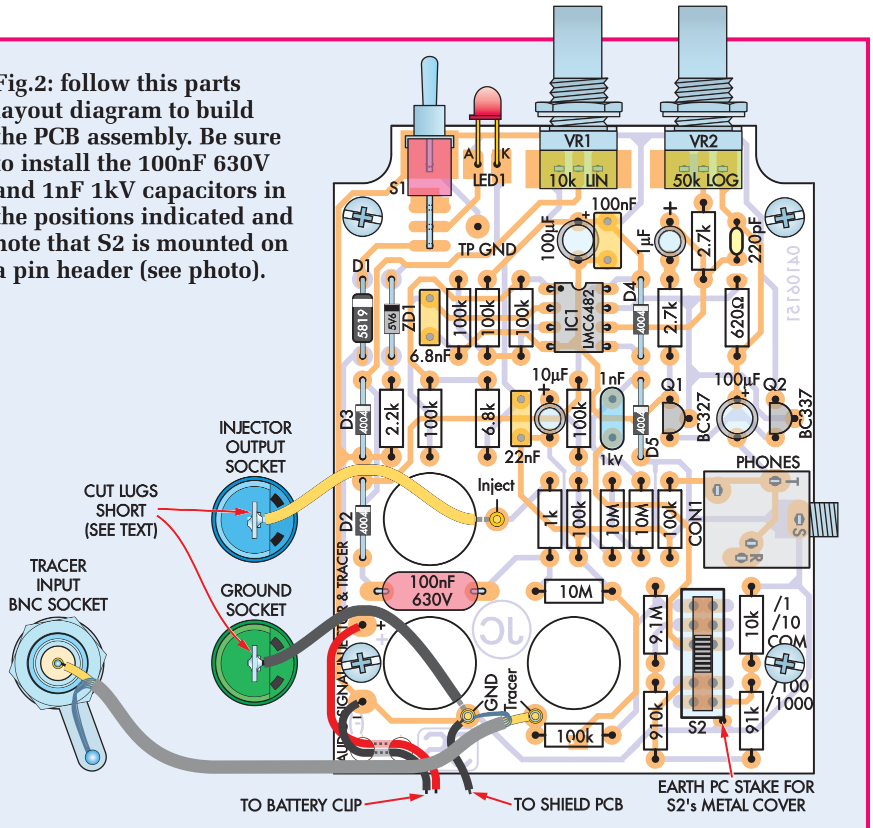
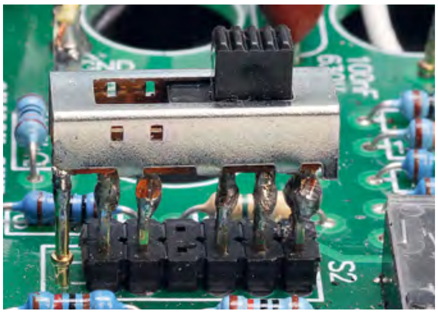


Fig.2: follow this parts layout diagram to build the PCB assembly. Be sure to install the 100nF 630V and 1nF 1kV capacitors in the positions indicated and note that S2 is mounted on a pin header (see photo).



This photo shows how switch S2 is mounted. It's soldered to a pin header so that its top metal face is 12.5mm above the PCB.

demodulator probe for the amplitude-modulated (AM) RF signals that should be present in the circuit being tested. As stated, a suitable RF demodulator probe is described in the next article.

Construction

The *Audio Signal Injector/Tracer* is built on a double-sided PCB, which is available from the *EPE PCB Service*, coded 04106151 (85 × 63mm). This is housed in a plastic remote control case measuring 135 × 70 × 24mm. A panel label measuring 114 × 50mm is attached to the front of the case.

To make the assembly easy, the PCB is designed to mount onto the integral mounting bushes within the case. The top of the PCB is also shaped to fit around the case mounting pillars at that end – see Fig.2 and photo.

Fig.2 shows the parts layout on the PCB. Begin by installing the resistors. Table 1 shows the resistor colour codes, but it's also a good idea to check each one with a digital multimeter before soldering it to the PCB.

The diodes can go in next. Note that there are two different types – D1 is a 1N5819, while D2-D5 are 1N4004s. Be sure to mount them with the correct polarity, then install zener diode ZD1, again taking care with its polarity.

The seven PC stakes can now be fitted. These are installed at the five external wiring points, at TP GND (near LED1) and at the bottom right of S2. IC1 can then be soldered in place. Do not use a socket for this IC, as this would exacerbate noise pick-up.

Installing switch S2

Switch S2 does not mount directly onto the PCB, but is instead raised off the PCB using a 6-way DIL pin header. Before installing this DIL header, remove a pin from each side so that there are three pins, then a gap, then two pins (ie, on each side of the header to correspond with the switch pins).

That done, position the header on the PCB with the longer pins facing upwards, then push each pin down so that it extends only 5mm above the top

Table 2: Capacitor Codes

Value	µF Value	IEC Code	EIA Code
100nF	0.1µF	100n	104
22nF	0.022µF	22n	223
6.8nF	0.0068µF	6n8	682
1nF	0.001µF	1n	102
220pF	NA	220p	221

Table 1: Resistor Colour Codes

❏	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❏	3	10MΩ	brown black blue brown	brown black black green brown
❏	1	9.1MΩ	white brown green brown	white brown black yellow brown
❏	1	910kΩ	white brown yellow brown	white brown black orange brown
❏	8	100kΩ	brown black yellow brown	brown black black orange brown
❏	1	91kΩ	white brown orange brown	white brown black red brown
❏	1	10kΩ	brown black orange brown	brown black black red brown
❏	1	6.8kΩ	blue grey red brown	blue grey black brown brown
❏	2	2.7kΩ	red violet red brown	red violet black brown brown
❏	1	2.2kΩ	red red red brown	red red black brown brown
❏	1	1kΩ	brown black red brown	brown black black brown brown
❏	1	620Ω	blue red brown brown	blue red black black brown

of the PCB. The pins on the underside can then be soldered to their respective pads, making sure that the header itself is flush against the PCB.

Once it's in position, switch S2 can be mounted by soldering its pins to the top of the header pins, so that its top metal face sits 12.5mm above the PCB (see photo). The best way to do this is to lightly tack-solder two diagonally-opposite pins first, then make any necessary adjustment before soldering the remaining pins. Don't forget to resolder the first two pins, to ensure reliable connections.

Once it's in position, the adjacent earth PC stake is soldered to the earth tag on S2's metal cover.

Completing the PCB

Now for the capacitors. **Install the 100nF 630V polyester and 1nF 1kV ceramic capacitors in the positions shown,** then install the remaining MKT polyester types. The electrolytics can then go in, taking care to fit each one with the polarity as indicated on Fig.2. Note that the tops of the electrolytics must be no more than 12.5mm above the PCB, otherwise you will not be able to fit the case lid later on.

Follow with potentiometers VR1 and VR2, toggle switch S1 and the 3.5mm socket. VR1 is a 10kΩ linear potentiometer, while VR2 is a 50kΩ log potentiometer, so don't get them mixed up. LED1 can then be installed – it mounts horizontally with its leads bent down through 90° exactly 7mm from its lens, so that they go through the PCB pads. Push it down so that its horizontal lead sections sit exactly 6mm above the PCB (use a 6mm-wide cardboard spacer) and check that it is correctly oriented before soldering it to the PCB.

That completes the PCB assembly. It can now be checked and placed to one side while the case is drilled.

Preparing the case

Figs.3 and 4 show drilling templates for the front panel and for the top of the case. They can either be photocopied from the magazine or downloaded as PDF files from the *EPE* website and printed out.

It's just a matter of cutting the templates out, temporarily attaching them to the case panels and then drilling the various holes. The top of the case requires holes for potentiometers VR1 and VR2, switch S1 and LED1, while the front panel is drilled to accept the two banana sockets, the BNC socket and slide switch S2.

The rectangular cut-out for S2 is best made by drilling a row of holes inside the cut-out area, joining these and then filing the job to shape. The two banana socket holes can simply be drilled and reamed to size, but the BNC socket hole needs to be shaped as shown on the template. It can be made by first drilling a small hole in the centre, then finalising its shape using small files, with the flat side positioned as shown.

A hole must also be cut in one side of the case to accept the 3.5mm jack socket. To do this, temporarily position the PCB in the case, mark out the socket position, then remove the board and make a semi-circular notch in the base using a small round file. Once that's been done, temporarily assemble the case and complete the hole by filing a matching semi-circular cut-out in the lid.

Finally, you have to remove an internal pillar inside the case lid so that it doesn't foul the nut for the earth banana socket. This can be done using side cutters. Note also that, as provided, the banana socket terminals are too long for the case and have to be shortened by 5mm. A fine-tooth hacksaw blade is the best tool for this job – do not bend the terminals, as they will break. File off any sharp edges after cutting them to length.

Having drilled all the holes, the front panel label can be attached. This can be downloaded from the *EPE* website, printed out (preferably onto photo paper) and affixed to the lid using either glue or neutral-cure silicone.

Alternatively, for a more rugged label, print it out as a mirror image onto clear overhead projector film (be sure to use film that suits your printer), so that the printed side will be on the back of the film when the label is affixed. The film will have to be attached using a light-coloured silicone applied evenly over the surface, as the lid is black.

Once the label is in position, cut out the holes using a sharp hobby knife.

Making a shield PCB

Since the *Tracer* has such a high input impedance, it has the potential to pick up hum from transformers, but it will also pick up the *Injector* signal as well, due to direct radiation of the *Injector* signal into the input attenuator and other components in the op amp's input circuitry.

We can reduce this by a significant amount by installing a small shield board, made from copper laminate, underneath the PCB, with its copper side earthed to the PCB's GND stake. The dimensions of this shield board are shown in Fig.5. It fits between the four integral pillars used to mount the PCB and it has a cut-out to clear the back of the *Injector* jack sockets.

Alternatively, if you don't wish to make your own shield board, you can

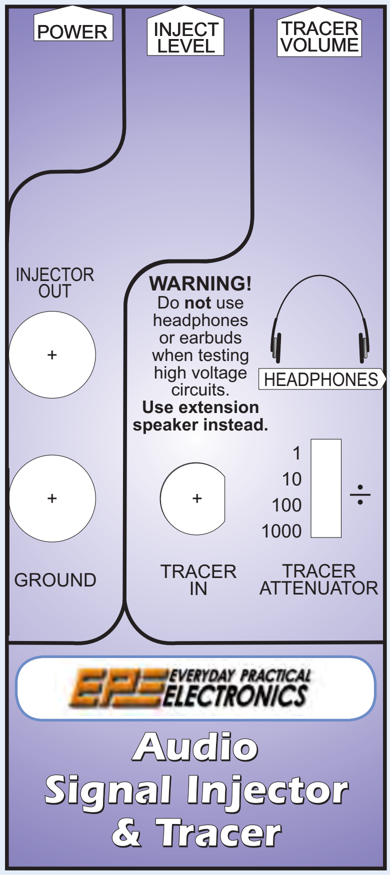


Fig.3: this front-panel artwork can be copied or downloaded from the *EPE* website and used as a drilling template.

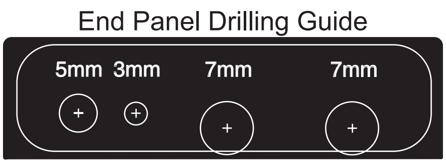


Fig.4: the end panel drilling template. Drill pilot holes first to ensure they are accurately positioned, then carefully enlarge them to size.

Parts List

1 double-sided PCB, available from the *EPE PCB Service*, coded 04106151, 85 × 63mm
1 single-sided shield PCB, *EPE PCB Service*, coded 04106153, 62 × 63mm
1 remote control case, 135 × 70 × 24mm
1 panel label, 114 × 50mm
1 9mm square PCB-mount 10kΩ linear potentiometer (VR1)
1 9mm square PCB-mount 50kΩ log potentiometer (VR2)
1 SPDT PCB-mount toggle switch (S1)
1 DP4T PCB-mount slider switch (TE Connectivity STS2400PC04) (element14 Cat. 1291137) (S2)
1 PCB-mount 3.5mm stereo jack socket (CON1)
2 knobs to suit VR1 and VR2
1 panel-mount BNC socket
1 blue insulated banana socket
1 green insulated banana socket
1 9V alkaline battery
1 9V battery snap connector
4 No.4 × 6mm self-tapping screws
7 PC stakes
1 DIL 6-way pin header
1 150mm length of hookup wire
1 50mm length of single-core shielded wire

Semiconductors
1 LMC6482AIN dual CMOS op amp (IC1)
1 3mm high-intensity red LED (LED1)
1 BC327 PNP transistor (Q1)
1 BC337 NPN transistor (Q2)
1 5.6V 1W zener diode (ZD1)
1 1N5819 Schottky diode (D1)
4 1N4004 diodes (D2-D5)

Capacitors
2 100µF 16V PC electrolytic
1 10µF 16V PC electrolytic
1 1µF 16V PC electrolytic
1 100nF 630V polyester
1 100nF 63V or 100V MKT polyester
1 22nF 63V or 100V MKT polyester
1 6.8nF 63V or 100V MKT polyester
1 1nF 1kV ceramic
1 220pF disc ceramic

Resistors (0.25W, 1%)
3 10MΩ
1 9.1MΩ
1 6.8kΩ
2 2.7kΩ
1 910kΩ
8 100kΩ
1 91kΩ
1 10kΩ
1 2.2kΩ
1 1kΩ
1 620Ω

Test Leads

Tracer In

Option 1: 1 × 1:1 oscilloscope probe

Option 2: 1 × BNC plug-to-RCA plug lead fitted with a PC stake and 5mm and 10mm heatshrink tubing (see text)

Option 3: 1 × BNC line plug, 1 × RCA line plug, 1 × 500mm-length of single-core shielded audio cable, 1 × M4 nut, 1 v PC stake and 2mm, 5mm and 10mm heatshrink tubing (see text)

Injector Out

Option 1: 1 × multimeter lead set with accessory alligator clips

Option 2: 1 × red banana plug, 1 × black banana plug, 1 × red alligator clip, 1 × black alligator clip, 1 × 500mm length of red medium-duty hookup wire, 1 × 500mm length of black medium-duty hookup wire (made into two banana plug to alligator clip leads).

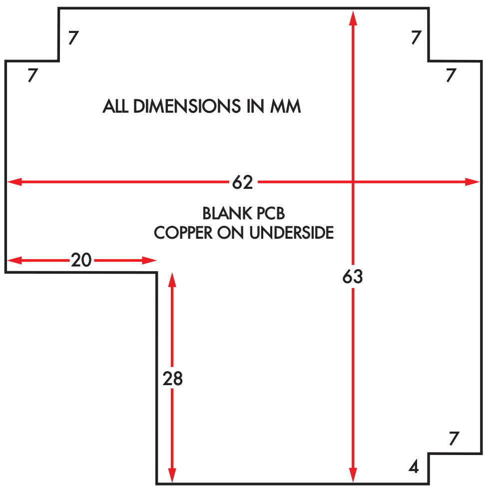


Fig.5: this diagram shows the dimensions of the blank shield PCB.

buy a ready-made board (available from the *EPE PCB Service*, code 04106153).

The shield board is installed in the case with its copper side facing downwards, away from the underside of the PCB (otherwise it would short the component pigtails!). Before doing this, solder a short piece of wire to the copper side and then connect its other end to the earth pin (GND) for the BNC connection, on the PCB. The shield PCB is then secured inside the case using silicone adhesive.

Final assembly

Now for the final assembly. First, attach the sockets to the front panel, then solder short lengths of hook-up wire to the Inject and GND terminals on the underside of the PCB. That done, pass these leads up through their respective holes in the PCB, ready to solder to the banana socket terminals.

Next, attach a short shielded cable (for the BNC socket) to the GND and *Tracer* PC stakes on the top of the PCB. The 9V battery snap can then be fitted. Its leads are fed through from the battery compartment before being looped through stress relieving holes in the PCB and soldered to the '+' and '–' terminals.

The next step is to fit the end panel to the potentiometers, switch and LED and install this into the base of the case. The PCB is then secured using four No.4 × 6mm self-tapping screws that go into integral mounting pillars.

Once it's in place, complete the wiring to the banana sockets and the BNC socket, then secure the lid to the base using the supplied screws. **You will need to make sure that the wires do not interfere with the banana sockets – if they are sandwiched beneath the banana sockets, they will prevent the lid from fully closing.**

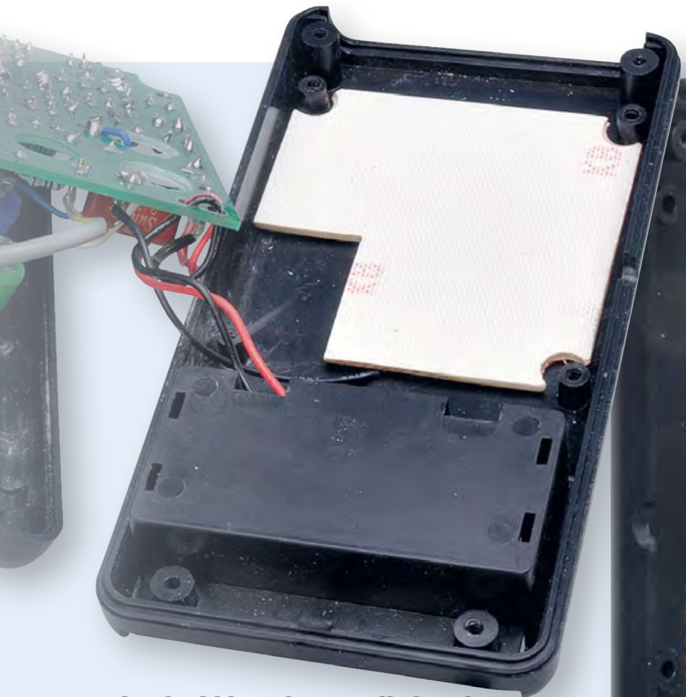
Similarly, any wires running over the battery compartment or over the slider switch will prevent the case from closing. If necessary, move the wires out of the way using a small screwdriver as the case is being closed.

Finally, fit the battery and the assembly is complete.

Test leads

As mentioned earlier, a 1:1 oscilloscope probe makes a suitable test lead for the *Audio Signal Injector/Tracer's* BNC input. Alternatively, a cheaper test probe can be made using a BNC-to-RCA lead. This can be a commercial lead, but these tend to be made from stiff large-diameter cable.

A do-it-yourself cable using a line RCA plug, a line BNC plug and standard shielded audio cable will be much more flexible. The connections to the BNC plug can be made using the



The shield board is installed in the case with its copper side facing down and is secured in place using silicone adhesive. Its copper side is connected to the GND stake on the main PCB.

This is the view inside the completed unit. Make sure that the wiring leads to the banana sockets aren't squashed under them as the lid is closed (push the leads towards the outer edge of each hole using a small screwdriver).

method described in the article (next page) on the *RF Demodulator Probe*.

The tip of the RCA plug can be used as the probe, but note that the outer metal earth shell must be insulated using 10mm-diameter heatshrink tubing to prevent it making contact with the circuit under test. In addition, a PC stake can be soldered to the centre pin of the RCA plug to extend it. That's done by first drilling a 1mm hole in the end of the plug's tip, then inserting the PC stake and soldering it.

It's a good idea to cover the RCA plug's centre terminal with 5mm diameter heatshrink tubing, leaving only the PC stake 'probe' exposed. This will help prevent inadvertent shorts when probing closely-packed circuits.

The *Injector* signal can be fed out using a multimeter probe. Alternatively, you can use a lead fitted with a banana plug at one end and an alligator clip lead at the other. A banana plug-to-alligator clip lead can also be used for the ground lead.

Testing

To check that the unit is working correctly, connect the 'Injector Out' signal to the 'Tracer In' (BNC) socket, then plug in headphones (or earphones) and listen for the 1kHz signal. Assuming that it's present, check that the level varies when the 'Inject Level' potentiometer, the 'Tracer Volume' potentiometer and the 'Tracer Attenuator' switch are adjusted.

As noted above, if the *Tracer* input is disconnected from a circuit, the unit will pick up hum and the 1kHz *Injector* signal due to the *Tracer* circuit's high input impedance (ie, the 1kHz signal will be heard even when there is no connection). The pick-up level will depend on the capacitance of the input cable, the attenuator setting (S2), the *Injector* level setting (VR1) and the gain (Volume) setting (VR2).

Obviously, it will be at a maximum when the attenuator is set to 1:1 and VR1 and VR2 are at maximum, but this combination of settings would not be used in practice. Basically, it's just a matter of choosing settings to suit the job at hand and to minimise extraneous noise pick-up.

Under normal use and when connected to a circuit for testing, the crosstalk from the *Injector* will be minimal and will be swamped by the signal from the circuit under test.

Ground connections

Finally, note that when using the *Audio Signal Injector/Tracer*, the Ground banana socket must be connected to the ground of the circuit under test. This can be done using a lead fitted with an alligator clip as described above or by using the earth lead on the 1:1 oscilloscope probe.

Now turn to the next page for the optional *RF Demodulator Probe*.

By JOHN CLARKE

Simple unit uses just a handful of parts . . .

AM RF Demodulator Probe for Signal Tracers

If you want to troubleshoot an AM radio with the *Signal Tracer/ Injector* described in this issue, you need a demodulator probe to detect the amplitude-modulated RF signals that should be present in the circuit being tested. This one is compact and easy to build.

Fig.1 shows the circuit details of the *RF Demodulator Probe*. It uses a fast BAT46 Schottky diode (D1) as the detector and its output is filtered with a 1nF capacitor to remove the RF signal, leaving the audio modulation which can then be fed to the *Tracer*.

The audio frequency response of the probe is about –3dB down at 1.6kHz, as set by the 1nF capacitor and associated 100kΩ resistor. Since the RF probe is intended for use in valve AM radios, its 100pF capacitor is a 1kV-rated ceramic type.

Note that the probe is a passive device and requires no external power.

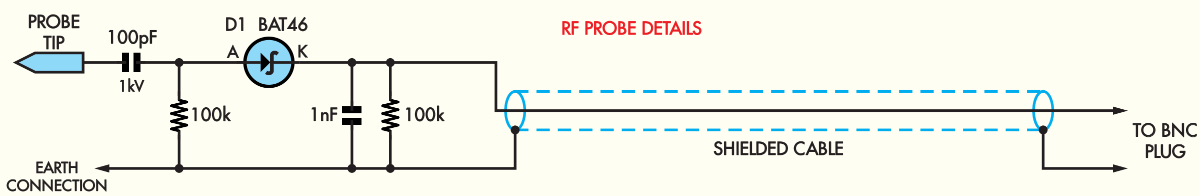
Construction

The *RF Probe* is built on a PCB, available from the *EPE PCB Service*, coded 04106152 (45 × 11mm) – see Fig.2. Install the two 100kΩ resistors and the two capacitors first, followed by the diode. Check that the diode is correctly oriented (ie, banded end towards the right).

The probe tip is made using a 3-way right-angle pin header. Solder this in place and then cut the outer two pins flush with the end of the PCB, leaving just the centre pin.

PC stakes are used to terminate the three external wiring connections. Fit these to the PCB, then attach the earth wire to the GND stake and the shielded cable to the SIG and GND terminals. The shielded wire and the earth wire are then secured to the PCB using two cable ties.

Once all the parts are in place, the assembly is covered in a 55mm length of 16mm-diameter heatshrink



RF DEMODULATOR PROBE

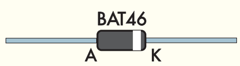


Fig.1: the circuit uses a BAT46 Schottky diode (D1) as the detector plus a 1nF capacitor to filter out the RF signal. The 100pF 1kV input capacitor blocks DC signals, while the 100kΩ resistor sets the frequency response to -3dB at 1.6kHz.

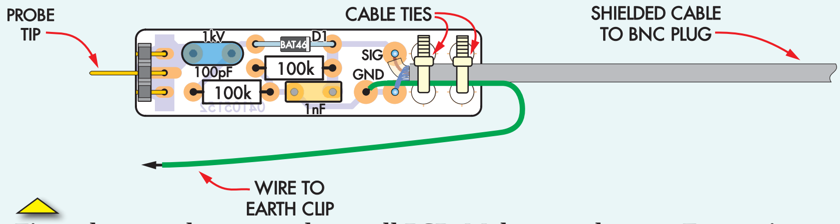


Fig.2: the parts layout on the small PCB. Make sure the 100pF capacitor is rated at 1kV and take care with the orientation of Schottky diode D1. The photo at right shows the completed PCB before the heatshrink sleeve was fitted.

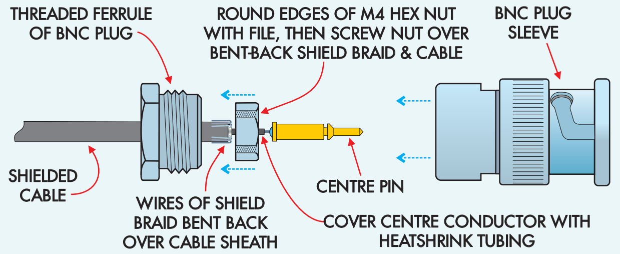


Fig.3: this diagram shows how the shielded audio cable is connected to the BNC plug (see text).

RF Probe parts list

- 1 PCB, available from the *EPE PCB Service*, coded 04106152, 45 × 11mm
- 1 BNC line plug
- 1 right-angle 3-way SIL header
- 1 500mm-length of single-core shielded wire
- 1 black alligator clip
- 1 300mm-length of black hook-up wire
- 1 BAT46 Schottky diode (D1)
- 1 1nF MKT polyester or ceramic capacitor
- 1 100pF 1kV ceramic capacitor
- 2 100kΩ 0.25W resistors
- 2 100mm cable ties
- 1 M4 metal nut
- 3 PC stakes
- 1 55mm-length of 15mm-diameter heatshrink tubing
- 1 5mm-length of 2mm-diameter heatshrink tubing

tubing that's shrunk down with a heat-gun.

The far end of the earth lead can be terminated in an alligator clip or a hook clip, while the shielded cable goes to the BNC plug. Note that this type of plug is designed for use with a larger-diameter shielded cable than the shielded audio cable used here. However, a satisfactory connection can be made if an M4 metal nut is used as part of the assembly hardware.

Fig.3 shows the details. The first step is to file the six corners off the M4 nut, so that it will fit into the back of the BNC plug. Once that's done, strip the outer insulation and the centre wire insulation as shown in Fig.3 and solder the centre wire to the BNC socket's centre pin.

Next, bend the shield wires back along the cable and twist the M4 nut on over these wires. A short length of 2mm-diameter heatshrink tubing is then used to cover (and stiffen) the centre wire before it meets the centre pin, after which the plug sleeve can be fitted and the threaded ferrule tightened to secure the assembly.

Finally, the wire can be secured inside the threaded ferrule using neutral-cure silicone sealant.

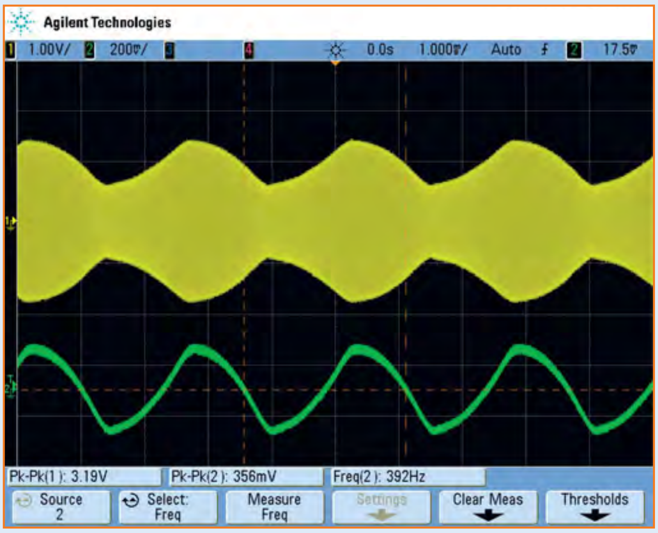


Fig.3: the yellow trace in this scope grab shows a 1MHz carrier from an old Leader signal generator, amplitude modulated with a 400Hz audio signal. The modulation depth is about 30%. The green trace shows the 400Hz (actually 392Hz) audio modulation from the RF probe. Note that the recovered modulation is a somewhat distorted sinewave.

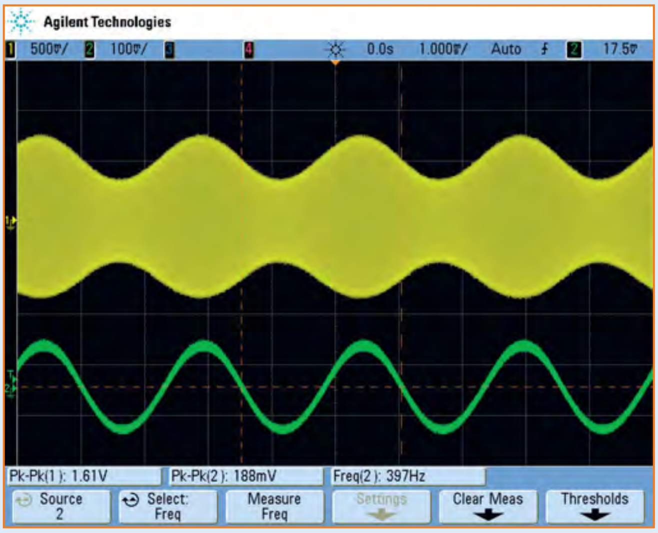


Fig.4: the yellow trace in this scope grab shows a 1MHz carrier from an old Marconi signal generator, amplitude modulated with a 400Hz audio signal. The modulation depth is about 30%. The green trace shows the 400Hz (actually 397Hz) sinewave audio modulation from the RF probe.

Champion Preamp

By LEO SIMPSON

You can use this simple unit as a general-purpose stereo preamp or as a dual-channel preamp, with a microphone for one channel and guitar in the other. One channel can have fixed gain while the other is variable with an on-board trimpot or external potentiometer. Better still, it gives good performance and will work over a wide range of supply voltages.

Over they years we have offered very many amplifiers. Early designs were of course quite bulky by today's standards, and with the inexorable march of technology it is now possible to offer much more sophistication and power in a very compact module. So, with that thought in mind, here is a superb pre-amplifier in a very small package.

I should state at the outset that this 2-channel preamp is not an absolutely brand-new design. It is based on the preamp section of the *Champion* amplifier module which was featured in the January 2014 issue. The major feature of that article was the tiny AN7511 monolithic amplifier chip, which can deliver up to 7W peak power, depending on load and supply voltage. The preamp section might have been seen almost as an afterthought, but it would be a pity for it to have passed mostly unnoticed.

Main features

- 2-channel preamplifier configurable for different inputs
- Low distortion
- Low current drain: 2mA
- Signal-to-noise ratio: ~80dB
- Operating voltage range: 6-12V with LP2950CZ-5.0 5V LDO regulator; 12-20V with 78L09 9V regulator

This is partly why we have decided to devote an article just to the preamp; that and the fact that we have recently had a number of requests for preamps which would be neatly answered by this design.

So what is good about it? First, it can use one of two dual rail-to-rail op amps and these have the outstanding feature of maximum output voltage swing. So, for example, if you have a 9V supply rail, the maximum undistorted output voltage can be within a whisker of 9V peak-to-peak; about 8.5V p-p, to be more precise. This in itself is very handy, much better than the old *PreChamp* design and you don't have to tweak the input bias to obtain it.

Another advantage is that the specified rail-to-rail op amps can be designed into a preamp with a very high input impedance. This is highly desirable if you want a preamplifier to suit a ceramic phono cartridge or a piezoelectric pick-up in a musical instrument such as a violin. In both cases, an input impedance of 5MΩ is useful when chasing good bass response.

Optional electret microphone

One of the attractions of the *PreChamp* was that you could install an on-board electret microphone. The only modification required was to add a bias resistor. That feature can also be included in this 2-channel design and you could, in fact, have two electret microphones, **although for useful channel separation you would need to install them both on shielded leads.**

Circuit details

The circuit is similar to but not exactly the same as the preamp in the January 2014 article. Fig.1 shows the details. Both channels are shown and the dual op amp is an LMC6482.

Since we are employing a single DC supply rail, we need a half-supply reference from which to bias the inputs of both op amps. This reference is derived from the supply rail via a voltage divider consisting of two 10kΩ resistors bypassed with a 100µF electrolytic capacitor. We can use such high-value resistors for the divider because the bias current drawn by each input of the op amps is a just a fraction of a picoamp. On the other hand, we want that bypassed half-supply to have quite a low impedance, hence the relatively large capacitor value of 100µF.

Both op amp circuits are identical, although it is possible to have different gains in each channel, depending on your application. For the moment though, let's assume that both are identical and we will just describe channel 1, based on op amp IC1a.

The input signal from CON2 passes through a low-pass filter consisting

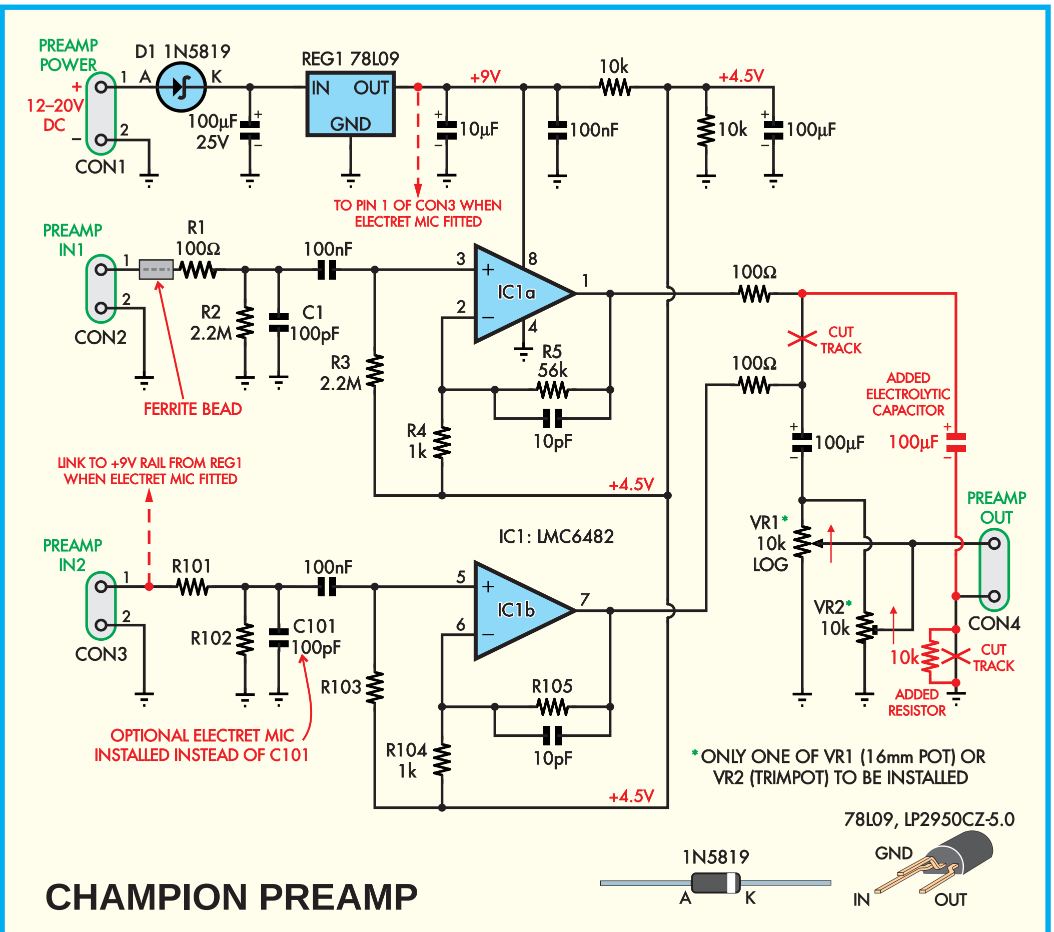


Fig.1: the preamplifier circuit. It's based around dual rail-to-rail op amp IC1. The signal from each input is AC-coupled and biased to half supply, then amplified and re-biased to 0V DC before being fed to CON4.

of a 100Ω resistor (R1) and a small ferrite bead in series, together with a 100pF capacitor connected to the 0V line (C1). This is to attenuate any RF signals that may be picked up by the input leads. There is also a 2.2MΩ resistor to pull the input signal to ground (R2).

If you are going to feed the preamp with an iPod or similar player you will need to use a much lower value of, say, 1kΩ to provide it with sufficient load current. For the moment though, the values we have shown on the circuit for channel 1 are selected to suit the pick-up in an electric guitar.

The signal is then AC-coupled via a 100nF capacitor to pin 3 of IC1a and a 2.2MΩ resistor biases the op amp's input to the half-supply rail. This ensures that the output waveform will swing symmetrically within the supply rails of dual op amp IC1. The two 2.2MΩ resistors on either side of the 100nF AC-coupling capacitor are in parallel as far as the signal source is concerned, setting the unit's input impedance to around 1.1MΩ.

IC1a buffers and amplifies the signal from CON2, while IC1b does the same for the signal from CON3. Gain is set at 57 times (35dB) by the 56kΩ (R5) and 1kΩ (R4) feedback resistors. The 10pF feedback capacitor reduces the gain for high-frequency signals, giving a little extra stability and noise filtering.

Changing the gain

Note that this high gain suits a musical instrument such as a guitar, but you can easily increase or reduce the gain by changing R5, and you can change the input impedance as well.

For example, if you want to configure it for a dynamic microphone, R2 and R3 are changed to 100kΩ each to give an input impedance of 50kΩ, while R5 is changed to 100kΩ to give a gain of 101 times (41dB).

If you want to install an electret microphone insert on the PCB, you would install it in place of 100pF capacitor C101. At the same time, R101 is changed to 10kΩ and it provides the bias current for the electret. The other end of the 10kΩ resistor is connected to the positive supply rail, from REG1.

Finally, R102 is omitted, R103 is 220kΩ and the gain is set to 23 (27dB) with R105 being 22kΩ.

Ceramic cartridge

Another interesting application is to use the *Champion* preamp with a stereo ceramic cartridge (don't laugh; this was a standard fitment on millions of record players and many people are dragging them out to listen to their old record collections). Ceramic cartridges require a high input impedance and this is an easy option with this preamp. Both R2 and R3 are specified at 10MΩ, giving an input impedance of 5MΩ which ensures good bass response.

The gain does not need to be high though, and so we can set R5 to 2.7kΩ. This gives a gain of 3.7 (11.3dB). The same configuration can be used for a piezo pick-up on a musical instrument such as a violin.

So to summarise, depending on what type of source you are using and the gain required, you can easily obtain the required input impedance and gain. Table 1 shows the values to use.

Table 1: RC gain selection values

Input	Gain	R1/101	C1/101	R2/102	R3/103	R4/104	R5/105
Guitar	57	100Ω	100pF	2.2MΩ	2.2MΩ	1kΩ	56kΩ
Microphone	101	100Ω	100pF	100kΩ	100kΩ	1kΩ	100kΩ
Electret	23	10kΩ*	–	–	220kΩ	1kΩ	22kΩ
MP3	28	100Ω	100pF	1kΩ	220kΩ	1kΩ	27kΩ
Piezo pick-up	3.7	100Ω	–	10MΩ	10MΩ	1kΩ	2.7kΩ

* Connect one end of this resistor to the +9V rail from REG1.

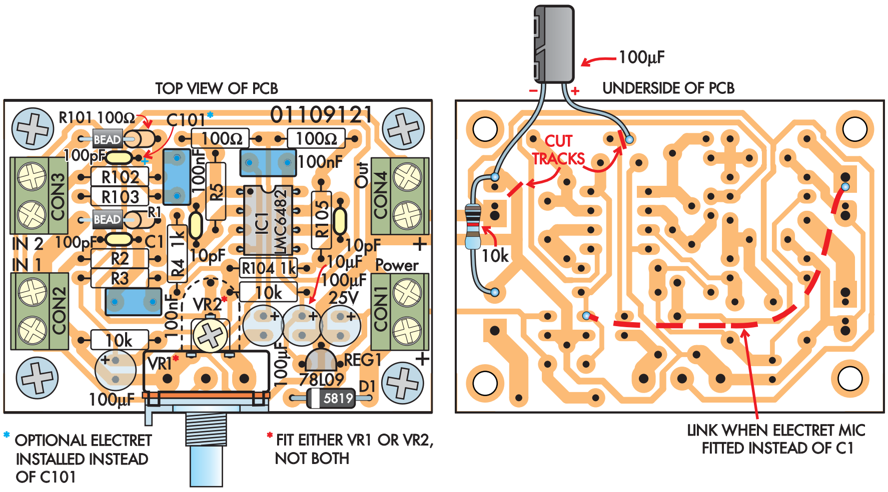


Fig.2: follow this layout diagram to assemble the PCB. It's best to cut the tracks first and then check with a continuity meter before fitting the parts.

Table 2: Resistor Colour Codes

❏	Value	4-Band Code (1%)	5-Band Code (1%)
❏	10MΩ	brown black blue brown	brown black black green brown
❏	2.2MΩ	red red green brown	red red black yellow brown
❏	220kΩ	red red yellow brown	red red black orange brown
❏	100kΩ	brown black yellow brown	brown black black orange brown
❏	56kΩ	green blue orange brown	green blue black red brown
❏	27kΩ	red violet orange brown	red violet black red brown
❏	10kΩ	brown black orange brown	brown black black red brown
❏	2.7kΩ	red violet red brown	red violet black brown brown
❏	1kΩ	brown black red brown	brown black black brown brown
❏	100Ω	brown black brown brown	brown black black black brown

Two outputs

In the original *Champion* preamplifier, the outputs of the two op amp stages are mixed using a pair of resistors and then AC-coupled to potentiometer VR1 or VR2, depending on which is installed. In our application, we want two separate outputs and so if an output level control is to be used, it can only affect one channel. As shown on the circuit of Fig.1, the output of IC1b connects to VR1 (or VR2) via a 100Ω resistor and 100µF DC blocking capacitor. The wiper of VR1 then connects to one terminal on CON4.

The output of IC1a is also fed via a 100Ω resistor with a second blocking capacitor and bias resistor added under the board. This output goes to the other terminal on CON4. Note that two track cuts on the PCB need to be made, in order to give this independent two-channel operation.

IC1 is powered via a 78L09 low-power 3-terminal 9V regulator, assuming you are using a DC plugpack with an output of 12V or more (up to 20V DC). This regulator is fed from CON1 via Schottky diode D1 which protects against reversed supply polarity.

Table 3: Capacitor Codes

Value	µF Value	IEC Code	EIA Code
100nF	0.1µF	100n	104
100pF	NA	100p	101
10pF	NA	10p	10

Note that if you intend using a 9V battery for this project, you may want to employ the LP2950CZ-5.0 5V regulator. No other modifications are required if you make this change, but the preamplifier will inevitably have a reduced output voltage swing and therefore a reduced overload margin for strong input signals.

Construction

You will be using the *Champion* PCB for this project (available from the *EPE PCB Service*, coded 01109121/22) and you will need to cut off the section for the AN7511 audio amplifier. Don't discard it – it's a handy little amplifier module in its own right and the AN7511 amplifier chip is quite cheap.

The remaining preamplifier PCB measures just 57 × 41mm. It has provision for mounting pillars at its four corners and four 2-way connector blocks.

Parts List

1 PCB, available from the *EPE PCB Service*, coded 01109121/22, 57 × 41mm (see text)
1 PCB-mount electret microphone insert (optional; see text)
1 10kΩ log PCB-mount 16mm potentiometer (VR1) OR
1 10kΩ mini horizontal trimpot (VR2)
2 ferrite beads, Jaycar LF1250
4 mini 2-way terminal blocks (CON1-CON4) (omit one if electret is installed)
1 8-pin DIL socket
4 M3 × 10mm tapped nylon spacers
4 M3 × 6mm machine screws
1 short length hookup wire (60mm)

Semiconductors
1 LMC6482 or LMC6032 dual op amp (IC1)
1 78L09 or LP2950CZ-5.0 5V LDO regulator (REG1) – see text
1 1N5819 Schottky diode (D1)

Capacitors
1 100µF 25V electrolytic
3 100µF 16V electrolytic
1 10µF 16V electrolytic
3 100nF MMC or MKT
2 100pF ceramic (omit one if electret is installed)
2 10pF ceramic

Resistors (0.25W, 1%)
3 10kΩ 2 100Ω
See Table 1 for R1-R5

Note: Jaycar sell a kit of parts for this project: Cat. KC-5531.

One of those blocks is used as the terminals for the two preamplifier outputs.

Since there are changes to the component layout, this means that you will have to follow the parts layout of Fig.2 and ignore most of the resistor values shown on the screen-printed layout on the PCB itself. You also need to cut the copper tracks of the PCB in two places, as shown on Fig.2.

Having cut the tracks, start the assembly by installing the resistors. You will need to refer to Table 1 for the values for R1-R5 and R101-R105. Table 2 shows the colour codes, but it is good idea to also check each value with a multimeter. A ferrite bead should be slipped over one leg of each 100Ω input resistor, if fitted (ie, R1 and R101).

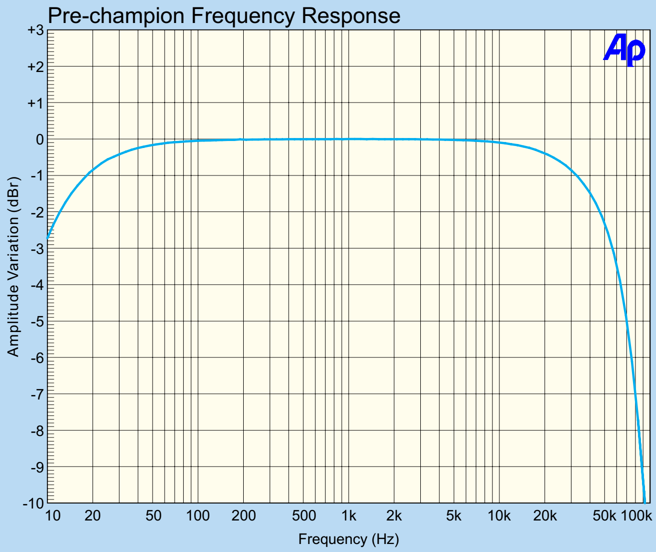


Fig.3: frequency response is within +0,–0.5dB between 30Hz and 20kHz with –3dB points around 8Hz and 55kHz. It's less than 1dB down at 20Hz.

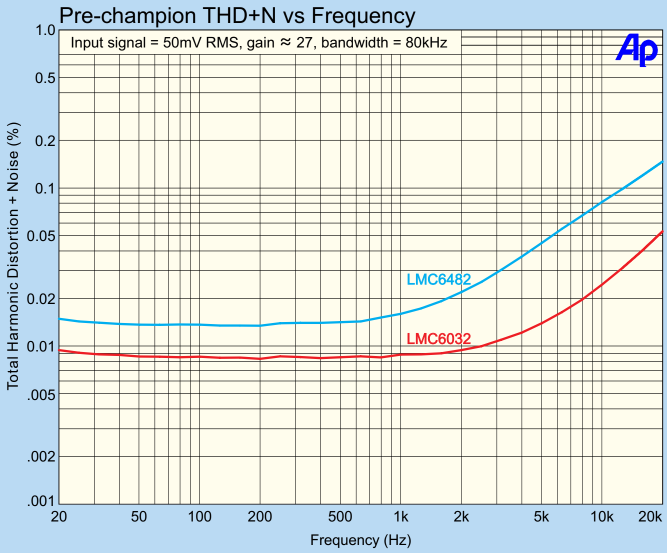
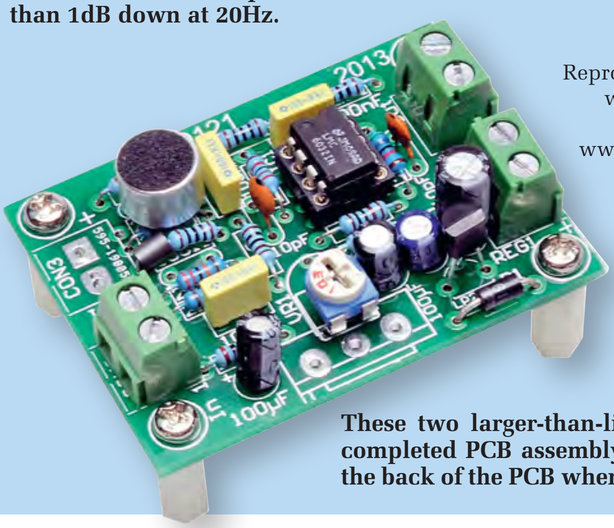
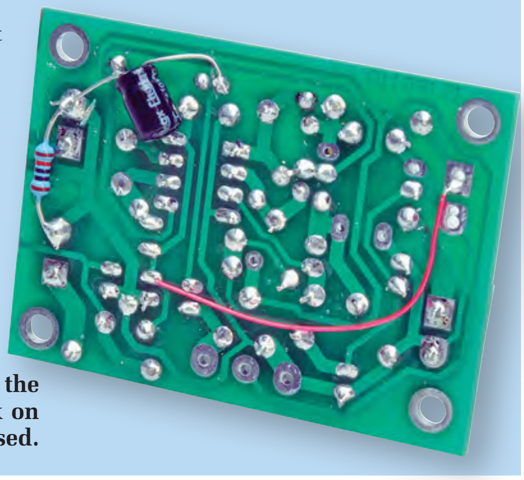


Fig.4: the LMC6032 has about half the noise of the LMC6482. The LMC6032 requires slightly more operating current than the LMC6482, but still under 1mA.





These two larger-than-life-size views show the completed PCB assembly. Note the wire link on the back of the PCB when an electret mic is used.

Follow with diode D1 and then fit the IC socket with its pin 1 notch oriented as shown. Next, fit the 78L09 or LP2950CZ-5.0 regulator, REG1. Follow with the ceramic and monolithic capacitors.

The 2-way terminal blocks are next, each installed with their wire entry holes facing outwards. Note that CON3 is not installed if you have fitted an electret microphone insert for channel 2.

The next step is to decide whether to fit potentiometer VR1 or trimpot VR2. It will only control the output signal level from one channel and you may decide to link it out. You can then fit all the electrolytic capacitors. In each case, the longer lead goes into the hole marked with a '+' sign.

Once those parts are in, fit the M3 × 10mm tapped spacers to the corner mounting positions using M3 × 6mm machine screws.

If you are installing an electret, wire a 10kΩ resistor in the position for R101 and connect the end adjacent to CON3 to the output of the 3-terminal regulator. We show this with a dotted red line on Fig.2. In addition, R102 and C101 are omitted.

Electret orientation

Make sure that the electret mic is correctly oriented. Its positive terminal must go to the side marked with a blue '+' sign on Fig.2. Connect the electret via shielded cable if you want to mount it off the PCB.

If you are going to use only one channel of the preamplifier, it's a good idea to short the unused channel's input to 0V by using a wire link for resistor R1 (or R101) and by shorting the two terminals of CON2 (or CON3).

When you have carefully checked your assembly and soldering against the circuit of Fig.1, Table 1 and the overlay diagram of Fig.2, you are ready to apply power. Check that the output of REG1 is 9V (or close to it) if a 78L09 has been fitted. If an LP2950CZ-5.0 has been fitted, REG1's output should be close to 5V.

Next, turn off the power, insert the op amp (carefully), power back on and then check the DC voltage at pins 1 and 7. In each case, they should be sitting at half supply; 4.5V for a 9V supply and 2.5V for a 5V supply.

Performance

Figs.3 and 4 show the frequency response and total harmonic distortion curves of the preamplifier. Note that of the two op amps we've specified, the LMC6032 gives the best performance but it isn't as easy to get as the more common LMC6482.

To achieve a THD+N this low, the preamp will need to be installed in an earthed metal box. Otherwise, hum and RF pick-up will reduce the signal-to-noise ratio and consequently the total harmonic distortion performance.

Teach-In 2016

Exploring the Arduino

Part 5: 1-Wire interface

by Mike and Richard Tooley

Welcome Welcome to *Teach-In 2016: Exploring the Arduino*. This exciting new series has been designed for electronics enthusiasts wanting to get to grips with the immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. So, whether you are considering what to do with your Arduino, or maybe have an idea for a project but don't know how to turn it into reality, our new *Teach-In 2016* series will provide you with a one-stop source of ideas and practical information.

In last month's *Teach-In 2016: Exploring Arduino*, we looked at ways in which the Arduino can sense and act upon what's going on in the real world. *Arduino Workshop* looked at the Arduino's analogue ports, while *Arduino World* introduced some low-cost devices that can sense temperature. Our programming feature, *Coding Quickstart*, explained the functions that will let you use serial communication via the Arduino's USB port. Finally, *Get Real* showed you how you can build a simple thermostatic controller based on the Arduino Uno.

This month

In this month's *Teach-In 2016: Exploring the Arduino* we will be looking at ways in which an Arduino can handle multiple sensors using a limited number of wire connections. To help with this task, *Arduino Workshop* introduces the highly versatile 1-wire bus system, while *Arduino World* looks at temperature sensors that have their own integrated ADC offering a much higher resolution than the ADC converters built into the Arduino Uno. Our programming feature, *Coding Quickstart*, shows you how to use some code to store your valuable data on an ordinary SD card. Finally, our *Get Real* project takes the form of a stand-alone environmental monitoring system that can capture large amounts of data, conveniently processing and storing it on a conventional SD memory card.

Arduino Workshop: using the 1-Wire interface

Developed by the Dallas Semiconductor Corporation, the '1-Wire' bus offers a means of exchanging low-speed data between a microcontroller and a sensor or other device using just one or two wires, plus a ground connection. The bus allows for a single 'master' to control and exchange data with a virtually unlimited number of 'slaves' connected to the same bus line. A device is supplied pre-programmed with a unique 64-bit identification number, which incorporates an 8-bit family code to identify the type of device and its function. Many 1-Wire devices are capable of operating without a separate power supply connection; instead, they derive their supply from the bus itself in what's referred to as a 'parasitic supply' arrangement.

Just about the most basic 1-Wire device is one that just supplies its own unique 64-bit identification when demanded by the bus master. This might not sound very useful, but by pairing a microcontroller with a unique slave device it becomes possible to have a very high level of authentication. Put simply, if the device isn't the expected slave then either the system won't work or some other appropriate action can be taken. Many other 1-Wire devices are available, including temperature sensors, timer/counters, and non-volatile memories. Later in *Arduino World* we will show how a low-cost, high-resolution temperature sensor can be connected using the 1-Wire bus.

A notable advantage of the 1-Wire bus is that it offers a simple multi-drop capability in which a number of slave devices can all share the same bus line. This keeps the wiring extremely simple and, where a parasitic bus-powered supply is used, only two wires are needed to link all of the sensors together, as shown in Fig.5.1.

Using the 1-Wire bus, commands and data are sent with the least-significant bit first. To prevent potential conflict, 1-Wire devices must be interfaced to the bus by means of an open-drain tri-state port. This allows the bus to be released for other devices to use when data is not actually being transmitted (the tri-state device enters a high-impedance state when not being used). In order to ensure that the bus line is taken high when idle, an external pull-up resistor of typically 4.7kΩ is connected between the positive supply and the bus line. A typical bus interface is shown in Fig.5.2. Note the open-drain connection to the bus.

If for any reason a transaction needs to be suspended, the bus must be left in the idle state so that the transaction can be resumed. Infinite recovery time can occur between bits so long as the 1-Wire bus is in the inactive (high) state during the recovery period. If the bus is held low for more than 480µs, all components on the bus will be reset. Several signal types are defined in the 1-Wire protocol, including reset pulse, presence pulse, write 0, write 1, read 0, and read 1. With the exception of the presence pulse, the bus master initiates all of these signals. *Arduino World* picks up this theme as we look at temperature sensors that incorporate a built-in 1-Wire interface.

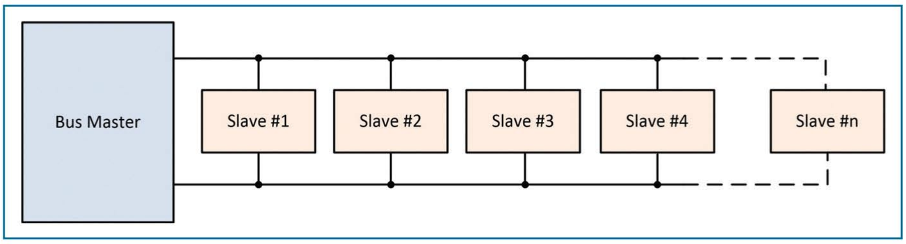


Fig.5.1. Single and multi-drop bus arrangements

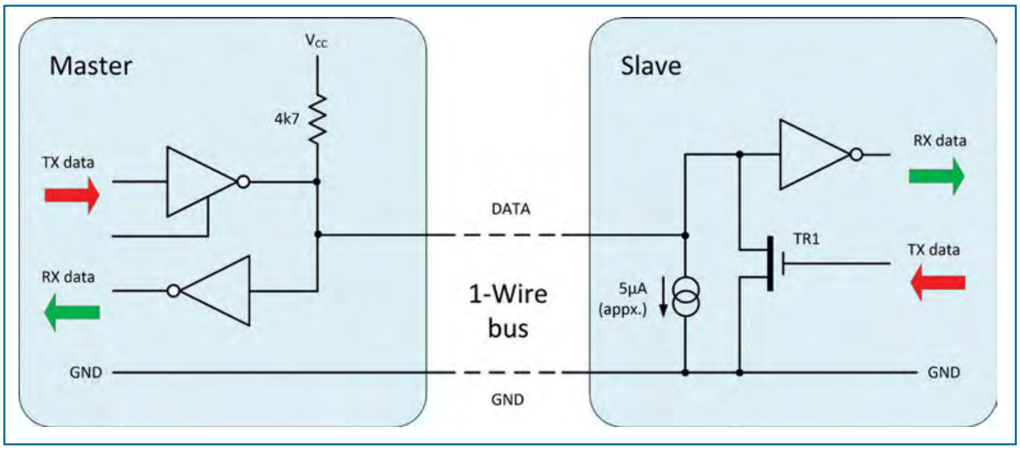


Fig.5.2. A typical 1-Wire bus interface

Arduino World: Bus-connected temperature sensors

Last month, we introduced two popular and inexpensive families of temperature sensors. These simple 10-bit sensors are ideal for many simple Arduino temperature-sensing applications, but where increased resolution and multiple sensors are needed there are some better solutions. Chief among these is the family of 1-Wire bus temperature sensors from Dallas Semiconductor (see Fig.5.3).

The 1-Wire bus makes it possible to use a single microcontroller to communicate with a large number of sensors distributed over a large area. Applications that can benefit from this feature include heating, ventilation and air conditioning (HVAC), environmental controls and temperature monitoring systems, as well as process monitoring and control systems.

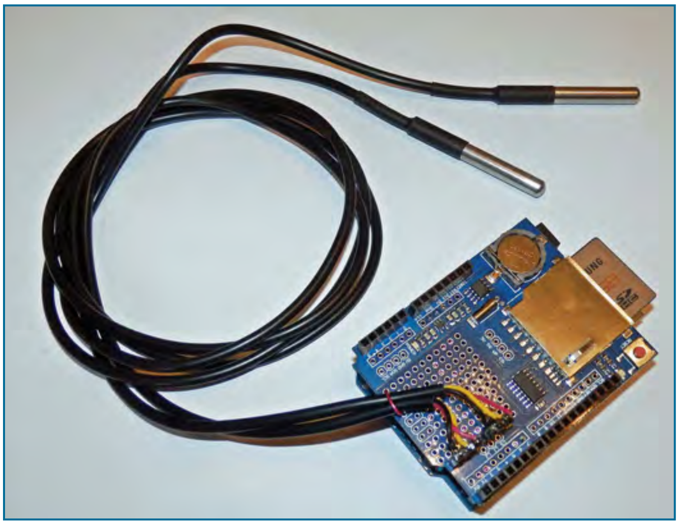


Fig.5.3. I/O connections for SPI communication

The DS18B20

The DS18B20 1-Wire temperature sensor provides a resolution of up to 12-bits. In addition, the device incorporates an alarm function with user programmable upper and lower thresholds that can be stored in on-board non-volatile memory. The device operates over a temperature range of –55°C to +125°C with a nominal accuracy of ±0.5°C in the range of –10°C to +85°C. In addition, the DS18B20 can derive power directly from the data line using a parasitic power supply (see *Arduino Workshop*), eliminating the need for an external power supply.

Resolution

The DS18B20 1-Wire temperature sensor can be configured for resolutions of either 9, 10, 11, or 12 bits. These respectively correspond to temperature increments of 0.5°C, 0.25°C, 0.125°C, and 0.0625°C (note that the device has a default resolution of 12-bits).

Operation

On power-up, the temperature sensor enters an idle state and then waits until the bus master sends a command to initiate temperature measurement and analogue-to-digital conversion. Following the conversion, the resulting temperature data is stored in a two-byte temperature register in the sensor's scratchpad memory, after which the sensor reverts to the idle state.

The sensor's output temperature data is calibrated in degrees Celsius. In applications where Fahrenheit indications are required, it will become necessary to use a conversion routine or a lookup table of corresponding values. Temperature data is stored as a 16-bit sign-extended two's complement number in the temperature register (see Fig.5.4). The sign bits (S) indicate if the temperature is positive or negative: for positive values S = 0 and for negative values S = 1.

If the DS18B20 is configured for 12-bit resolution (as it will be by default), all bits in the temperature register will

Listing 5.1 Using the 1-Wire bus to connect multiple sensors

```
/* DS18B20 temperature sensors connected using the 1-Wire bus */

#include <OneWire.h>  // Include the 1-Wire and Dallas
#include <DallasTemperature.h>  // Temperature libraries
#define ONE_WIRE_BUS 7 // Use digital I/O pin-7 for the bus

OneWire oneWire(ONE_WIRE_BUS);  // Setup the 1-Wire interface
DallasTemperature sensors(&oneWire);

void setup(void)
{
  // start serial port
  Serial.begin(9600);
  sensors.begin();
}

void loop(void)
{
  Serial.print("Requesting temperature ... ");
  sensors.requestTemperatures(); // Request temperatures
  Serial.println("DONE");
  Serial.print("Temperature for Sensor 1 (index 0) is: ");
  Serial.print(sensors.getTempCByIndex(0));
  Serial.println(" deg.C");
  Serial.print("Temperature for Sensor 2 (index 1) is: ");
  Serial.print(sensors.getTempCByIndex(1));
  Serial.println(" deg.C");
  delay(1000);  // Wait one second
}
```

Table 5.1 Digital output data and corresponding temperature indications for 12-bit resolution

Temperature (°C)	Digital output (binary)	Digital output (hex)
+125	0000 0111 1101 0000	07D0h
+25.0625	0000 0001 1001 0001	0191h
+0.5	0000 0000 0000 1000	0008h
0	0000 0000 0000 0000	0000h
–0.5	1111 1111 1111 1000	FFF8h
–55	1111 1100 1001 0000	FC90h

contain valid data. For 11-bit resolution, bit 0 is undefined whereas, for 10-bit resolution, bits 1 and 0 are undefined, and for 9-bit resolution bits 2, 1, and 0 are undefined. Table 5.1 gives examples of digital output data and the corresponding temperature reading for 12-bit resolution conversions. In order to identify individual sensors connected on the 1-Wire bus, each DS18B20 has a 64-bit serial code stored in an on-board ROM. This number is unique and cannot be changed. Data conversion time is a maximum of 750ms, which is adequate for most practical temperature sensing applications.

Coding

In conjunction with the 1-Wire bus, the DS18B20 sensor is very easy to use. You simply need to include the 1-Wire and Dallas Semiconductor libraries (`OneWire.h` and `DallasTemperature.h` respectively) and then configure the bus for operation with the temperature sensor. Thereafter, reading sensor values into variables within your code is extremely straightforward, as the example in Listing 5.1 shows.

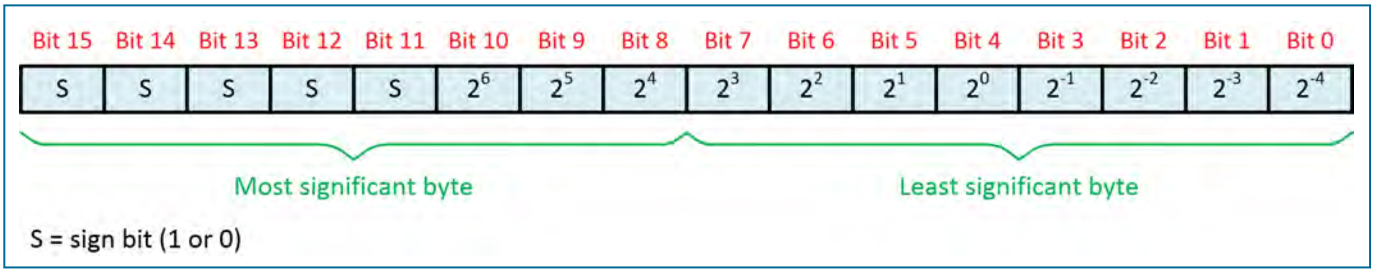


Fig.5.4. Temperature data is stored as a 16-bit signed extended two's complement number

Coding Quickstart: using SD cards

For many applications it can be useful to store data in the form of a file that can be saved and later recalled or transferred to another system for further processing and analysis. This can be accomplished with the aid of an ordinary SD card and some simple code to handle the necessary file processing. There are several different ways that you can connect an SD card, including (in rough order of cost):

1. An outboard SD card module with an SPI bus interface
2. A datalogger shield such as those produced by Adafruit (these have the added bonus that they usually incorporate a real-time clock for 'date stamping' your data)
3. An Ethernet shield fitted with an SD card slot.

Regardless of which of the above is used, the interface between the microcontroller and the SD card module is achieved by means of the Arduino's Serial Peripheral Interface (SPI) bus. SPI is a communication bus that is used to interface one or more peripheral devices (known as 'slaves') to a microprocessor or microcontroller (referred to as the 'master'). In addition to SD card modules, a large number of SPI devices are available, including analogue-to-digital converters (ADC), digital-to-analogue converters (DAC), general purpose input/output (GPIO) expansion chips, temperature sensors and accelerometers. The bus is capable of operating at high speed over short distances (faster than the I^2C bus) but it normally requires a four-wire connection with one additional chip select wire for each peripheral SPI device.

The SPI bus is a synchronous (serial clocked) bus capable of supporting data transfer in both directions, master to slave and slave to master, at the same time (this is referred to as 'full duplex' operation). The Arduino's SPI implementation uses four signal wires (plus ground). These are listed in Table 5.2 together with the pin connections conventionally used on the Uno.

It is important to be aware that conventional SD cards are designed for operation from a 3.3V supply and thus it is necessary to ensure that the I/O levels and supply voltage are level-shifted within the hardware interface. This is normally the case with Arduino shields and modules, but it is important to check when modules may have been designed for operation with other systems and may have links or switches fitted.

Table 5.2 SPI implementation in the Arduino Uno

Designation	Function	Direction	Uno pin
SCLK	Serial clock	Output from Uno	13
MOSI	Master output/slave input	Output from Uno	11
MISO	Master input/slave output	Input to Uno	12
CS/SS	Chip select/slave select	Output from Uno	10
GND	Ground	Common	GND

Using the SD Library

The Arduino's built-in SD Library provides you with a set of tools that you can use to read from and write to an SD card. The library supports the popular FAT16 and FAT32 file systems commonly used with standard SD and SDHC cards. Filenames should follow the normal '8 + 3' convention and can include paths separated by forward-slashes, /. It is worth noting that, because the working directory is always the root of the SD card, a name refers to the same file *whether or not* it includes a leading slash. Thus, `mydata.dat` is the same as `/mydata.dat`. The SD library currently supports multiple file opening.

To communicate with an SD card you will need to make use of the SPI bus (see earlier) which is available on digital I/O pins 11, 12, and 13 of the Arduino Uno. A further pin must be used to select the SD card via the chip select (CS) pin. On the Uno this is usually pin-10 (the hardware SS pin) but an alternative pin can be specified in the call to `SD.begin()`. Note that even if you don't use the hardware SS pin, it must be left as an output or the SD library will not function.

At the start of your code you will need to include the SPI and SD card libraries:

```
// Include the SD and SPI libraries
#include <SPI.h>
#include <SD.h>
```

Next you will need to set up the variables that you will use in the SD library:

```
// Set up variables for use with
the SD library
Sd2Card card;
SdVolume volume;
SdFile root;
```

The next step is rather important because you will need to specify the pin number

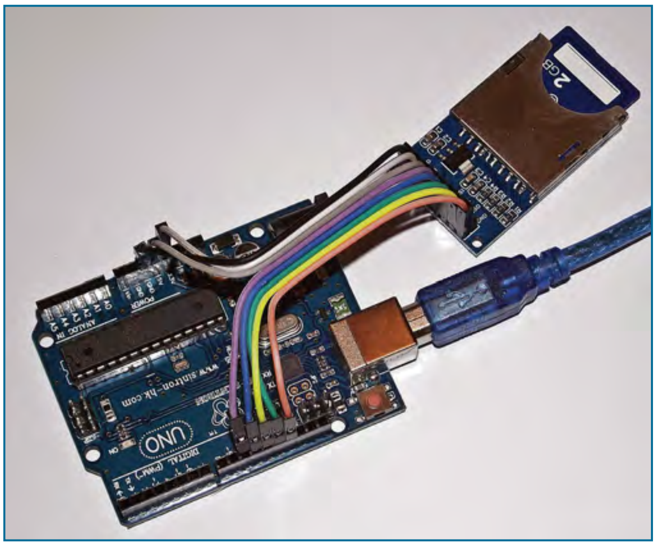


Fig.5.5. An SD card module connected to an Arduino Uno using the SPI bus

that will be used for the chip select (CS) signal to the SD module. Because this varies with SD card modules and shields from different manufacturers you will need to check the documentation supplied. The standard Arduino Ethernet shield and several types of stand-alone SD card module use pin-4, while Adafruit SD shields and others appear to use pin-10, and Sparkfun shields use pin-8. In the code fragment that follows we have used pin-10 for use with the SD card module shown in Fig.5.5.

```
// CS signal (change as required)
const int chipSelect = 10;
```

Testing the SD card interface

The best way to test an SD card module or shield and (also to get information on the SD card that you're using) is to use the CardInfo program supplied with the examples in the Arduino IDE. To locate this program you need to select the File option from the main menu and then Examples followed by SD from within the section marked 'Examples from libraries'. Finally, you can select CardInfo at the top of the list, as shown in Fig.5.6 and upload it to your Arduino. At this point you might need to modify the example program so that the correct pin number is used for the card's chip select (CS) signal, as described above.

The CardInfo example first checks that the interface is working and that there's an SD card present. If this is not the case an error message like that shown in Fig.5.7 will appear when you first open the Serial Monitor in the Arduino IDE. If everything is working correctly and the card is functional you will be presented with summary information like that shown in Fig.5.8. Note that this displays some useful data on your card, including the file system (FAT16 in this case) and the size of the card (2GB in this case). You should also be presented with a list of files present on the card. In this case, four files are stored on the SD card; one text file, one web page, one data file, and one image file (see Fig.5.8). The date and size of each of these files is given in bytes. Note that the files are shown here sorted in order of size, with the smallest first.

Reading and writing data

Data can be very easily written to an SD card or read from it. First you will need to initialize the card. This can be done using a few lines of code:

```
Serial.print("Initializing SD card...");
if (!SD.begin(10)) {
  Serial.println("Card not ready!");
  return;
}
Serial.println("Card ready!");
```

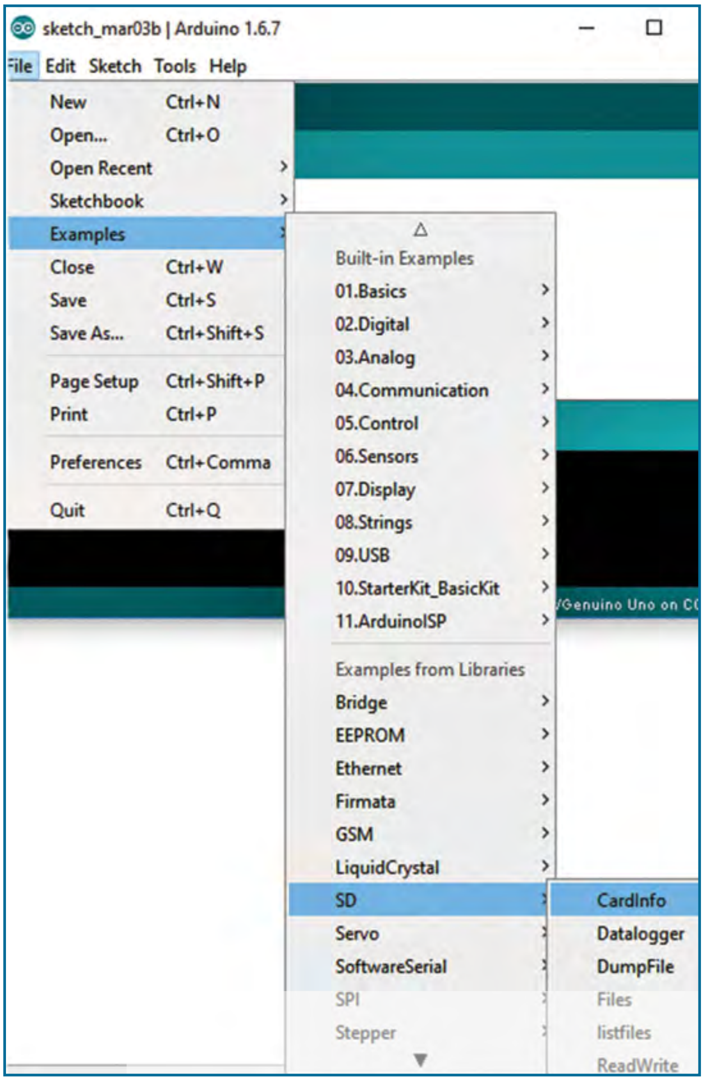


Fig.5.6. Selecting the CardInfo example program

Notice in this code that we've explicitly stated the pin used for the CS signal (in this case pin-10). We could do this in a more elegant way by defining the chip select pin as an integer at the start of the code, like this:

```
const int chipSelect = 10; // CS on pin-10
```

We would then need to change the initialising code so that it reads as follows:

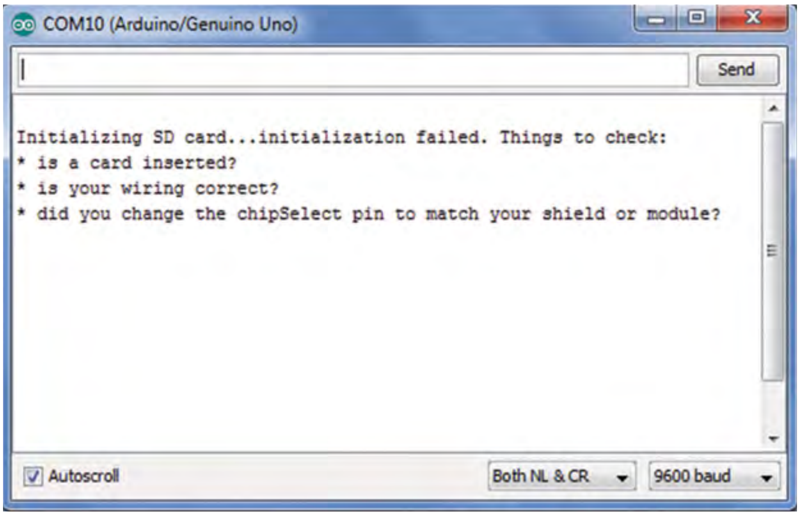


Fig.5.7. When an SD card is not present or non-functional an error message will appear in the Serial Monitor window

```
Serial.print("Initializing SD card...");
if (!SD.begin(chipSelect)) {
  Serial.println("Card not ready!");
  return;
}
Serial.println("Card ready!");
```

Before you can write to a file you need to open it using the `SD.open()` function, as follows:

```
myFile = SD.open("data.dat", FILE_WRITE);
```

If the file opens without an error you will be able to write to it. If myFile returns true, then the file has been opened, but if myFile is false, then an error will have occurred and you will be unable to write to the file. Here's some code that writes a series of values to the file that we've (hopefully) just opened (note that you will need to close the file when you have finished writing to it):

```
if (myFile) {
  Serial.print("Writing file ...");
  myFile.println("207, 188, 219, 155, 0");
  myFile.close(); // Close the file
  Serial.println(" done.");
} else {
  // It didn't open so print an error message
  Serial.println("Error opening the file!");
}
```

Reading a file is just as easy. First you need to open the file for reading:

```
myFile = SD.open("test.txt");
```

Then you need to read data from the file, sending it to the Serial Monitor until you reach the end:

```
if (myFile) {
  Serial.println("test.txt:");
  while (myFile.available()) {
    Serial.write(myFile.read());
  }
myFile.close(); // Close the file
} else {
  // It didn't open so print an error message
  Serial.println("Error opening the file!");
}
```

If you need to see an example of how this code works, take a look in the Example file under the heading SD and ReadWrite in the Arduino IDE.

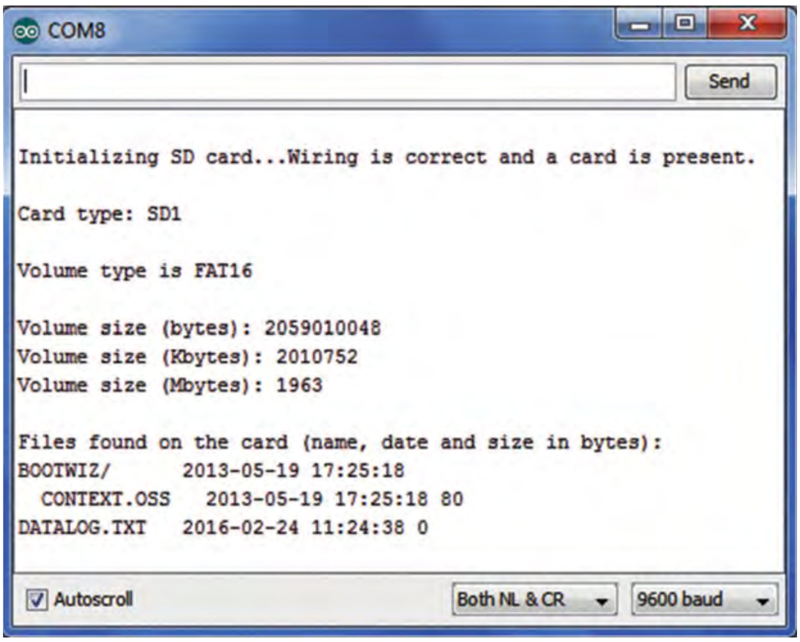


Fig.5.8. CardInfo displays some useful information about the SD card

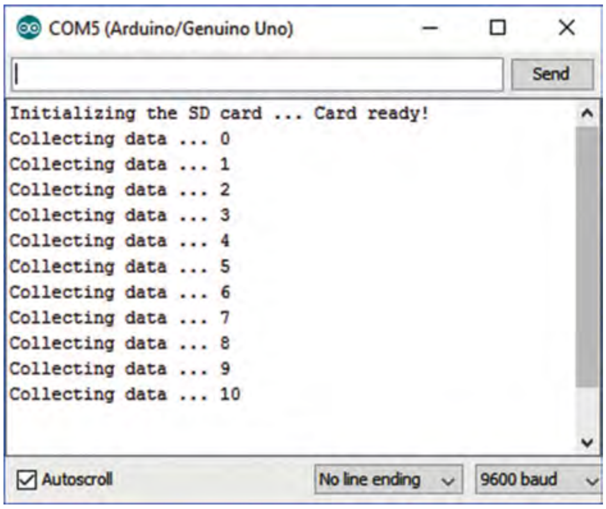


Fig.5.9. The Serial Monitor confirms that the SD card is ready and that data is being captured

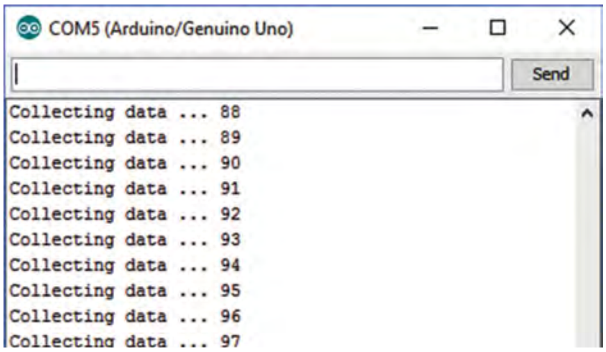


Fig.5.10. After 100 data values have been logged and saved the data file is complete

Get Real : environmental monitor

In this month's *Get Real* we will be describing another useful project that has a wide range of applications in the home and at work. This takes the form of an environmental monitor that will record relative humidity, temperature (in °C and °F), and heat index. Large amounts of data can be captured and stored on a standard SD card and then used for later analysis with virtually any spreadsheet package. The environmental monitor uses a popular low-cost temperature sensor, the DHT11. A typical application for this *Get Real* project would be monitoring the humidity and temperature in a greenhouse, or in any area where plants are cultivated.

You will need:

Arduino Uno with power supply
USB Type-A to Type-B cable
Computer with an available powered USB port
1 DHT11 humidity/temperature sensor
1 Arduino Uno SD card shield
1 SPST switch, S1
1 4.7kΩ resistor, R1 (see text)
1 9V battery or DC power supply, B1
Connecting wires and PCB headers

Listing 5.2 A simple Arduino data logging application

```
/* SD card datalogger - reads analogue input A0 and records 100
data values, one every second */

#include <SPI.h> // Include the SPI library
#include <SD.h>  // Include the SD library

const int chipSelect = 10; // Change as required by the hardware
const int analogPin = 0;   // Input to analogue A0
File outputFile;

void setup()
{
Serial.begin(9600); // Open the serial monitor
while (!Serial) {
  ; // Wait for the serial port to connect
}
Serial.print("Initializing the SD card ... ");
if (!SD.begin(chipSelect)) {
  Serial.println("Card not ready!");
  while (1) ;
}

Serial.println("Card ready!");

outputFile = SD.open("voltage.dat", FILE_WRITE);
if (!outputFile) {
  Serial.println("Could not open the file!");
  while (1) ; // Error so wait for user intervention
  }
}

void loop()
{
int count = 0; // Loop counter
while (count < 100) {
  Serial.print("Collecting data ... ");
  Serial.println(count);
  String dataString = "";  // Create a string to hold the data
  int input = analogRead(analogPin);// Read the input
  dataString += String(input);      // Add it to the string
  outputFile.println(dataString);   // Write data to the file
  outputFile.flush();               // and then flush the buffer
  // Take 1 measurement every second
  delay(1000);
  count = count + 1; // Increment the count
  }
Serial.println("Data file created/appended!");
while (1) ; // Finished so wait for user intervention
}
```

Circuit

The complete circuit of our Arduino Uno environmental monitor is shown in Fig.5.11. Apart from the DHT11 humidity/temperature sensor and the SD card shield, the circuit uses very few

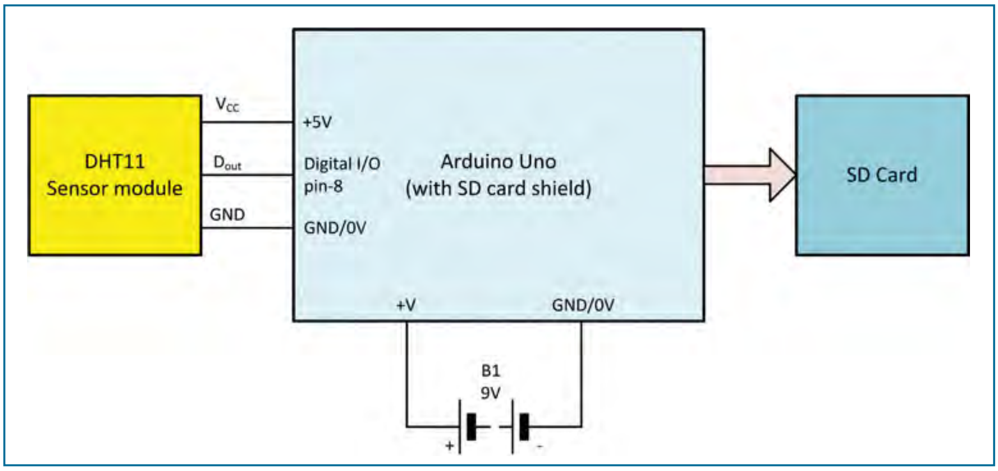


Fig.5.11. Complete circuit of the Arduino-Uno-based environmental monitor

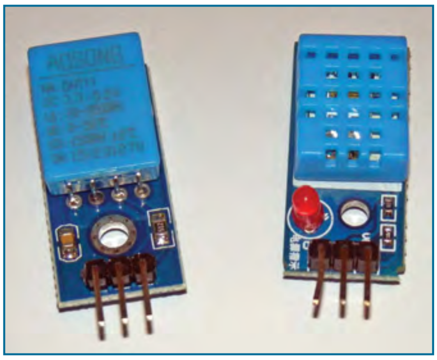


Fig.5.12. Two DHT11 combined humidity/temperature sensors

components and shows just how easy it can be to use an Arduino in a simple but worthwhile application. If you would prefer not to use an SD card shield, you can make use of an SD card module like the one that we used earlier in *Coding Quickstart* – the choice is yours!

The SD card shield mounts directly over the Arduino Uno and it provides a convenient and low-cost way of assembling the components and making connections to the Uno's I/O and power headers. The DHT11 humidity/temperature sensor is normally supplied already mounted on a small printed circuit board (see Fig.5.12) and it will only require three short male/female leads to make the required connections to the Uno's I/O and power connections. If necessary, the DHT11 can be mounted in a small enclosure, taking care to ensure that the sensor is exposed to the external environment. For obvious reasons it should not be mounted in a sealed enclosure!

If you look carefully at Fig.5.12 you will notice that the basic DHT11 sensor is supplied in a small four-pin package, while the printed circuit board has only three pin connections. These pins are often labelled, GND, OUT (for data), and Vs, as shown in Fig.5.13. Note that differently labelled connections are used by different manufacturers, so it is wise to check the actual pin markings on the particular module that you use. Note also that if you are using the basic sensor in its four-pin package you will need to ensure that a 10kΩ resistor is connected between the data terminal (OUT) and the positive supply (Vs or Vcc). This 'pull-up' resistor is not needed if your sensor is supplied already mounted on printed circuit board which has its own 'pull-up' resistor fitted.

When outputting raw temperature and humidity values the 8-bit resolution of the DHT11 humidity/temperature sensor supplies only the decimal part of each, keeping the fractional part zero. The more expensive (and also more accurate) DH21 and 22 sensors fill the fractional parts with data. However, with the lower-cost device the fractional part is not really important as it is usually less than the accuracy of the sensor (which is quoted as typically ±4% of relative humidity and ±2°C for temperature). The DHT11 device is specified for a temperature range from 0°C to 50°C and relative humidity from 20% to 90%. The sensor has a typical response time of 10s and is specified for a maximum cable length of about 20m.

Code

Listing 5.3 shows the complete code for the Arduino Uno environmental monitor. As always, we've included numerous comments in the code to help you understand what's going on. The code requires three libraries: `DHT.h`, `SPI.h` and `SD.h`. The first of these provides functions that facilitate the use of the DHT family of humidity/temperature sensors, while the second deals with the serial peripheral interface (SPI) used by the sensor. The third provides the functions associated with reading from and writing to the SD card. Note that if you are using an earlier version of the Arduino IDE you might also need to include the mathematics library that provides the function for rounding the temperature values before they are stored on the SD card, `math.h`. The rounding function is important to remove the fractional part of the values returned from the DHT11 sensor which might otherwise confuse a conventional spreadsheet program (it might regard the data as text rather than numerical).

For demonstration purposes we've restricted the number of data values captured to 20. We've also kept the interval between capturing data values to the minimum recommended. In practice, you would want to increase the number of times around the loop and also the interval between readings. For stand-alone applications you will also need to remove the serial monitor functions because they will normally only be required for local testing.

As with our previous *Get Real* projects, the code should first be entered into the IDE and then saved before compiling and uploading to the Uno, as described in last month's *Arduino Workshop*. When you have debugged and corrected your code don't forget to save it by clicking on 'File' and 'Save' or 'Save As…'. Next, click on 'Sketch' and 'Verify/Compile'. Any compilation errors will then be reported in the window at the bottom of the IDE. Don't forget that, if they are not already present, you may need to add library files using the IDE's File Manager. The procedure for adding and managing library files was described in Part Three of *Teach-In 2016*.

Listing 5.3 Code for the simple Arduino-Uno-based environmental monitor

```
/* Humidity, temperature and heat index data logging with a
DHT11 sensor. Records data on an SD card */

#include "DHT.h"     // Include the sensor library
#include <SPI.h>     // Include the SPI library
#include <SD.h>      // Include the SD library
#define DHTPIN 8     // Sensor connected to digital I/O pin-8
#define DHTTYPE DHT11
DHT dht(DHTPIN, DHTTYPE);
File outputFile;
const int chipSelect = 10; // Change as required for the SD card

void setup() {
  dht.begin();
  Serial.begin(9600); // serial monitor commands can be removed

  if (!SD.begin(chipSelect)) {
    Serial.println("SD card not present or not recognized");
    return;
  }
  outputFile = SD.open("htsdata.dat", FILE_WRITE);
  Serial.println("Ready .... collecting data!");
}

void loop()
{
int count = 0; // Loop counter
while (count < 20) {    // Change as required
  delay(10000); // Set the interval between measurements
  float h = dht.readHumidity();
  // Read temperature as Celsius (the default)
  float t = dht.readTemperature();
    // Read temperature as Fahrenheit (isFahrenheit = true)
  float f = dht.readTemperature(true);
  // Compute heat index in Fahrenheit (the default)
  float hif = dht.computeHeatIndex(f, h);
  // Compute heat index in Celsius (isFahreheit = false)
  float hic = dht.computeHeatIndex(t, h, false);
  // Prepare data to be written to the card as an ASCII string
  String dataString = ""; // Create a string to hold the data
  dataString += String(round(h)); // Add humidity
  dataString += ","; // Comma separator
  dataString += String(round(t)); // Add raw temp in deg.C
  dataString += ","; // Comma separator
  dataString += String(round(f)); // Add raw temp in deg.F
  dataString += ","; // Comma separator
  dataString += String(round(hic)); // Centigrade heat index
  dataString += ","; // Comma separator
  dataString += String(round(hif)); // Fahrenheit heat index
  outputFile.println(dataString); // Write the data to the file
  outputFile.flush(); // ... and then flush the buffer
  count = count + 1; // Increment the count
  }
  outputFile.close();
  Serial.println("Finished ... data ready!");
while (1) ; // Finished so wait for user intervention
}
```

Testing

When you've corrected any coding errors that the compiler reports you will be ready to upload your code to the Uno. Just click on the upload arrow and watch the progress report. After the Uno performs a reset you should open the serial monitor and check that the SD card has been detected. If the SD card is not present, or if the SD card interface is not functioning correctly, the program will stop and an error message will appear. If this is the case the first thing to check is that you have set the chip select line correctly. Depending on the type of SD card interface, this will usually be 4, 8 or 10.

Once the interface is ready it will start to collect data, writing it to the SD card on each pass through the loop. You should always wait until the program terminates before attempting to remove the SD card so that you can transfer the data to a PC or other device. If you run the program several times (without removing the SD card) you will find that further data will be appended to the file. If necessary, you can always remove the SD card, place it in a PC card reader slot and simply rename the file manually.

The data stored on the SD card is in comma-delimited format. Each time round the loop five data values are stored in the file, namely:

1. The relative humidity (as a percentage)
2. The raw temperature in °C
3. The raw temperature in °F
4. The Centigrade heat index
5. The Fahrenheit heat index.

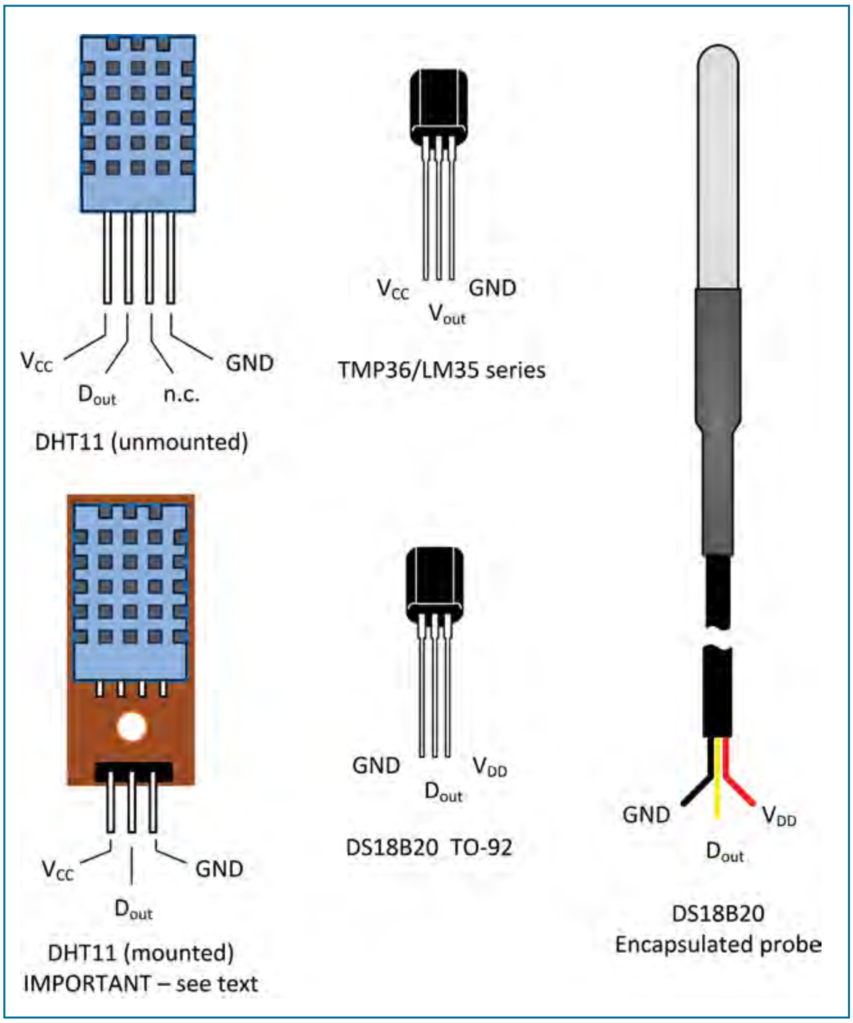


Fig.5.13. Pin connections for various humidity/temperature sensors

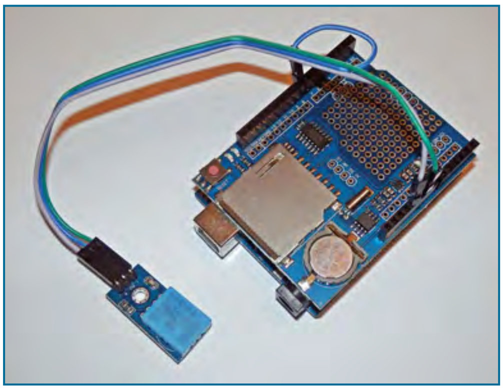
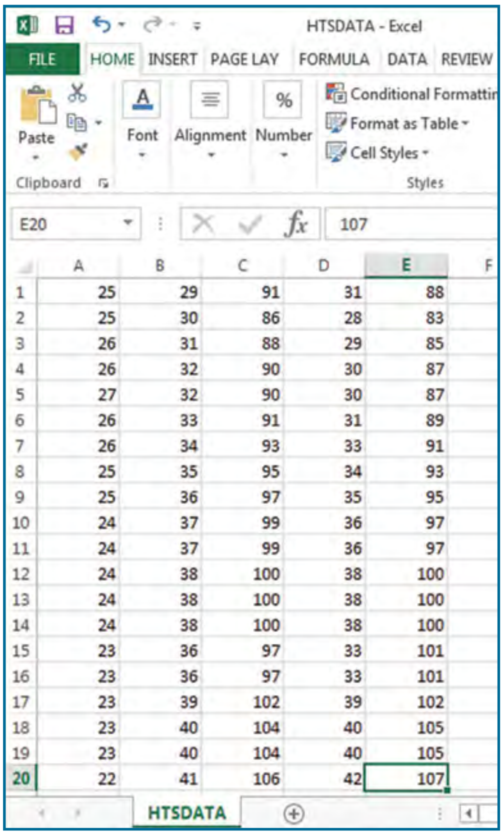


Fig.5.14. Complete Arduino Uno environmental monitor showing the SD card shield / DHT11 humidity/temperature sensor



HTSDATA - Excel

E20 107

	A	B	C	D	E
1	25	29	91	31	88
2	25	30	86	28	83
3	26	31	88	29	85
4	26	32	90	30	87
5	27	32	90	30	87
6	26	33	91	31	89
7	26	34	93	33	91
8	25	35	95	34	93
9	25	36	97	35	95
10	24	37	99	36	97
11	24	37	99	36	97
12	24	38	100	38	100
13	24	38	100	38	100
14	24	38	100	38	100
15	23	36	97	33	101
16	23	36	97	33	101
17	23	39	102	39	102
18	23	40	104	40	105
19	23	40	104	40	105
20	22	41	106	42	107

HTSDATA

Fig.5.15. Captured data is easily imported into a spreadsheet package for analysis

If you don't require all of these values you can simply comment out the ones that you don't need. However, if you import the data into a spreadsheet (such that each set of values appears in a different column) you can easily operate on just those that you need. Note that, in common with many spreadsheet packages, if you open the data file in Excel you will need to specify that the file uses 'delimiters' and that the character used as the delimiter is a comma. Fig.5.15 shows how a typical set of data appears when imported into Excel, while Fig.5.16 shows how the data can be represented visually within Excel.

Going further

As always, there's a great deal of scope for going further with our Arduino-based environmental monitor. Alarms could be set when critical values are detected and outputs could be used to operate indicators, piezoelectric sounders or relays. Another refinement might be date/time stamping of the filename (we will be looking at this in a later instalment of *Teach-In 2016*) so that unique names are generated each time the program is run. All of this is relatively simple to do and will provide you with a great opportunity to further develop your coding skills.

Next month

In next month's *Teach-In 2016* we will be looking at ways in which an Arduino can communicate with remote devices using low-cost wireless modules. To this end, *Arduino Workshop* will introduce wireless modules while *Arduino World* looks at short-range wireless systems that will allow you to send data from one Arduino to another. Our programming feature, *Coding Quickstart*, introduces the RadioHead Packet Radio library for embedded microprocessors. Finally, our *Get Real* project will take the form of a simple wireless-linked rain alarm.

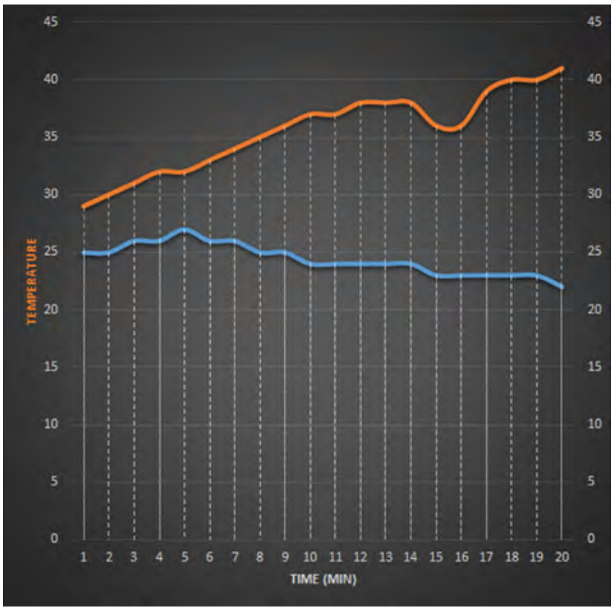


Fig.5.16. A graph produced by Microsoft Excel showing how the humidity (blue line) and temperature (orange line) vary during a period in which 20 sets of data have been captured by the Arduino Uno environmental monitor

WYSIWYG

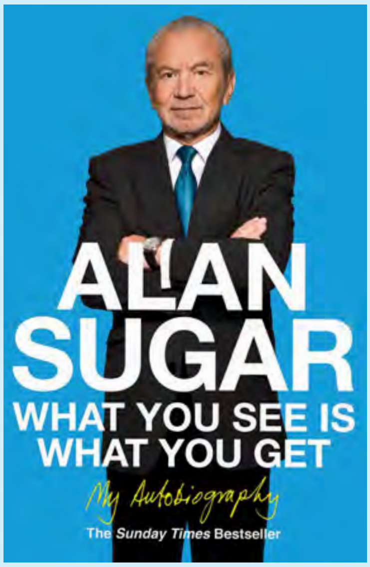
Alan Winstanley

Today, Lord Alan Sugar is perhaps best know for his appearances on television as the gruff hirer and firer in *The Apprentice*. However, if you grew up in the 1970s, 80s or 90s then it will be his market-dominating, keenly priced electronic equipment that you associate with the name 'Sugar'. Alan Winstanley reviews the entertaining autiobiography of a giant of Britain's retail electronics industry.

ALAN SUGAR is the name behind 'Amstrad', a brand that will be familiar to European consumers of audio and home computer equipment from the 1980s onwards. His story is a genuine and warming rags-to-riches tale and his autobiography charts the ascent of Alan (now Lord) Sugar from boyhood. As a lad from the East End of London, his opportunistic approach to life took shape early on, as he describes how, aged 11, he collected woollen offcuts from a garment factory to re-sell to a rag-and-bone merchant; he wheeled pramloads of tar- impregnated wooden blocks from roadworks and resold them as firelighters; he would even bottle and sell ginger beer. He progressed into amateur photography and repackaged large cans of 35mm film into cartridges to resell to his schoolmates: anything to earn some precious pocket-money.

He describes the incomprehension felt when he was gradually cold-shouldered by his East-End friends, simply because he came from a Jewish family. Undeterred, he writes how he left school and sought a 'scientific' job but failed an interview for a trainee programmer with IBM. Very satisfyingly, 24 years later he would sign a licensing agreement with IBM and snatch 30 percent of the European PC market away from them; he also bought IBM's European HQ in London for £112 million ($168 million), he writes with justifiable pride.

The principles of business were fast sinking in, and he learned some painful lessons along the way. Seizing opportunities, sourcing products, marketing and reselling almost anything for a profit, business became his lifeblood. As a young salesman for various electrical wholesalers, he learned of brands, customers, profit margins and how the 'electricals' sector worked. One shop has a stack of faulty TV sets going free, so Alan Sugar hit upon the idea of reconditioning and reselling them himself. Eventually this lucrative sideline allowed him to quit the day job and set up his own business and the AMS Trading Company was born, selling car aerials.



What You See Is What You Get
Alan Sugar
First published 2010
Pan Books
ISBN 978-0-330-52047-8

His rise to success in Europe's audio and computer market would be spectacular. Along the way he introduced injection-moulded record deck covers, vinyl-covered loudspeakers (a tough sell!), the 'tower' Hi-Fi and twin-cassette decks, all industry firsts in their time. The book describes in captivating detail how he launched his own British-made audio range at affordable prices, dealing with retail chains like Comet, Dixons, Laskys, Currys and others. He shares some comical nuggets about Amstrad product development (using buttons from the hotel sewing kit to mark out the apertures for a CB handset, for example). An unswerving hands-on man, the book is a treasure trove of detail that spells out the nitty-gritty of his career in those pioneering days: you can almost smell the solder fumes at times.

From Hi-Fi to PCW

The audio market then peaking, I will be forever grateful that Alan Sugar diversified in the mid-1980s and produced a highly successful self-contained word processor, the famous Amstrad PCW range – a machine that played a role in shaping my own early career. Amstrad then rescued the Sinclair brand, and the autobiography lays bare the almost unbelievable gamble that he took before closing this groundbreaking computer deal.

As you would expect, *What You See Is What You Get* is a very frank, candid and often abrasive insight into Lord Sugar's success story, written exactly as he speaks and his opinions on some British brands and institutions (unprintable in EPE!) pull no punches. It charts his life from a council-flat upbringing all the way to his entry to the House of Lords and the firm's acquisition by BSkyB. As someone whose life embraced the Amstrad brand in the 1980s and 1990s, I found Alan Sugar's story an enthralling and inspirational one and I simply could not put the book down. Readers of my generation will certainly enjoy it.

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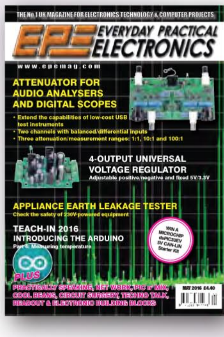

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NET WORK

by Alan Winstanley

It's a cardboard world

IN a former career, the writer designed, amongst other things, all kinds of consumer product packaging, even down to the humblest cardboard box. The joys and qualities of corrugations (known as 'flutes') of an 0201 double-wall corrugated carton (palletloads of them) made of 150 Kraft/Test B/C flute frequently received his earnest attention. The integrity of packing cases was tested by shipping full ones all the way to London and back, and if the contents were still intact on arrival then we had a winner. If you're interested, the industry styles for common cartons are depicted on manufacturers' websites such as: **www.allpack.co.uk/styles.htm**

The applications for corrugated cardboard are legion, and the material's surprising strength can be realised by utilising the flutes perpendicular to the direction in which they run: it wraps around things easily in one direction, but if you roll some up into a solid shape the result is so strong that you can stand on its ends without a qualm. The world of virtual reality has also been harnessing the merits of corrugated board: specifically, 'Google Cardboard' is the name for Google's VR application and cheap and cheerful VR viewers made from cardboard now permit smartphone owners to immerse themselves in a virtual world, powered by the Internet. Now that you're intrigued, this month's *Net Work* gets to grips with Cardboard!

VR headsets

Readers might have noticed online or TV adverts featuring the latest wave of VR headsets – large plastic visors held in place with headbands while the wearer turns and bobs around in any direction to view a 3D virtual environment (looking up at stars and galaxies, for example). These wrap-around viewers contain a smartphone running an app with fixed 'spectacle' lenses focussing on the phone's LCD screen. More expensive models might have adjustable lenses to focus the wearer's eyes on the display. Split-screen footage is viewed stereoscopically through the lenses and the wearer can 'travel' in three dimensions, perhaps taking a virtual tour of the Large Hadron Collider (LHC) or going on a rollercoaster ride. Movies can also be viewed privately this way.

Google Cardboard is a nifty example of lateral thinking that aims to bring the virtual world experience to anyone with a smartphone. There's no need to buy expensive, elaborate plastic visors when a Google Cardboard-compatible viewer can be produced cheaply from, er… cardboard! Google released blueprints for their viewer as open source, showing the dimensions and direction of those all-important flutes. Anyone can manufacture Cardboard viewers to this standard and a good variety is now readily available online. As smartphone screen sizes have grown within the last couple of years, Google's original effort announced in 2014 proved too small to contain the latest-generation phones, so Cardboard V2 is intended to accept any modern Android phone or iPhone up to 6-inch screen size. The new Cardboard V2 is also much easier to build than its predecessor (think of assembling R-Kive banker's boxes, only smaller) and V2 has an improved 'switch', more of which shortly.

Google Cardboard V2 viewer showing the smartphone positioned inside. The rear flap is secured with the Velcro fastener on top

A Cardboard V2 viewer arrives in a small carton (what else?) that is precision diecut from E-flute corrugated sheet with an oleophobic (oil-repellant) skin-safe coating. To assemble, simply fold back the sides of the carton and secure them using the Velcro dots already in situ, which takes seconds.

Board's eye view

All Google V2 Cardboard-compliant viewers are licensed to the same specification. For my own tests I chose the 'Minkanak Cardboard V2', which costs about £14 ($20). The plastic stereoscopic lenses are the standard 80° 34mm (visible) Google spec. with 64mm, IPD (interpupillary distance) and the viewer has that all-important capacitive switch: this is effectively an elaborate cardboard lever that, when pressed, delivers a gentle 'tap' to the touchscreen using a small pillow of metallised conductive foam. This allows you to use on-screen menus and controls, or explore the virtual environment by pressing the button like a camera shutter to tap the screen. A stick-on piece of foam rubber, included as an extra, greatly improves comfort on the nose when holding the viewer up to your eyes: it's a must-have. An elastic headband is also bundled with the kit, which can be stuck onto the box using some Velcro strips supplied to make the visor hands-free. The purpose of a mysterious elastic band supplied with the kit is not explained anywhere. In fact, it acts as a simple grip to prevent the smartphone from sliding around. It's fitted on the base of the rear flap near the hinge perforation.

Set up and use

Setting up and using Cardboard V2 could not be simpler. Some QR codes (see *Net Work*, August and September

A capacitive button applies a gentle tap to the screen when pressed – this idea works well

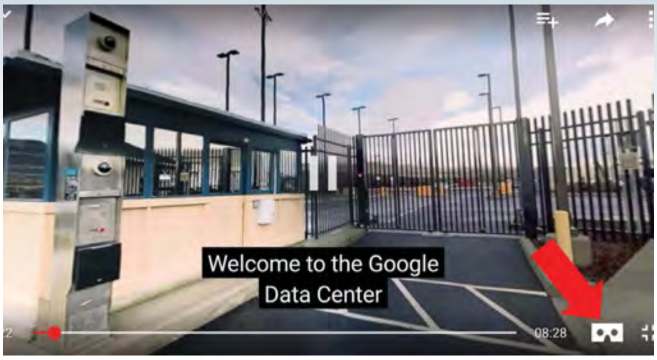
2011) printed on the instructions can be scanned to play an assembly video and also download some 3D apps for Android or iPhone. The Cardboard app is soon installed and a 'Viewer Profile' QR code printed on the viewer is scanned by the smartphone. This programs the Cardboard app for that individual visor's screen-to-lens distance, separation and other parameters incorporated by the manufacturer.

Also supplied is a blank NFC tag to stick inside the viewer, so by using a suitable app such as NFC Tools, users can make their NFC-enabled phone run the separate Cardboard app with one tap. (Details of using Near-Field Communications were outlined in *Net Work*, February 2014.) To program the NFC tag, open NFC Tools and choose to Add an Application Record, selecting Google Cardboard from the list of apps. Then write this to the NFC tag by tapping the tag with the phone, and then you can stick the programmed tag onto the rear flap. In future, the Cardboard app will open automatically on your phone when you tap the tag.

Users will soon recognise the new Cardboard icon that appears in compatible videos or apps. By tapping it, the smartphone switches to VR split-screen mode with a bold white line down the centre: this aligns with the V-notch in the viewer aperture, and then the phone is placed in the viewer and secured using the cardboard flap and Velcro fastener. The principle was effective enough with the author's HTC One phone.

The Cardboard app includes virtual tours and a basic Google Street View demo. Menus can be accessed on-screen by moving the VR viewer to align a dot or circle with a menu item, then press the 'camera button'. It works very well and in no time the author was taking a virtual tour of the Palace of Versailles, the brief tour enhanced by the stereo sound of the HTC One. With last month's column in mind, a very interesting virtual 360° tour of a Google data centre can also be taken.

Smartphone in split-screen VR mode



A 360° Cardboard-compatible video, with Cardboard icon (arrowed)

The Google Street View app takes on a whole new dimension – literally – when viewed through Cardboard. Traditionally, Windows PC users are probably used to opening Google Maps in a web browser and then dropping the yellow 'Pegman' icon onto a street to launch Street View at that location. An Android mobile phone includes a stand-alone Street View app, so if Wi-Fi is available you can open Street View and choose the 'Explore' menu. Swipe around to find a place of interest or type a location into the Search box. Pegman soon appears on the map and photo snapshots of that locality displays on-screen. Click a photo to enter Street View mode: if necessary, tap or swipe at the top to display the menu and the Cardboard icon will appear. Tap it and the screen changes to split-screen mode and the smartphone can now be inserted into the Cardboard viewer. If you're used to mousing around on a widescreen web browser then this setting-up process on a phone screen is pretty fiddly.

Follow the arrows

Navigating or looking around in Street View means turning one's head – the display changes view accordingly – and pressing the button when a Street View arrow icon is in view will move you to the next snapshot, in the same way that the PC-based version works. It is worth remembering that Google Street View may have several iterations of the same scene if Google re-photographs the locality several years later, and users can find themselves suddenly going back in time if the display reverts to an earlier version. This was the case with Wimborne's town centre, for example, which mysteriously changed to show a one-way traffic scene with smart new shops, before reverting to the old scene from years earlier. It is sometimes frustrating to get 'trapped' in a location and you may have to remove the phone and start again.

Over on Youtube, some videos are shot in 360° and can be viewed on Cardboard the same way. Other apps to explore are offered by the Cardboard app, or visit **https://www.google.com/get/cardboard/apps** or the Google Play Store to fetch more VR apps. Some file sizes are huge (350MB or more) and Wi-Fi is a must, and do note that a few may tempt you with in-app purchases too. Sadly, some promising-looking VR apps were a bit unstable on the author's phone and were quickly uninstalled, and one or two tended to flicker, which is possibly a hardware problem. However, the VR guide tour of a Google data centre worked perfectly and it was fascinating to experience the sight and sounds of a typical server building.

The cardboard casing itself is reasonably hardwearing and I estimate it should last a few months or so. The need to open and close the rear flap contributes most to wear and tear. Small Bluetooth wireless controllers are sold separately, which acts as a gamepad (joystick and button controller) or camera shutter. This removes the need to press the Cardboard button and will be handy if you wear the viewer using headbands; it means you can navigate around menus and options in hands-free mode.

Be warned that sometimes a lot of head-swivelling (body too!) comes as part of the deal, and sitting on my office swivel chair helped an awful lot! The 'floaty' feel of some apps may bother some users and some scenes can sometimes drift a little. After a while, the process can become a bit dizzying, which can induce a little nausea if users overdo it – some users can only manage a few minutes before stopping. It's like getting used to life at sea.

Google Cardboard makes virtual reality more accessible and it is a remarkable achievement given the extent of technology and resources being offered to us, just for the price of a cardboard box. The Minkanak Cardboard V2 viewer, along with many alternatives, is readily available on Amazon and eBay, so now you can explore virtual reality cheaply and easily.

Still on a VR theme, cutting-edge virtual reality has also been applied to a familiar old retro toy in the shape of the View-Master Viewer that many of us grew up with as youngsters. Remember those enchanting circular film discs? Mattel's View-Master VR is the latest iteration of the classic toy, which uses an app and 'Experience Packs' such as Destinations or Space on a smartphone to produce an augmented and virtual reality experience through its viewer. It is intended for children aged seven years or older. More details are at: **www.view-master.com** or the YouTube channel at: **http://preview.tinyurl.com/j2jmkrg**. The View-Master VR viewer is readily available in major stores and online.

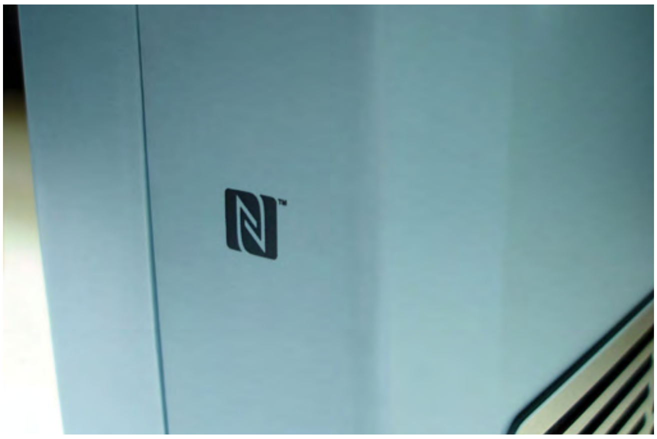
21st century radio

Somewhere in the bottom of a wardrobe – Ah, there it is! – lies our faithful old portable radio, which my counterparts on sister magazine *Radio Bygones* will recognise instantly. The Bush TR130 is a British design icon from the 1960s and apart from its crackly potentiometers, my one plays as well as ever. Its large air-spaced tuning capacitor is visible through the tuning scale, and its germanium transistors have held up well over the decades.

In with the new... Goodmans Oxford BT is a fresh new version of the classic Bush TR130 portable radio

Like the Mattel View-Master, the Bush TR130 has recently enjoyed a 21st Century makeover, taking the shape of a delightful remake sold under the popular Goodmans brand. The Goodmans Oxford BT is a cute DAB/FM portable radio in the same retro style housing of the Bush, with a modern technological twist up its sleeve. Bluetooth is built in, and there is also an NFC icon on the side of the radio. By tapping it with an NFC-enabled phone, the Goodmans Oxford BT pairs instantly with it to become a retro-styled Bluetooth loudspeaker.

I found this idea irresistible and treated the household to an Oxford BT moulded in an attractive sky blue plastic (other colours are available). The radio is extremely simple to use and the familiar-looking tuning control scrolls through a list of DAB stations. Reception and audio quality were crystal-clear. The Bluetooth pairing and NFC functions were totally flawless and – here's the *Net Work* interest – using my smartphone on Wi-Fi I quickly accessed music stored on my Synology NAS and played it over the Goodmans portable radio. NFC is still seen as a bit of a novelty and it was encouraging to see NFC being used sensibly in this way.



Tap an NFC-enabled smartphone to pair it to the Goodmans Oxford BT

Overall, it's a welcome and charming redesign of an old family favourite that works perfectly, drawing admiring comments from several visitors too. The Goodmans Oxford BT is battery (6 × C cells) or mains powered and is available from several online retailers including **very.co.uk**. Please check carefully before you buy: if you want the Bluetooth connectivity then be sure to seek out the newer BT version (also called Oxford II) and not the *earlier* Oxford radio, which is not Bluetooth or NFC enabled. More details are at: **www.goodmans.co.uk/product-oxford-bt.html**. Retro-styled tabletop 'heritage' radios are also available from Goodmans, which also offer Bluetooth connectivity the same way, providing a novel way of listening to your music over your local network.

See you next month, when I will bring you more news of current trends and online developments. You can email the author at: **alan@epemag.demon.co.uk**

INTERFACE

By Robert Penfold

Raspberry Pi 3

IT DOES NOT seem that long ago that the Raspberry Pi 2 Model B was launched, but the new Raspberry Pi 3 Model B (Fig.1) is now readily available. It was launched exactly four years after the original version was released onto the market, and sales of the various Raspberry Pi boards now exceeds eight million. Version 2 did not look significantly different to its predecessor, the Model B+, and visually there is not a great deal of difference between the new Raspberry Pi and the two previous versions (Fig.2). The audio, HDMI video, Ethernet, and four USB 2.0 ports are all there on the board, and in more or less the same places as before. Of more importance in the current context, it still has a 40-pin GPIO port that is unchanged from the B+ and Model 2 B, and with a suitable lead it can be used with hardware designed for use with the original 26-pin GPIO port.

Lead free

There are some important enhancements on the new Raspberry Pi, in the form of wireless connectivity. It has both Bluetooth and Wi-Fi built-in. In addition to making it easier to connect the unit to the Internet, this should make it possible to use it with a wide range of hardware such as printers, keyboards, mice, and headphones without the need for any leads. The Raspberry Pi boards are all quite small, and unless fixed to something fairly substantial, a Pi board tends to go where the leads dictate, rather than where you would like to position it. The thicker leads can put quite a strain on the port connectors. Fewer leads might ease the situation, in addition to reducing the tangle of 'connection spaghetti' that you seem to end up with before too long.

The processor has been upgraded to a 1.2GHz 64-bit quad core ARM Cortex-A53 CPU. The higher clock speed and other improvements are said to give a speed increase of about 50 to 60 per cent compared to version 2 boards, and a potential tenfold increase over the original Raspberry Pi. With software that cannot exploit the four cores of the processor, the new version is still about 2.5-times faster than the original model A/B boards.

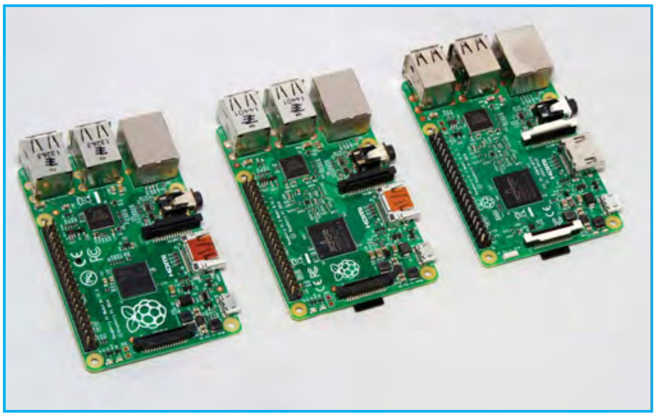


Fig.2. If you've seen one, you've seen 'em all. Visually there is little difference between the Model B+ (left), the Pi 2 Model B (middle), and the Pi 3 Model B (right)

There is more power available from the four USB ports, making it possible to use some peripherals directly, where a powered USB hub would be required with previous versions. However, a 2.5A power supply is now needed in order to ensure that the board itself, plus the USB ports do not pull the supply to an inadequate voltage and crash the computer. An approved 5.1V, 2.5A mains adapter is available (Fig.3), but for some reason this is not recommended for use as a general-purpose power supply for gadgets that have a mini USB power connector.

Adaptors with a lower current rating can be used with the Raspberry Pi 3, but the power available from the USB ports will be reduced accordingly. Also, it has to be borne in mind that the extra hardware of the new version, together with its higher clock frequency, result in the board itself

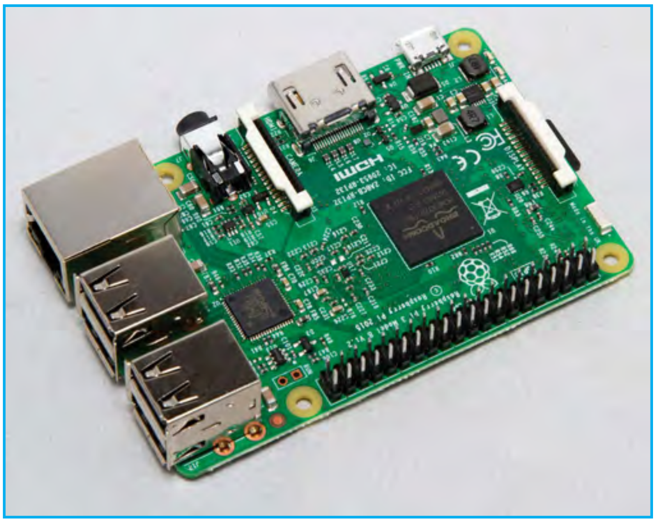


Fig.1. The new Raspberry Pi 3 Model B retains the all-important GPIO port, which is a 40-pin type that is compatible with hardware for earlier versions. The new Pi also has built-in Wi-Fi and Bluetooth wireless connectivity

Fig.3. More power is needed to fully exploit the USB ports of the new Raspberry Pi. This is the official 5.1V, 2.5A mains power supply, complete with adapters that enable it to be used internationally

having a higher current consumption than its predecessors. An adapter that is just about adequate with a previous version might not be up to the task of powering a version 3 board. I found that it worked all right with a 1.6A supply, but this probably leaves little current available for peripherals connected to the USB and GPIO ports. The USB ports are still of the USB 2 variety, not USB 3.

For the time being at any rate, no earlier versions are being discontinued with the introduction of the Raspberry Pi 3. If all you need is something like a model B+, then it should still be available.

Counting on it

An ultra-simple capacitance meter project for the Raspberry Pi was described in the previous *Interface* article. This had limitations due to its use of the built-in timing facilities of Linux and the Python programming language. Better results can be obtained in many applications by using an external binary counter and clock oscillator. It is possible to count pulses on a GPIO input line, but using a Python program it is likely that pulses will be missed at input frequencies of anything more than a few kilohertz. An inexpensive binary counter chip can typically handle input frequencies of up to about 100MHz. The built-in timing facilities seem to struggle with even 1ms (one millisecond) resolution, but using an external crystal oscillator a resolution of 100ns (0.0001ms) is easily achieved.

The 74HC4040 is a good choice for a binary counter for use with a Raspberry Pi, since it is reasonably inexpensive, and works well on a 3.3V supply. This enables it to operate with the GPIO input/output lines without the need for any level shifting. The high-

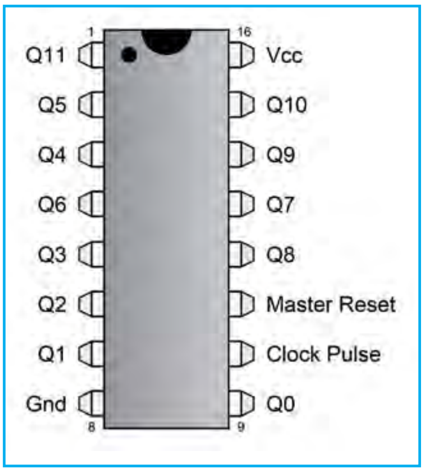


Fig.4. The pin functions for 16-pin DIL versions of the 74HC4040 and 4040B binary counter chips. Using a 3.3V supply the 74HC4040 can operate with clock frequencies up to at least 50MHz

speed CMOS version is preferable to the ordinary 4040B CMOS device because it can operate at much higher frequencies when a 3.3V supply must be used. The maximum clock frequency depends on the particular example of the chip and the load capacitance, but it should operate up to at least 50MHz, and in most cases it will go to 90MHz or more. The 4040B is limited to operation at no more than about 2MHz when used with a 3.3V supply, although this is certainly adequate for some applications.

Pin functions for the 16-pin DIL version of the 74HC4040 and 4040B chips are shown in Fig.4. It is basically a series of twelve divide-by-two circuits, with the outputs available on Q0 to Q11. This gives the required binary counter action, with Q0 and Q11 respectively providing the least- and most-significant bits of the count. The input signal is applied to the negative-edge-triggered Clock Pulse input. Taking the Master Reset input high blocks the clock pulses and sets all twelve outputs low. Placing this input low activates the device, and the input pulses are then counted. If the maximum count of 4095 is exceeded, the count cycles back to zero and starts again from there. Any number of counters can be used in series to give a higher maximum count. It is just a matter of connecting the Q11 output of one counter to the Clock Pulse input of the next one in the chain. The Master Reset inputs are simply connected together and driven in unison.

Throw of the die

As an initial experiment with an external counter I tried the circuit of Fig.5, which is intended to be used as the basis of a random number generator, and an electronic die. A common way of generating random numbers digitally is to have a counter that cycles through its full range at high speed. In order to produce a random number, it is just a matter of halting the count and reading the value stored in the counter. There is no way of predicting the number held in the counter at the instant the count is stopped, as it could be at any number in the full range of values covered by the counter. This method is analogous to some mechanical methods of generating random numbers, such as roulette wheels.

The clock signal is generated by a crystal-controlled Colpitts oscillator based on Tr1, which operates as an emitter follower. Crystal X1 effectively forms a centre-tapped tuned circuit in conjunction with C2 and C3. The voltage gain through Tr1 is slightly less than unity, and is not sufficient to sustain oscillation. However, in-phase feedback from the emitter of Tr1 to the centre tap does produce oscillations due to the voltage step-up through the tuned circuit. Tr2 operates as a common-emitter amplifier, which ensures that there is a sufficiently strong output signal to drive the counter circuit reliably.

IC1 is the 74HC4040 binary counter. With a clock frequency of 10MHz it is essential to use a 74HC4040 for IC1, and not an ordinary CMOS 4040B. The Master Reset input at pin 11 is simply connected to the 0V supply rail because the starting count is unimportant in this application, and the counter must

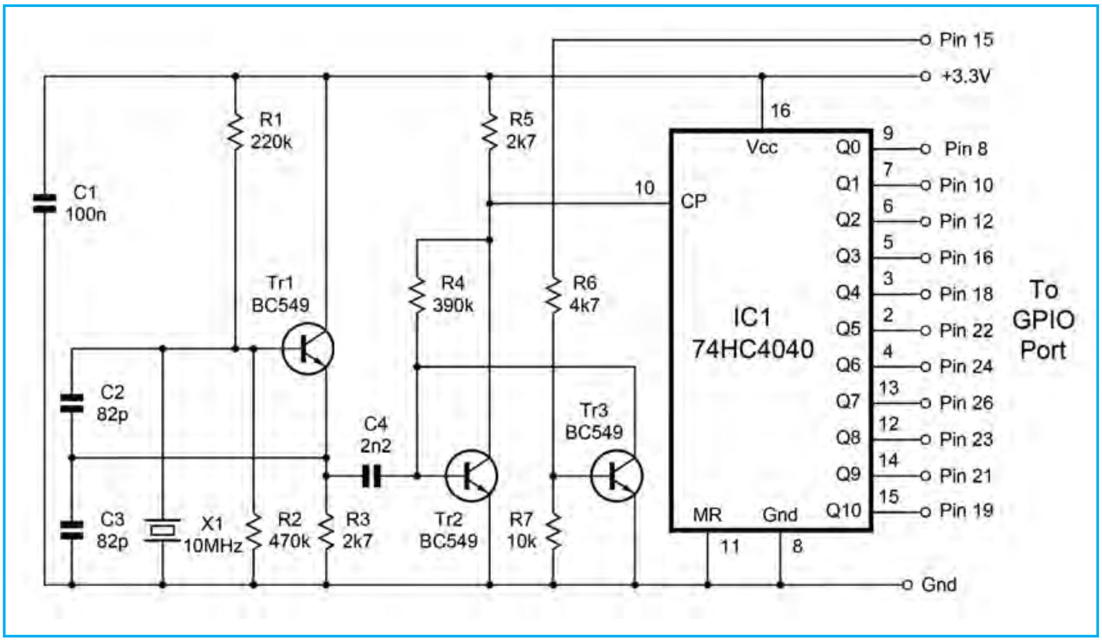


Fig.5. The circuit diagram for the random number generator. A high control signal from the GPIO port is used to switch on Tr3 and halt the count so that a reading can be taken.

cycle until it is halted by stopping the clock signal. This gating of the clock signal is achieved by using an output of the GPIO port (GPIO 17 at pin 15) to control Tr3, which is used as a simple switching transistor. With a low control signal, Tr3 is switched off and the circuit functions normally. A high control signal switches on Tr3, which in turn cuts off the base current to Tr2, switching it off and blocking the clock signal. This is only done briefly while the counter is read, and the control signal is then returned to the low state.

I only implemented 11 of the 12 outputs, because subsequent counter projects would only require a 10-bit count plus an additional bit to act as an overflow counter. Simply omit the connections for the most-significant bits if less than an 11-bit count is required. There are plenty of unused lines left on the GPIO port, so the twelfth bit could be implemented, if required. In fact, with a 40-pin GPIO port there are sufficient lines to handle all 24 outputs of two 74HC4040s connected in series.

The 74HC4040 is a CMOS device, and it therefore requires the usual anti-stating handling precautions. Any fairly high gain silicon NPN transistors can be used for Tr1, Tr2, and Tr3. The exact clock frequency is not important in this application. It simply needs to be quite high, and a crystal oscillator provides an easy way of generating a suitable clock signal. Any crystal having an operating frequency in the range 4MHz to 16MHz should work well in this circuit.

Software

The Python program of Listing 1 generates and prints a random number in the range 0 to 2047, and uses some simple mathematics to produce from this the die simulation, with a number from 1 to 6 being printed on the screen. The first section of the program does the usual initial setting up, and then the next section sets the appropriate eleven GPIO lines as inputs, and one as an output. At the beginning of the main section of the program, the output at pin 15 is set high (True), which halts the count.

The variable called `'byte'` is then set to an initial value of zero. The eleven inputs are then read one-by-one, and `'byte'` is augmented by the appropriate value if a bit is set high. This eventually builds up the full 11-bit value in `'byte'`, which is then printed on the screen. Pin 15 is then set low again so that the counter starts cycling through its range of values again. A `do... while` loop is used to repeatedly deduct 6 from the value stored in `'byte'`, stopping when the value is no longer greater than 5. This gives a number in the range 0 to 5, and 1 is added to it to give a number from 1 to 6, which is then printed on the screen.

With the aid of an external binary counter and a clock generator it is possible to produce some useful and interesting Raspberry Pi projects. This is something that will be explored further in the next *Interface* article, with an improved capacitance meter project.

Listing 1

```
import RPi.GPIO as GPIO
GPIO.setmode(GPIO.BOARD)
GPIO.setwarnings(False)

GPIO.setup(8, GPIO.IN)
GPIO.setup(10, GPIO.IN)
GPIO.setup(12, GPIO.IN)
GPIO.setup(16, GPIO.IN)
GPIO.setup(18, GPIO.IN)
GPIO.setup(22, GPIO.IN)
GPIO.setup(24, GPIO.IN)
GPIO.setup(26, GPIO.IN)
GPIO.setup(23, GPIO.IN)
GPIO.setup(21, GPIO.IN)
GPIO.setup(19, GPIO.IN)
GPIO.setup(15, GPIO.OUT)

GPIO.output(15, True)
byte = 0
if GPIO.input(8):
        byte = byte + 1
if GPIO.input(10):
        byte = byte + 2
if GPIO.input(12):
        byte = byte + 4
if GPIO.input(16):
        byte = byte + 8
if GPIO.input(18):
        byte = byte + 16
if GPIO.input(22):
        byte = byte + 32
if GPIO.input(24):
        byte = byte + 64
if GPIO.input(26):
        byte = byte + 128
if GPIO.input(23):
        byte = byte + 256
if GPIO.input(21):
        byte = byte + 512
if GPIO.input(19):
        byte = byte +
1024
print (byte)
GPIO.output(15, False)
while byte >5:
        byte = (byte -6)
print (byte +1)

GPIO.cleanup()
print ("Finished")
```

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PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

PICs and the PICkit 3: A beginner's guide – Part 1

MICROCHIP'S recent release of their new cloud-based integrated development environment (IDE) – MPLAB Xpress – means this is a great time to return to basics and look at why and how you should design, build and program your own PIC-based projects. This new series is intended for anyone who's curious about the PIC, but doesn't know where to start. It's also for those of you, who may have plenty of experience, but wouldn't mind a refresher. MPLAB Xpress is a great opportunity for newbies to take the plunge and start 'PICing'.

Why use the PIC?

First off, a simple question: 'why use a PIC, and why not an Arduino or a Raspberry Pi?' I could write pages and pages about the differences between a wide variety of electronic platforms, but let's do a brief comparison with the Arduino and Raspberry Pi, two of the most popular non-PIC routes to adding intelligence to a project.

Microcontrollers and Microprocessors

Let's be clear, the PIC, Arduino and Raspberry Pi are all very different beasts. The PIC is a microcontroller and also just a single component. The Arduino is a microcontroller-based kit, and the Raspberry Pi is a multi-component, single-board computer with a microprocessor. That doesn't tell us too much, so let's examine the difference between a 'microprocessor' and a 'microcontroller'. A microprocessor contains a central processing unit (CPU), which contains registers, clocks, memory and programmable logic. We control this with a piece of software stored in memory that alters the registers and the programmable logic at a specific clock speed. This is a simplification, but it will suffice for the moment, as we will be returning to explain these concepts when we begin to code.

Building upwards from that we have a microcontroller, which contains a microprocessor with all its registers, *but* it also contains programmable input and output peripherals. Peripherals are our bridge to the outside world, whether it be a simple LED, an analogue sensor or a sophisticated motor controller. It can also contain much more memory space than a microprocessor. Think of a microprocessor as the brain, but a microcontroller is a brain with arms, legs, sensory capability and everything else you'd want in a fully functioning 'body'. The advantage of having the full body is that you can program it to do anything and everything. The PIC range, with its choice of inputs and outputs is one such example of a microcontroller. The AVR family of devices from manufacturer Atmel is another microcontroller. It was actually the ATMega128 (one of the AVR family of ICs) that was used in the original Arduino board. See Fig.1 for a comparison of the PIC and the AVR – they do look alike.

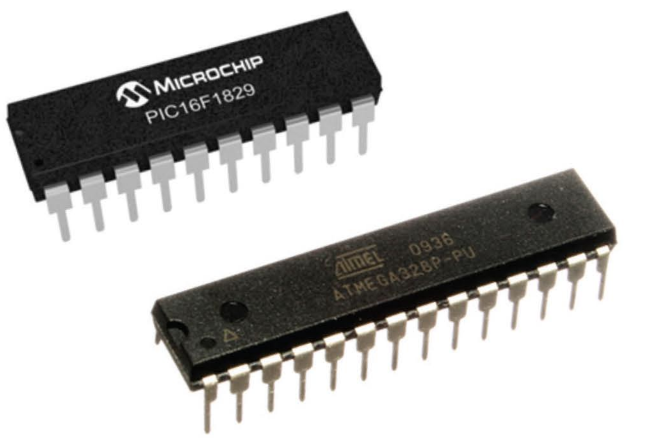


Fig.1. (top) Microchip's 8bit PIC16F1829-I/P and (bottom) ATMEL's 8bit AVR ATMEGA328p

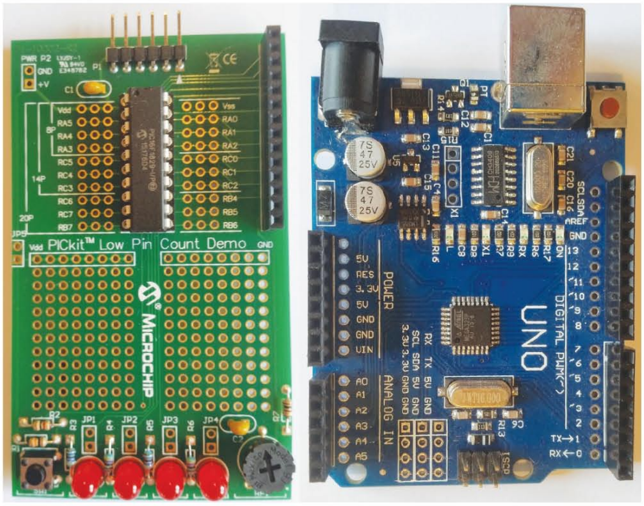


Fig.2. (left) Low Pin Count Demo Board, our PIC board of choice for beginners and (right) the popular Arduino Uno

It is interesting to note that although the AVR from Atmel is a direct competitor of Microchip's PIC microcontrollers, Microchip recently bought Atmel. Now, this doesn't necessarily mean we'll see PICs in the same Arduino format, because Arduino is actually an Italian company that just happens to use Atmel's ICs. But it does mean some interesting changes in the future for hobbyists and professionals alike.

Back to our comparison – the PIC is a single integrated circuit. To operate it needs to be connected to a board, with a power supply and some extra components. Atmel's AVR is exactly the same. Arduino provides the AVR, the power supply and everything else, ready to go. Not only do Arduino provide this beautiful little hardware platform, but also they provide the software via 'Sketch', which is their free-to-download, proprietary development environment (see later for what this is), which comes with a huge, easy-to-use software library. You can build a huge range of little projects simply by buying one of these Arduino kits without ever having to use a soldering iron.

Microchip playing catch-up

Microchip have been a little slow to the game in providing an alternative to the Arduino, but along with their new cloud-based IDE, they've also released their $10 Xpress

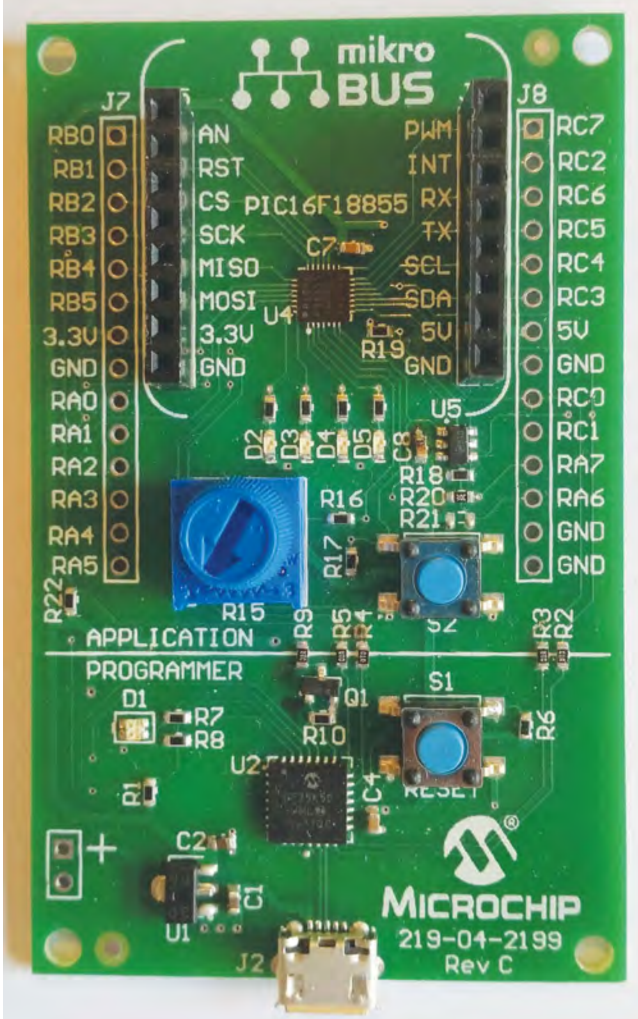


Fig.3. Microchip's Xpress Evaluation Board – it is similar to an Arduino in that it uses a bootloader and hence avoids the need for a separate external programmer

Evaluation Board (see Fig.3 or http://www.microchip.com/mplab/mplab-xpress). It doesn't have as catchy a name as the Arduino, but they are aiming for the same maker/hobbyist market. Much like the Arduino, you don't need a programmer to get up and running with the Xpress Evaluation Board. To make things happen you just plug in a USB cable, download the drivers and load up MPLAB Xpress. The Xpress Evaluation Board also uses a commonly used mikroBus header, allowing you to use a wide range of off-the-shelf modules from mikroElectronika. MPLAB X and the new MPLAB Xpress (cloud-based) are not as easy to use as Arduino's Sketch, but they are definitely more powerful, which I will cover later.

With this new board, it is finally in the running with Arduino. Microchip gave away the first 2000 for free, you may even have one, if you're lucky. Unfortunately, it's not fully available yet, so I am going to stick with an older board for the next few months. I hope to write a guide for the Xpress Evaluation Board when it is ready to purchase.

Demo board

The board I will be discussing over the next few articles is the 'Low Pin Count Demo Board' from Microchip. It can be purchased from the link below. It's not really fair to compare Arduino's easy-to-use hardware and software to this board. The Demo Board wasn't designed to be an Arduino competitor. The Arduino is more expensive and the software easier to use, whereas the Demo Board is less expensive and the software is harder to use, but it gives you much greater control and encourages better coding practices. Which is better or more suited for particular applications is a hotly debated subject – both have their place, but in certain areas the PIC wins hands down and that is why we are having this series. (Arduino fans do of course have the current *Teach-In 2016* series of articles from Mike and Richard Tooley) Plus, I'm biased, I love using PICs! I have developed projects with the Arduino boards and I have found them great to use, but I've been infuriated with their locked software libraries. The full control in the PIC really appeals to me. It might be harder in the beginning, but the rewards in the long term easily outweigh this.

PICs and Raspberry Pi

So what about the Raspberry Pi? This is a different beast altogether (see Fig.4). It really is a computer, comparable to your laptop or desktop PC. Plug in a power supply, keyboard, mouse and a monitor and you've now got a very small, very inexpensive computer. It runs with the Linux operating system (competitor to Windows and Mac OS) and you can write fully functional programs to do a lot of things really easily. It is leagues away from the low-level input/output control of microcontrollers. The Raspberry Pi works with a microprocessor and a large number of external peripherals. The real difference here is that the Pi operates at a much higher level to our microcontrollers. Using the Pi we write code, which talks to other code, which is executed by the microprocessor, which then talks to peripherals. By contrast, with PICs, we simply write code that talks directly to our peripherals, cutting out software and hardware middle men, and resulting in *much faster* operation. This is not a trivial difference – PICs really are leagues ahead of the Raspberry Pi and Arduino if you need fast operation.

Another vital difference is size and power requirements. To add some 'smarts' or control to a project you can 'simply' drop a PIC into a PCB design and run the device off existing power supplies used for the rest of the circuit. With luck your PCB won't even grow in size. However, with Arduino and the Raspberry Pi you are adding a pre-built box of tricks, connecting up wires and you may well need an extra PSU. Overall, it's clear that a PIC solution can be cheaper, neater, smaller *and* much more powerful!

Fig.4. Raspberry Pi and some extra plugin boards – a fully fledged computer

Programmer – enter the PICkit 3

Now we know a little bit about PIC microcontrollers and why we should use one over the Arduino or Raspberry. I mentioned the Low Pin Count Demo Board earlier, which is what I'm going to be working with. Although it has some similarities to the Arduino, for example, it has headers on either side to easily connect peripherals, its biggest difference lies in programming its on-board PIC. When we want to program it we'll need an additional piece of hardware called a 'programmer'. In terms of cost/performance, the best programmer to use is Microchip's own PICKit 3 (see Fig.5). This is powered by USB and connects to one side of the demo board. You use the PICkit 3 to not only power the Demo Board, but also to upload your new code to it – hence 'programmer'. You may come across Microchip's previous programmer – yes you guessed it, the PICKit 2 – as well as the more sophisticated Microchip ICD3 programmers. Being older, the PICKit 2 doesn't support all of the latest PICs and the ICD3 is an In Circuit Debugger, which is more powerful and more expensive. In reality the ICD3 will only be used for greater debugging control and faster code upload. We will use the PICkit 3; it's reasonably priced, a great bit of kit and can do everything we need.

It's worth pointing out that the Arduino doesn't need a separate programmer; it was cleverly designed to use what's known as a 'bootloader'. This is a special program written to a safe place in memory (which cannot be written to afterwards) that allows the user to connect their Arduino board to their computer with just a USB cable. This bootloader allows the user to upload their code via the USB interface instead of needing an external programmer. It is yet another reason why the Arduino's became so popular among the maker communities.

So what exactly is the PICkit 3 programmer and what does it do? The programmer takes our (converted) code and copies it to the target PIC. It can also power our project if we want it to. Its other main function is its debug ability. This is the ability to walk through our code as it is executed and look at various registers and variables to see if our code is behaving the way we want it to. This is a very powerful capability, and helps us debug our code when we run into problems.

Fig.5. Microchip's PICKit 3 USB Programmer – a powerful, reasonably priced bit of kit that will be at the heart of our PIC activity.

Compilers

Taking a step back from the programmer and the actual microcontrollers themselves. It's good to look at exactly what it is that we load into our microcontroller. Our micro will only understand 'machine language' or binary (ones and zeros). Binary is a numerical representation of a transistor output in either one of two states – on or off. So our code, which we write in the much more human-friendly 'C' software language or simpler 'assembly' language needs to be converted into these ones and zeros. This is what a 'compiler' does. It will take our human-understandable code and convert it into machine-readable binary code. Again this is an over simplification. They really do a lot more than this, but for now let's keep things simple. Binary code is often stored as 'hex' files. Hexadecimal is a numerical representation, similar to decimal or binary, except it uses the base 16 (with alphanumeric symbols 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F). It's commonly used in programming as an easier (more compact) way to represent larger binary numbers. Take the number 'F' in hexadecimal, this is '15' in decimal and '1111' in binary. So you can immediately see that F is only one character compared to the two characters for decimal 15 and four in binary.

The commonly used compilers for PICs are called 'XC8', 'XC16' and 'XC32'. These are freely available from Microchip's website. There are other compilers available, but these are the easiest to start off with. To improve your code in compile time, you can run what's called optimisations, the compilers handle these. The optimiser in the compiler can improve upon your code with regards speed, performance or memory usage. Unfortunately, you need to purchase a licence for these optimisations in Microchip's compilers. Microchip have recently updated their licensing structure so you can pay $30 per month instead of one large flat fee of $1000. You can even pay for just one month when you are nearing the end of your project and optimise it for better performance.

Development environments

Moving up the chain of design, we come to the IDE or 'integrated development environment'. This is where we write our code, select the behaviours of our device and even debug our code. MPLAB X is Microchip's IDE of choice, with MPLAB Xpress as their new online equivalent. It is an incredibly powerful platform and very useful when designing and building our projects. I will be covering this in much greater detail in next month's article.

What you will need

I'll be walking you through the setup, building and programming of our very own PIC projects, and I recommend getting your hands on the following software and hardware, so you can follow me as I introduce ideas and techniques:

1. Purchase the PICkit 3 Low Pin Count Demo Board (**http://tinyurl.com/h2jj2ek**)
2. Purchase the PICkit 3 Programmer + USB Cable (**http://tinyurl.com/zcpx3le**)
3. Download PICkit 3 Starter Kit User's Guide (**http://tinyurl.com/jyqfeuk**)
4. Download MPLAB X IDE (**http://tinyurl.com/hmehqja**)
5. Download XC8 Compiler (**http://tinyurl.com/h5g9k5l**)
6. PC with an internet connection to download the IDE, compiler and user guide.

Next month

I hope this has been helpful in laying a foundation for microcontroller development. While there is a lot of information, I want to try and keep it relevant and useful, without becoming boring. The plan is to spend the next few months building upon our foundations and from there designing some really interesting projects.

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

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

by Ian Bell

State machines – Part 1

REGULAR *EPE Chat Zone* contributor ***atferrari*** asked about microcontroller implementation of state machines: 'I am not C conversant; I do all in assembly for 18F micros. I've been thinking of implementing a basic elevator controlled by a micro. After reading several articles and references, I see that a state machine is frequently (if not always) mentioned – what I understand is the way to consider the problem.'

'I then browsed two pieces of software implementing the basics (I regret losing track of them) and depending on whether or not they were written in (maybe) C or assembly, what they did was create long blocks of 'switch case' chains or something similar... I found this quite a crude way to implement it, but I cannot see any other way of doing it. My question: is this the actual way you implement a state machine with a micro?'

State machine basics

At first sight this may not seem to a circuit-related issue, however, state machines are important in both digital hardware design and software development. An understanding of the basic principles of state machines is very useful for anyone interested in designing electronic circuits and systems, so we will expand this topic to discuss state machines in general.

The state machine concept developed as part of computational theory within what is called automata theory. It is not necessary to study all this theory and mathematics in depth to make use of state machines in basic digital circuit and software development. However, it is worth mentioning that Alan Turing, the famous English pioneer of computer science and World War II code breaker (cryptanalyst) made very important contributions to the development of automata theory, in particular with the concept of the Turing Machine.

The operation of many systems with which we interact in daily life can be described (modelled) in terms of state machines – even if they were not explicitly designed using a state machine approach. Elevators, as mentioned by ***atferrari***, are a classic example, as are combination locks, traffic lights and vending machines. The user interface controls in products such as digital clocks and radios provide further examples. We will look at such an example in more detail later.

Concept of 'state'

In digital electronics a number of common circuits can readily be described using state machines (and hence designed using a state-machine approach). Perhaps the most obvious examples are counter circuits, but circuits which identify particular digital input sequences are another classic example.

As is indicated by the name, *state* is a key concept here – at any given time a state machine has, or is in, a particular state called the *current state*. In practical terms, the state is held in a memory – in flipflops in a digital circuit or in a variable or other data structure in software (thus requiring memory usage in the microcontroller/computer). Typically, each state is identified in some unique way (by a name, symbol or number) and may correspond to some specific external actions performed by the state machine or a system that it is controlling.

The memory requirement implies a physical limit to the number of possible states that a real state machine can have (limited by the size of available memory). Thus, in more formal discussions the term 'finite state machine' (FSM) is used to reflect this limit. Theoretical state machines (or other types of automata) can have an infinite number of states – at least in mathematical descriptions. In this context, one can even consider such things as the maximum amount of information that could be theoretically stored in a given volume of space and even how much information the universe contains. This of course goes beyond what you have to worry about to design a state machine circuit, but gives some idea of the potential depth of the subject of automata a whole.

State actions and transititions

The actions associated with a state may simply be that a particular output value, pattern or symbol is produced (for example a counter circuit outputs the number it has currently counted to). The action may be also defined in more specific physical terms (eg, in this state the motor which opens the elevator door is switched on). Not all states may produce unique actions or physical outputs. For example, a simple combination lock may have a number of states representing conditions part way through input of the correct combination, but all states apart from the one detecting the correct combination will result in a 'locked' output, and, for obvious reasons in this case, the user will not otherwise know what the current state is.

A state machine will change to a different state if certain conditions or events occur – this is called a 'transition'. The transition determines the *next state*, which becomes the new current state after the transition has occurred. Thus a state machine is defined in terms of its states and the possible transitions between states (specified in terms of the current state, next state and the condition required for the transaction to occur in each case).

A transition resulting from a given input condition will result in change to a single defined next state – at least that is the case if we dealing with a *deterministic* state machine. If this is not the case – an input condition can lead to more than one next state – we have a *nondeterministic* state machine, which is again beyond the realms of what we need to discuss here.

In addition to performing actions associated with states, state machines may perform actions (produce specific outputs) associated with transitions. Typically, what happens is that the machine is given a state and an input changes, this (almost) immediately causes an output change and (maybe) subsequently causes a state change when the machine next updates its state. The change in state may cause the output to change again, in which case the particular output condition may occur only during the transition (the time from the input changing to the machine achieving the next state).

Thus the current output from a state machine may directly depend solely on the current state – in which case is it called a 'Moore machine', or the output may depend directly on the current inputs as well as the current state – this is a known as 'Mealy machine'.

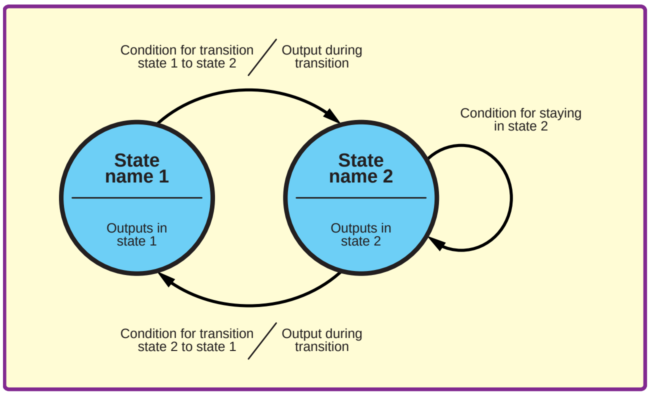


Fig.1. Elements of state diagrams – this is not meant to representing a meaningful machine

State diagrams

State machines can be defined using state diagrams, which are very useful for visualising the behaviour of the machine. Typically, when designing a circuit or software state machine you will start by drawing the state diagram – possibly changing it several times as you think through the behaviour of the machine you have currently drawn with respect to the requirements of what you are designing, working your way towards the correct solution.

Fig.1 shows the elements used in drawing state diagrams – they comprise a set of circles (square boxes can be used if you prefer) which represent the states, connected by arrows representing the transitions. The state circles are labelled with the state name and (below the name) with the outputs (or actions) produced in that state (if applicable).

The transitions are labelled with the condition required for that transition to occur and if (and only if) the transition results in specific outputs (as discussed above) these are shown next to or under the transition condition, separated by a line or dash. In some cases it is necessary to define the condition for staying in a particular state, in which case an arrow is drawn returning to the same state (known as a 'self-loop'). It is essential that the drawing and labelling of the transitions from each state fully and unambiguously define the behaviour of the machine in that state.

As previously mentioned, many everyday systems can be described using state machines. An example of such a state diagram is shown in Fig.2. This represents the behaviour of a microwave oven; it is simplified a little in comparison to the real microwave on which it was based to make our discussion more manageable. The purpose of this example is to show how the operation of a system like this can be defined in terms of a state machine. This will illustrate some of the thinking involved in developing and describing this machine. Similar approaches could be used when developing other designs (such as ***atferrari's*** elevator).

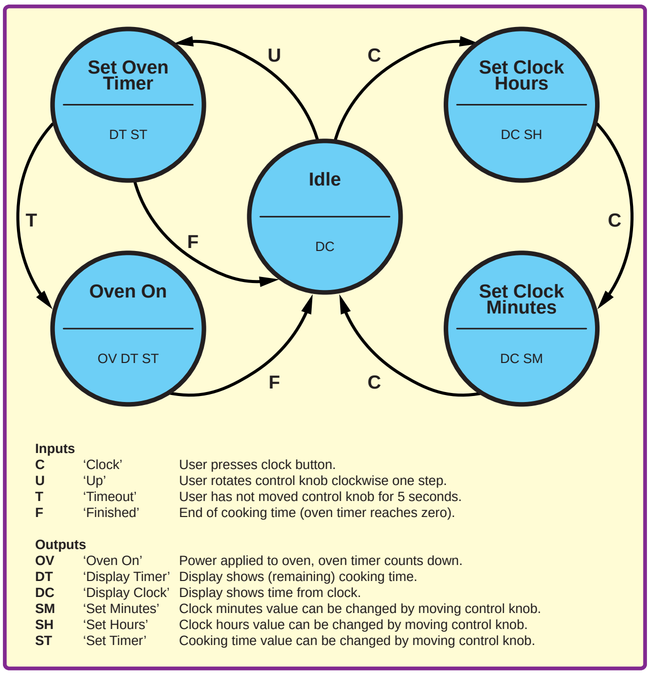


Fig.2. Example of a state machine based on a simplified microwave oven user interface

Microwave state machine example

The oven has two controls – a 'Clock' pushbutton which is employed if the user wishes to set current time on the clock, and an 'up/down' rotary control which is used to set the clock time and cooking time (this could be implemented using a rotary encoder and some associated logic). There is also a display which shows the time of day, unless the oven is being used, in which case it shows the cooking time (or timing remaining during cooking).

We can start to describe the behaviour of the microwave oven's controlling state machine by defining an 'Idle' state, which it is in when the oven is not being used. In this state the action it performs is to display the time of day. We can call this action/output 'Display Clock', abbreviated to DC on Fig.2. We can assume that the system contains a real-time clock and a timer to control the cooking time and has some means to select which of these outputs to the display at any given time. We have defined another output/action called display time' (DT) which selects the timer for display.

This representation (Fig.2) is abstract and may need to be refined if we actually implemented the system. For example, in digital circuit implementation we might use a single bit with 0 and 1 selecting the clock or timer. In which case it might be better to define a single state machine output called 'Display Select' (DS) and write DS=0 or DS=1 as the output on the state diagram, as appropriate. Alternatively, if were coding the state machine in software we might define an enumeration data type that could have two values: DT and DC, in which case Fig. 2 would be more directly representative.

A more abstract representation may help with the thought processes when trying to understand or define the system of interest. For a user, the state diagram using DT and DC is probably more directly expressive of what the system is doing than DS=0 / DS=1. The approach does not really matter as long as the state machine's behaviour is unambiguously defined. In this case, there is a potential issue in that it might not be obvious (unless we clearly state it) that DT and DC cannot both be active at the same time.

Setting the clock

If the user presses the clock button when the machine is in the idle state then the hours value of the clock can be changed. This represents a transition to a new state – the condition is 'clock button pressed' which abbreviate to C. In Fig.2 there is an arrow from the Idle state to the 'Set Clock Hours' state, which is labelled C to show that this is the condition for the transition.

When the machine is in the Set Clock Hours state the user can change the hours value using the rotary control. Note that this behaviour is not fully described by the state diagram alone. This is in effect an assumption (if we are modelling), or a design decision (if we are designing), that the rotary control is connected directly to the clock module/function and the state machine provides a control signal to the clock module to say, 'now use the rotatory control (up and down) signals to set the hours'. We have called this control signal 'Set Hours', abbreviated SH. The clock module itself could (most likely) also be described as a state machine – which illustrates the fact that systems are often built from sets of interconnected state machines.

If the machine is in the Set Clock Hours state and the user presses the clock button the machine transitions to the 'Set Clock Minutes' state, which is very similar to the Set Clock Hours state. Here the machine outputs a 'Set Minutes' (SM) control signal to the clock module in a similar manner to Set Hours discussed above. In the Set Clock Minutes state, pressing the clock button again returns the machine to the Idle state.

The instructions to the user relating to the state machine operations just discussed would be something like: 'To set the time, when the oven is not being used press the clock button and then rotate the control to set the hours. When the hours are connect press the clock button again and rotate the control to set the minutes. To finish and restore normal operation of the clock press the clock button again'.

Operating the oven

Continuing the instructions, using the oven might be described as follows. 'Rotate the control clockwise to set the required cooking time, which will be shown on the display. If you need to reduce the time rotate the control anticlockwise. To cancel cooking reduce the time to zero. Once the desired time is set, leave the control – cooking will start after five seconds with the display showing the remaining time. During cooking the time can be adjusted with the control and stopped by reducing it to zero'.

Creating the state machine

To obtain the state machine we need to make some assumptions about the structure of the system. First, we assume there is a timer module which can be set directly from the up and down signals from the rotary control when enabled to do so – this is similar to the clock setting. Thus, we need a state machine output signal 'Set Timer' (ST) to allow the timer to respond to the rotary control.

We can also assume there is a five-second timeout function, activated if the timer setting has not been changed. Specifically, we assume there is an output from the timer module which deactivates as soon as it receives an up or down signal and activates five seconds after the up or down signals stop changing. This is an input to the state machine called 'Timeout' (T). The state machine also needs to know when the cooking has finished, which can be provided by another signal from the timer. This activates when the time is zero (either because the timing has finished or because it has been reduced to zero by the rotary control – to account for the cancel capability). We will call this signal 'Finished' (F).

To describe the part of the state machine related to cooking we again assume we are starting from the Idle state. Cooking is initiated by rotating the control clockwise – which implies it is outputting an 'up' signal. Thus an Up input (U) causes a transition to a state in which the user can set the cooking time. This state is called 'Set Oven Timer'. In this state, the machine activates the Display Timer (DT) and Set Timer (ST) outputs, which have both been defined above.

When in the Set Oven Timer state, if the user winds the time down to zero the timer module will activate the Finished (F) signal, which will cause the machine to transition back to the Idle state (cooking is cancelled before it is started).

When in the Set Oven Timer state, if the user does not move the rotary control for 5 seconds the timer module will activate the Timeout (T) signal. This will cause a transition to the 'Oven On' state. In this state, the machine outputs the Oven On (OV) signal which activates the oven (assuming the door is shut). We do not have to worry about things such as the oven power level here as that is controlled separately. In the Oven On state the rotary control needs to still be able to adjust the timer so Display Timer (DT) and Set Timer (ST) are active. When the timer reaches zero, or the time is reduced to zero by the control, the timer activates the Finished (F) signal and the machine transitions back to the Idle state (where the oven is switched off).

Checking our initial state machine

At this point we have created our state machine and we may like to check if it can be simplified, or any ambiguities removed. Readers might have notices that the DT and ST outputs are always active at the same time. We could reduce them to a single signal, say 'Use Timer' (UT). This is shown in Fig.3. Referring back to our discussion on DC and DT we note that UT and DC are also mutually exclusive and have modified the output definition to reflect this.

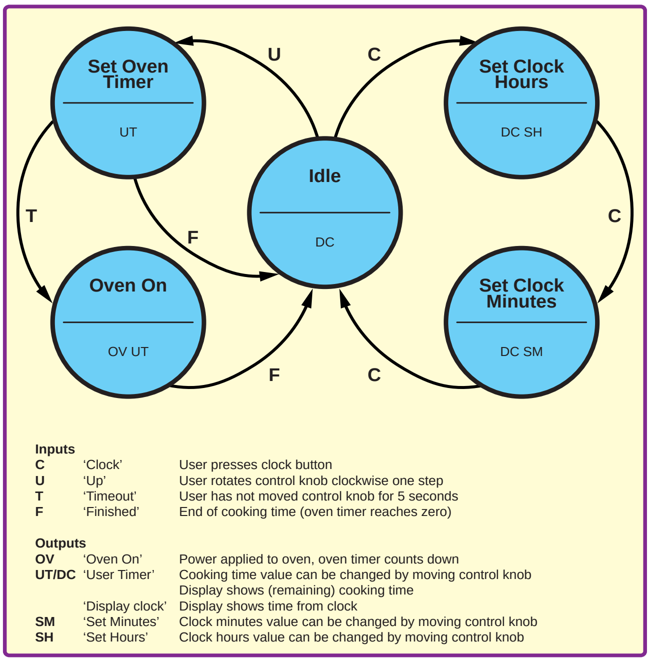


Fig.3. State machine from Fig.2 with simplified outputs. Further refinements next month

This illustrates the fact that we may go through several versions of a state machine as we develop our thinking. Furthermore, the machine shown in Fig.3 is not the only possibility given the general scenario discussed. For example, we have described the timer module controlling the five second timeout function, but this functionality could be controlled by the main state machine instead (we might add an additional state to reset an independant five-second timer when U or D where are active).

More generally, any attempt to design state machine may result in redundancies (equivalent outputs or states). There are formal/mathematical approaches that can process state machine descriptions to identify and merge states that are equivalent.

Implementing a state machine

Once we have a state diagram we happy with we can move on to implementing it in more detail. We can create the machine in digital logic hardware or in software. Software running on a microcontroller such as a PIC may seem an obvious choice for something like this oven example, although it could be implemented in hardware. In other cases, a hardware approach may be more appropriate than software. In general, the idea of hardware implementation may seem daunting due to the possibility of needing many basic logic chips (gates and flip-flops) to build the state machine. However, a better approach (if hardware is the best choice) may be to use a single programmable logic device (CPLD – complex programmable logic device or FPGA – field programmable gate array). Of course, these technologies require the use of design tools (which you have to learn to use), but that is equivalent to needing a software development tool to write code for a microcontroller.

The state machine is a powerful technique for designing digital electronic and software systems, although they are not always used where they could be. This is often the case when the design is created incrementally, rather than being set up as a state machine in the first place. Such designs could potentially be converted to a more structured form by modelling their behaviour in terms of state machines, but it may not always be worth the effort.

This article has looked at state machines at a relatively abstract level. Next month, we will resolve some issues with the current version of the example machine diagram and look at implementation in more detail. However, before finishing, ***atferrari's*** question should not be left hanging. The answer is 'yes' switch/case statements are commonly used to implement state machines in software (and hardware description languages).

AUDIO OUT

By Jake Rothman

Super-simple retro amp-speaker combo – Part 1

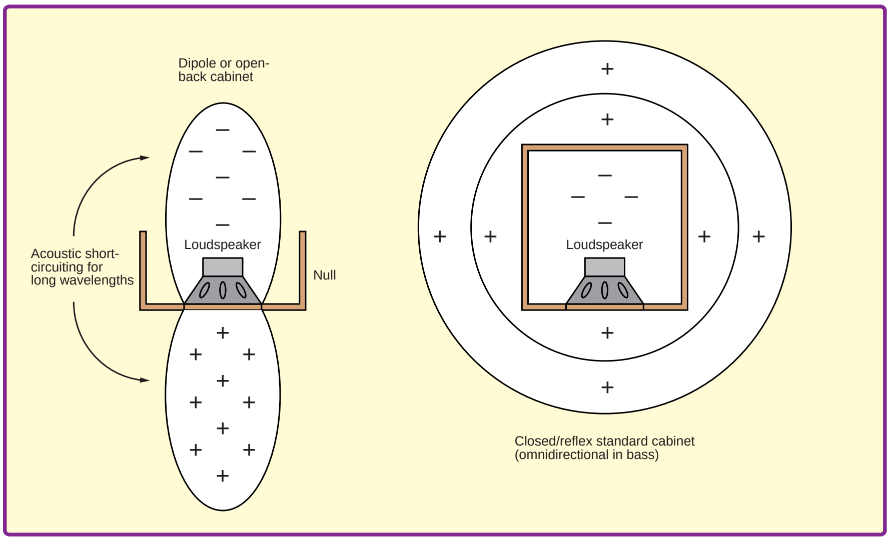


Fig.1. Comparing low-frequency radiation from open-back dipole and closed speaker cabinets.

That old-fashioned sound

I recently sold an old Bush valve radio just used for FM Radio 4 in the kitchen. Despite its greatly superior specification, the replacement, a pair of Tannoy M20 speakers and a Leak 2000 receiver, did not work well in this role. The Hi-Fi system, although excellent on music, failed utterly with low-level speech. My audio-obsessed friends agreed that two-way speakers with extended bass reduced the clarity of speech because the crossover was right in the middle frequency range. Also, radio speech on Hi-Fi speakers has a tendency to 'boom' when playing closely-miked speech radio. Finally, since the Leak amplifier operated in class AB, it was not happy running at very low volumes.

The old radio had a single Celestion 6 × 4-inch elliptical, light-weight, paper cone speaker in an open-back cabinet. This avoided the boom problem because the figure-of-eight dipole radiation pattern from such enclosures does not excite room resonances as much as normal (enclosed) speakers, which have an omnidirectional bass radiation characteristic, as shown in Fig.1 (**www.linkwitzlab.com** has some good data on this topic). The radio's amplifier was also a major part of its sound, comprising a single-ended UL84 pentode valve running in class-A, which ensured a good sound at low volumes. The circuit's relatively high output impedance was also a factor in reducing distortion in the speaker.

'Quiet' speakers

So, rather than sticking with the Tannoy/Leak Hi-Fi option, I decided to replicate the radio's quiet, non-fatiguing 'mid-fi' sound, reminiscent of an old radiogram. Of course, this goes against the grain for physics-driven audio engineers like me, but the proof of the pudding is in the listening, and I liked the spoken-word sound of the old radio. The radio's limited-bandwidth sound can be especially useful during electronics R&D, where scratchy computer speakers and big 'boom and tizz' Hi-Fi systems seem to steal bandwidth from my brain!

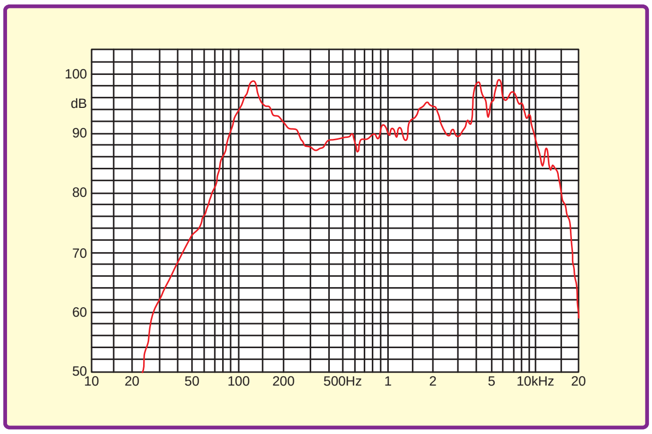


Fig.2. Frequency response of a Philips elliptical 6 × 4-inch AD46727 speaker – lots of little peaks.

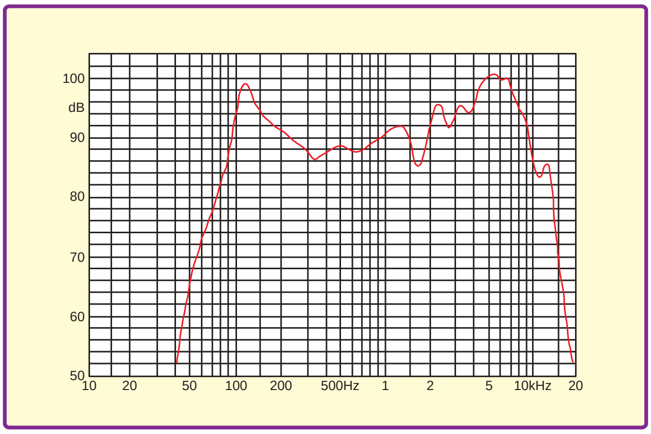


Fig.3. Frequency response of a 5-inch circular AD55725 speaker – a few big peaks.

Note that both the speakers in Fig.2 and Fig.3 have the same motor system and thus show just the difference purely from the cone shape. (Both curves are from the Mullard Technical Handbook – Part 6 Loudspeakers, *1986.*

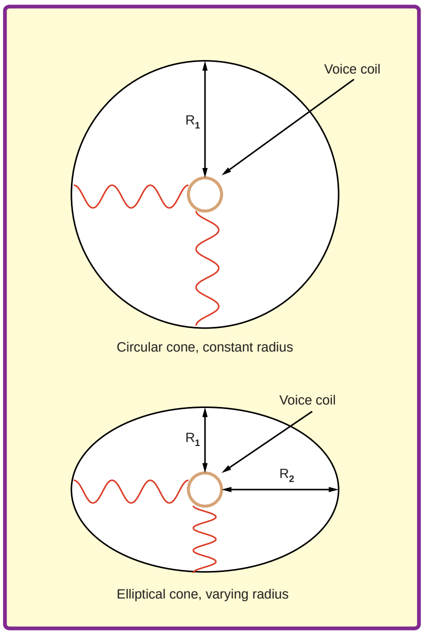


Fig.4. The different path lengths from the voice coil to the cone edge distribute the breakup frequencies. In the circular cone they coincide and reinforce.

This also applies when composing and tracking music on the computer late into the night.

Elliptical argument

Along with class-A valve amps, ellipse-shaped speakers are another technology mostly lost to modern designers. They died out because they became associated with dreadful TV slot speakers, had difficult tooling requirements and weren't as loud as circular ones. EMI were famous for their elliptical drivers, their main researcher, Dr GF Dutton emphasised their lower colouration from delayed resonance. This was a result of the multitude of small break-up resonances rather that the fewer higher magnitude ones produced by circular cones – see Fig.2 and Fig.3. This desirable property was because of the differing path lengths from the voice coil to the edge of the cone, as shown in Fig.4. The hangover from undamped radial breakup modes in some circular cones was shown to be impossible to equalise by DEL Shorter at the BBC research department in 1958. His paper, *The Development of High Quality Monitoring Loudspeakers* (accessible on the BBC website) even showed 3D delayed resonance curves, derived mechanically – before computers. The difference between the cone shapes was more pronounced with the efficient light-weight paper-cones of the past compared with today's plastic-coned rubber surround type units. Peter Baxandall was also an elliptical cone enthusiast, producing a design for *Wireless World* in August 1968. This used an Elac 8 × 5-inch unit with a damping compound on the surround and a passive LCR equaliser.

There appears to be an optimum ratio range for the dimensions for an elliptical speaker, which is 1:1.4 to 1:1.62 (the latter being the golden ratio). I have some old 8 × 2-inch TV speakers and other 'slot-shaped' sizes with ratios over 1:1.8 that have nasty 'N' shaped frequency response anomalies (see Fig.5, 1.5-2kHz). The optimum standard sizes seem to be 6 × 4, 8 × 5 and 10 × 6-inch (note that a 6 × 4-inch elliptical cone has the same radiating area as a 5-inch circular unit). For best dispersion an elliptical unit should always be mounted with its longest dimension (the major axis) vertical. Another aspect of cone geometry, shown in Fig.6, is that straight cross-section cones have a higher amplitude upper breakup peak than curvilinear one. This is good for high-power bass and compensating for the sideband cutting of AM radio, but gives a more coloured response, ie a mid-range boost over 1-4kHz.

In one of my germanium transistor hunts in an electronics shop in Cheltenham I found a load of old 30Ω 9 × 6-inch EMI 93870 AW elliptical speakers with curvilinear soft felted-paper cones. They must have been from the 1960s since they had Alnico magnets as opposed to ferrite ones. Their liberation from the loft had finally arrived and I hooked one up to the *Test Bench Amp* (*EPE*, Nov 2014) set to constant current output and the much-missed valve radio sound was almost there. The system's efficiency was very high because of the very low moving mass of the speaker diaphragm/coil assembly. However, the power handling capacity was low due to the short (5mm) voice-coil, which tended to jump out of the magnetic gap at around 5W. Interestingly, modern drive units with their heavy long coils wound on aluminium formers in wide gaps, as shown in Fig.7 need around 5W just to get going. That is the price paid for high power handling.

The resonant frequency of the EMI speaker was around 70Hz, giving a response down to about 100Hz in the enclosure. The high-frequency response extended to about 7kHz,

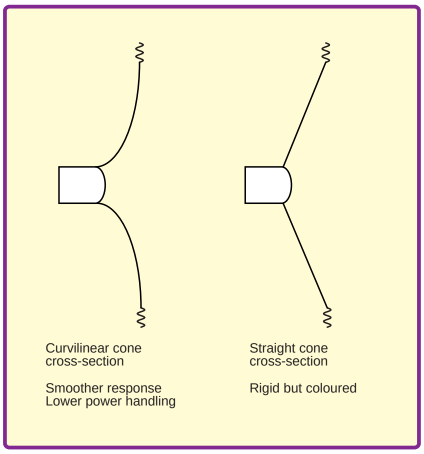


Fig.6. Straight cross-section vs curvilinear cones – the curved cones have smoother break-up and better dispersion. However, they are not as resistant to bending from high-power bass.

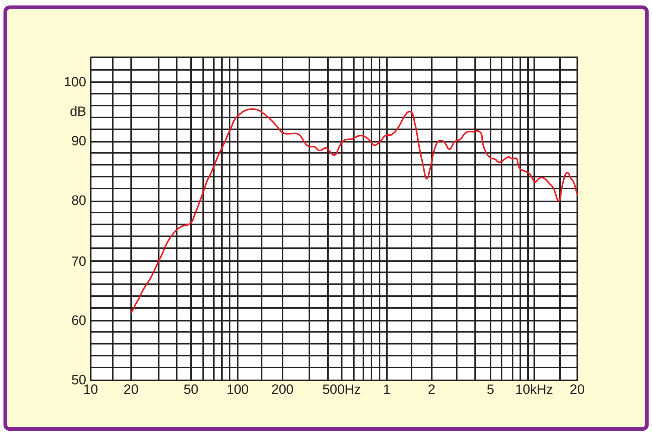


Fig.5. Frequency response of an AD38903 3 × 8-inch 'slot' elliptical speaker – note the nasty glitch.

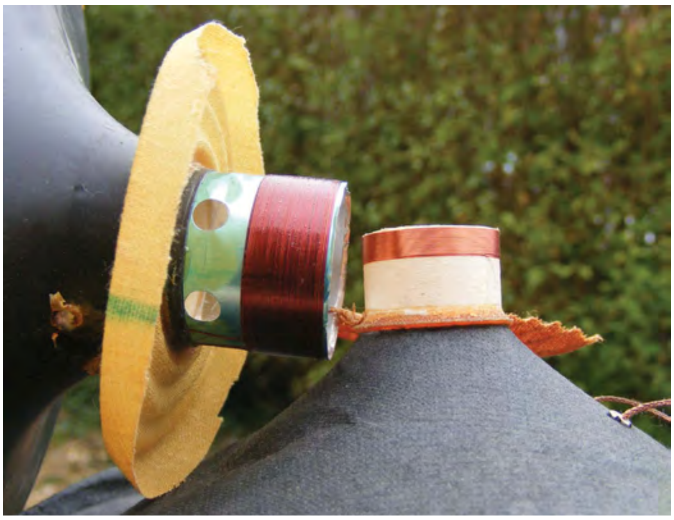


Fig.7. Modern high-power voice coil with aluminium former and low-power voice coil wound on paper.

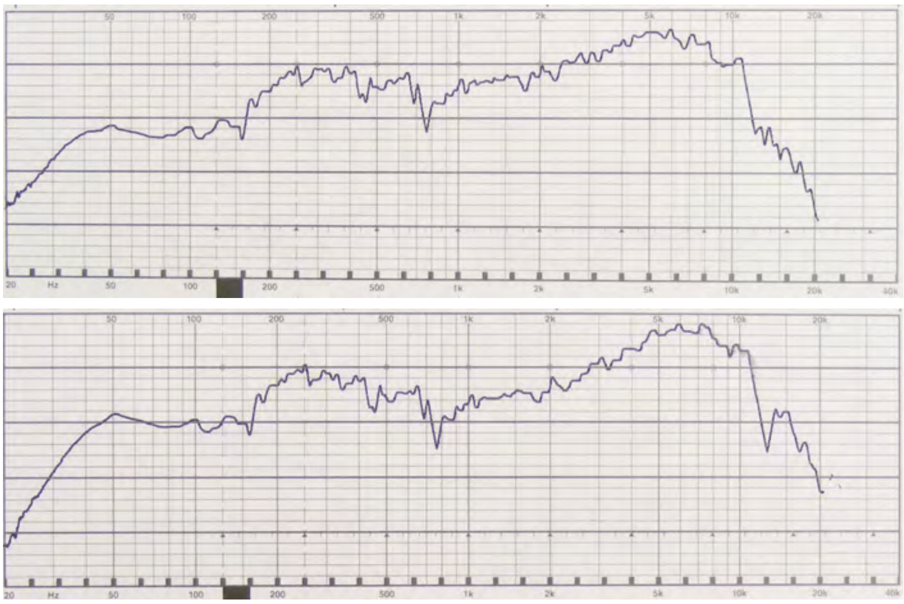


Fig.8. a) (top) Response of an EMI 93870 AW elliptical speaker in an open-back cabinet. It shows a rising response, which is good for speech, but it needs greater high-frequency cut for music use. b) (bottom) Response of the same unit but using current drive. There is only a small difference between these two curves, but there was a real improvement with sound quality using the current drive circuit. (Note the (vertical) amplitude divisions are 2dB.)

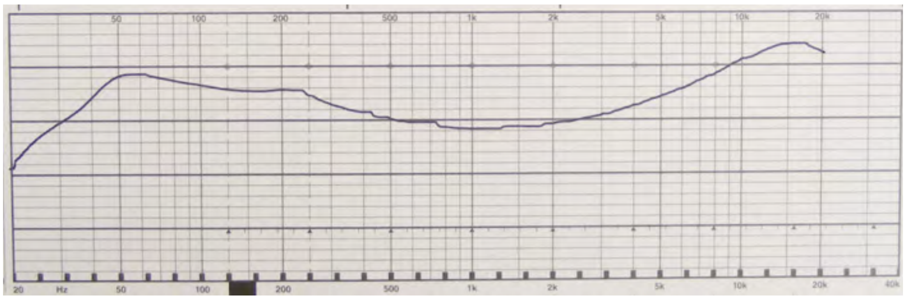


Fig.9. Frequency response of the amplifier's voltage output using the current drive. (Note the (vertical) amplitude divisions are 1dB.)

so definitely not 20Hz-20kHz Hi-Fi!. A forgotten idea in loudspeaker design to obtain a tonally balanced sound is that limited bass should be compensated by a corresponding high frequency cut (above 7kHz). *The Radio Designer's Handbook* (an essential analogue reference) states the product of the two frequency limits should equal around 600,000. Plastic computer speakers often go from 200Hz to 14kHz. The response of the EMI driver is shown in Fig.8a, and using current drive and a bit of bass boost it is as shown in Fig.8b. The voltage output of the amplifier with the speaker connected is shown in Fig.9. It's a little too bright for music, but good for speech. A suitable open-back cabinet is shown in Figs 10a and b. Open-back cabinets need to be relatively shallow to avoid bass resonance. The parallel sides should be lined with foam or felt to avoid reflections. Someday, I'd love to make a baffle from a piece of curved perspex with non-parallel sides, as shown in Fig.11. The size is not critical, but the longer the path length from the front of the driver to the back the better the bass response.

Simulating valves

In April's *Audio Out* column I described an interesting buffer circuit based on the *Wireless World* (June 1973) PL Taylor 30W and Nelson-Jones circuits. I said then it would lead to a new class-A power amplifier, and that is the project we are starting here. Since the EMI speaker could be driven with just 1W, there would be none of the usual thermal problems associated with class-A operation. 2W maximum, just like the valve radio, should be enough. This transistor circuit does sound valve-like until it clips – there is no output transformer to smooth out the square edges, plus it has high negative feedback.

Current drive

An inherent distortion problem with electromagnetic loudspeakers is due to their cone movement being the result of a changing current in a magnetic field. When loudspeakers are voltage driven, as is normally the case, the conversion of voltage to current takes place in the impedance of the voice-coil. Unfortunately, this impedance varies according to the position of the voice-coil. (Also, possibly there are hysteresis-distorted eddy currents induced in the magnetic pole-pieces and aluminium voice-coil formers.) These effects make the current response to the voltage drive non-linear, inducing considerable intermodulation distortion. These effects are generally

Fig.10. Front and rear views of the EMI unit in its cabinet – size: 410mm H × 255mm W × 200mm D.

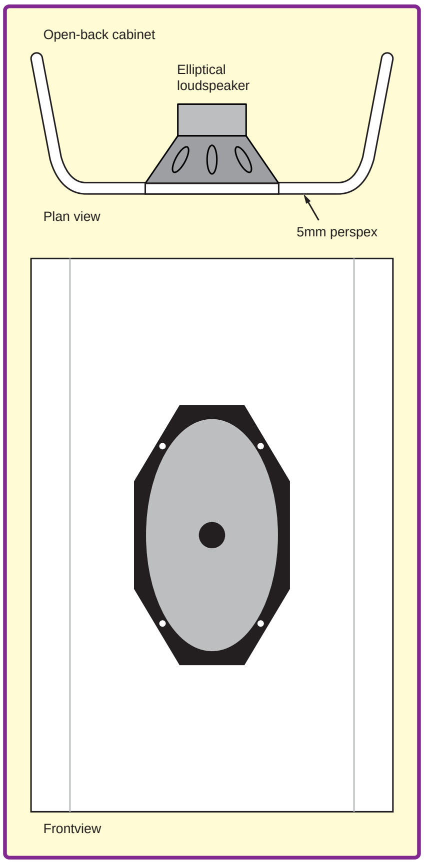


Fig.11. Idea for a curved perspex loudspeaker cabinet. Elliptical speakers should always be mounted vertically for best horizontal dispersion.

worse in low-power speakers with short voice-coil geometry. If the speaker is current driven from a high impedance rather than the almost zero-ohm output impedance of standard power amplifiers, the distortion has been shown to drop by a factor of almost ten. The amplifier controls the current rather than the speaker. It is a very noticeable effect, more so than most amplifier differences. The ATC SCM20SL (my monitor speaker of choice) is the only loudspeaker where these distortion problems are removed, but its huge long-gap magnet and patented non-conducting pole pieces don't come cheap (around £4000 per pair).

One side effect of current drive is that there is no speaker damping of the main resonance. In a closed box where the Q and frequency of the resonance have been pushed up by the enclosed air this is a major problem. In an open baffle/back cabinet it can compensate for the bass loss due to the acoustical short-circuiting (see Fig.1). This also increases cone excursion, but this is not a problem with low power levels. Another side effect is boosted high frequencies due to the inductive impedance rise, which can be corrected with a bit of cut in the high frequency response of the amplifier.

The pentode valve amplifier in the radio inherently had a high output impedance. Also the output transformer prevented the application of much negative feedback because of the risk of instability. Inadvertently, the valve radio had built in loudspeaker distortion reduction. This was part of the effect because current driving a speaker removes a characteristic hard 'loudspeaker sound'. There is an interesting book called *Current-Driving of Loudspeakers* by Esa Meriläinen, which is the most complete work on the subject, although it appears to be a translation of a Finnish MSc thesis. In the UK, Essex University-based Prof Hawksford's work is also worth reading (google him!).

Current drive topology

In the amplifier in this project, an inverting configuration is used, since a low input impedance is not a problem. This is shown in Fig.12 in op-amp form. Negative feedback is taken from the top of a current-sense resistor connected in the speaker ground lead. An additional benefit is that any distortion from the output electrolytic capacitor is also reduced, allowing a polymer type to be used. There is also a degree of high frequency cut applied through the network consisting of R4 and C3.

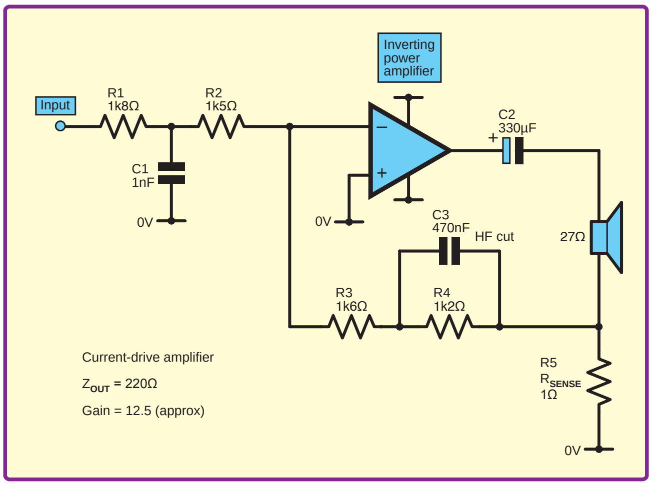
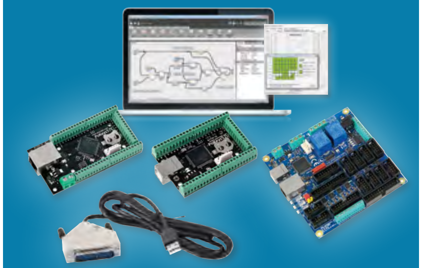
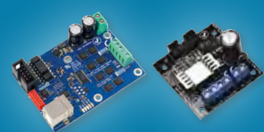


Fig.12. Op-amp 'representation' of the 2W class-A amplifier.

Next month

That just about wraps it up for this month; next month we will examine this amplifier circuit in detail and look at its construction.





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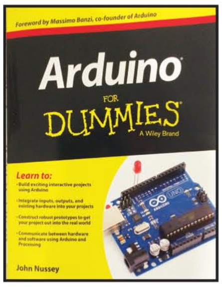

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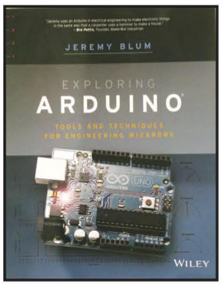

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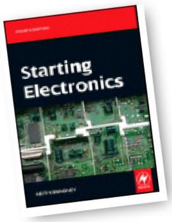

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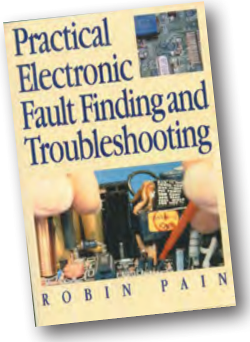

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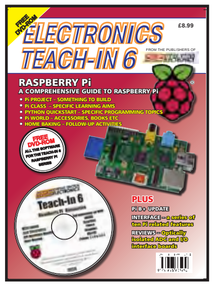

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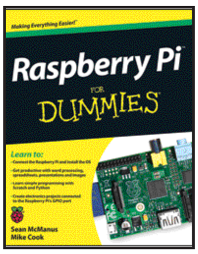

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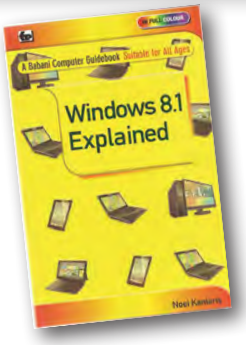

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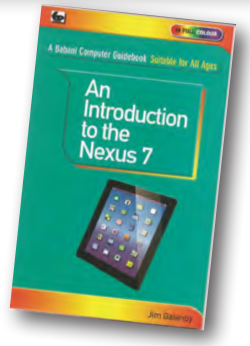

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Max's Cool Beans

By Max The Magnificent

Pull up a rock

I'm not sure if you remember this, but a few years ago I picked up a really nice 1950s wooden television cabinet. Admittedly, it was a little the worse for wear, but now it's been refinished it looks very tasty indeed.

Ever since I acquired this cabinet, I had the idea of creating a caveman diorama inside. Sad to relate, this project ended up on the back burner for quite some time because I didn't have a clue how to make the cave itself. I fought several battles with chicken wire and *papier mâché*, but to no avail.

My wife, Gina, is an estate agent, and as part of her job she really tries to get to know what people are looking for. Sometime last summer she met a couple. The guy, whom we'll call Mike (because that's his name), wanted a really large room upstairs. It turns out that Mike – a retired Apache attack helicopter pilot – builds large railway dioramas as a hobby. However, although he's great at landscapes and stuff, he knows next to nothing about electronics.

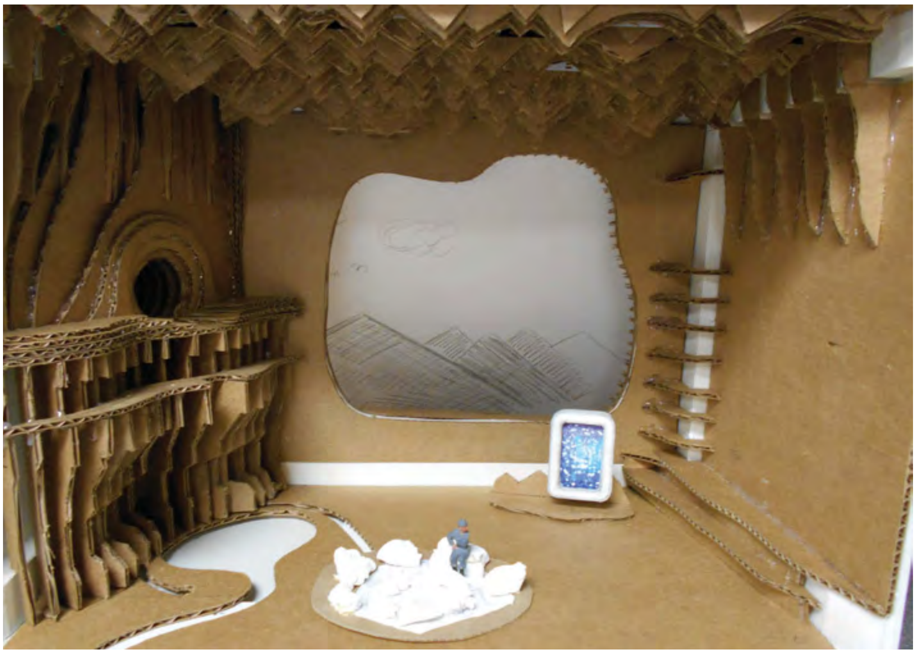

Fig.1. The current state of the caveman diorama

Mike told Gina he wanted to add lights to his streets and houses and trains and suchlike, but he wasn't sure how to control them all. Well, it was like a modeling match made in heaven – on the one hand we have Mike who knows how to implement the landscape stuff; on the other hand I'm the king of the flashing light people. Mike and I now meet up in my office on Saturday mornings and spend a happy few hours doing a mix of electronics and diorama building.

Just to give you a feel for what I'm talking about, the current state of play is shown in Fig.1. This is the underlying cardboard structure. We will be applying plaster-cloth and plaster to add a rock-like look this coming weekend. I should point out that we've spent several months experimenting with dummy ledges and rocks – shaping them and painting them to achieve a photo-realistic appearance. I flatter myself that we've actually become rather good at all of this.

Welcome to the pleasure dome

Let's take a quick stroll around the cave to see where we're going with this. On the left we have a ledge with a tunnel half way up the wall. There will be a small waterfall coming out of this tunnel, falling into the pool below. Not real water of course, but you can achieve some spectacular effects if you work at it (**http://bit.ly/236PQ02**).

We already have some tri-colored NeoPixels at the back of the tunnel (See my earlier NeoPixel columns…). I wish you could see how cool this looks with a dull, pulsing red glow (we're also experimenting with a very interesting 'electric arc welder' type of effect). Furthermore, we're thinking of having two Morlock figures crouching on the ledge spying down at the scene below.

Although this isn't apparent in Fig.1, the pool is going to protrude below the level of the cave floor, thereby adding to the illusion of depth. The pool will also be illuminated with NeoPixels (a low, eldritch-green glow is particularly effective, we've found). It might also be worth pointing out that we have 155 NeoPixels hidden in the roof. We aren't sure what we're going to do with these little scamps yet, but – as a general rule of thumb – you can't have too many flashing lights. (You may think this is a simple philosophy, but it's served me well over the years).

The mountains we see looking out of the mouth of the cave are currently just sketched on white card. In the fullness of time, however, we will replace this with a flat-screen computer monitor that will display a 3D-generated Tolkien-like scene. This will reflect what's happening in the real world – daytime here will be daytime there; nighttime will be nighttime; if it's stormy here there will be thunder and lightning in the diorama, etc. There will be two cavemen standing on the ledge at the mouth of the cave looking into the distance. Another caveman will be standing on a ladder creating a cave painting on the right-hand wall of the cave.

Towards the front of the scene (near the television's screen) will be a fire with several cavemen sitting around discussing the events of the day. We're working at 1/32 scale, so a 6-foot tall man will be 2¼-inches

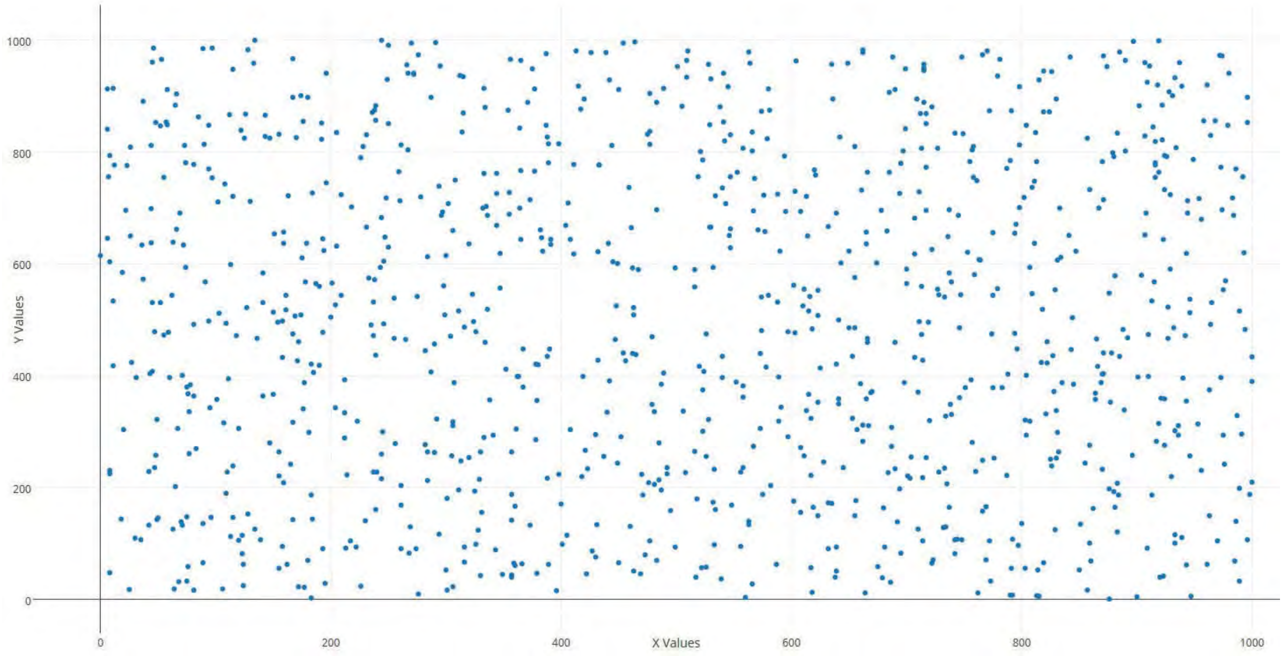

Fig.2. The X-Y pairs presented on an X-Y plot

tall in the diorama (the soldier figure sitting next to the fire pit in Fig.1 is there only to provide a sense of scale).

One of the figures sitting around the fire will be a depiction of yours truly wearing shorts and a Hawaiian shirt. The time portal floating in the far-right corner of the cave explains my presence in the scene, along with any other anachronisms, such as the Morlocks.

Lords of chaos

One thing we'll need to achieve in the various effects we envisage is a good source of random or pseudo-random numbers. In the case of the caveman diorama, we're using a number of Arduino Nanos to control the various effects. The Arduino does, of course, provide a `random()` function, but just how 'random' are the numbers it returns?

Some people may simply trust this sort of thing in the belief that whoever created the Arduino and its supporting environment knew what they were doing. Personally, I don't trust anybody or anything, except my mother, of course, but she really doesn't have much to offer regarding random numbers and chaos-related topics (she prefers to generate her own chaos wherever she goes).

The bottom line is that I don't like to take anything like this for granted; I'd feel really silly if I generated say 1,000 random numbers, each between 0 and 999, and used them to generate my special effects, only to discover that the vast majority of these numbers landed between 200 and 600, for example.

Thus, in order to perform a 'cheap-and-cheerful' verification of the Arduino's `random()` function, I threw a simple program together that loops around creating 1000 X-Y pairs, where each X and Y value is a randomly generated integer between 0 and 999. The core of this code is as follows:

```
for (int i = 0; i < 1000; i++)
{
     x = random(0, 1000);
     y = random(0, 1000);
     Serial.print(x);
     Serial.print(“,”);
     Serial.println(y);
 }
```

As we see, I streamed the comma-separated X-Y pairs out to the Serial Monitor in the Arduino's IDE. I then cut-and-pasted these values into a NotePad *.txt file (you can access these values at **http://bit.ly/23cb40b** if you want to play with them yourself). I then used an online tool called 'plotly' (**https://plot.ly**) to plot these results on an X-Y graph, see Fig.2.

You can access a full-size version of the resulting plot at: **http://bit.ly/1PUorVS**. As you'll see, the result is a reasonably gratifying even distribution. Of course, this is a somewhat simplistic verification technique, but 'it's better than a poke in the eye with a sharp stick,' as they say. Based on this test, I felt comfortable proceeding to the next step, which was to create a flickering fire effect.

Quest for fire

As I mentioned earlier, we're really trying to make this diorama look mega-realistic. The fire around which the cavemen will be sitting is a case in point – if this is less than stellar, the overall effect will suffer. To kick off our experiments, we took just three regular LEDs – one red, one orange, and one yellow – and put them in a box with a hole cut in the top. Then we took some twigs and charred the ends and placed them around the hole. Next we used a snippet of code a bit like the following to control the brightness of the LEDs using the Arduino's pseudo-analogue (PWM) outputs:

```
int redVal, orangeVal, yellowVal;

 while (1) {
     redVal    = random(155,255);
     orangeVal = random(155,255);
     yellowVal = random(155,255);

     digitalWrite(redPin,    redVal);
     digitalWrite(orangePin, orangeVal);
     digitalWrite(yellowPin, yellowVal);

     delay( random(1, 100) );
 }
```

Fig.3. The original array (top left) versus the new array (top right); the glass bead cone (bottom left) versus the crushed glass cone (bottom right).

With regard to the physical implementation, we started off with an array of 16 pixels created from segments of NeoPixel strip in a 5-6-5 arrangement. We also created a small cone of glass pebbles stuck together using clear epoxy. The idea behind the pebbles was to bring the light up to the logs while also reflecting and refracting it to add visual interest. The end result was pretty good, but not great; also, the array consumed too much area (sad face).

Happily, while rooting around the **Adafruit.com** website, we realised that a 7-NeoPixel Jewel (**http://bit.ly/22g53tt**) fits exactly inside a 12-NeoPixel Ring (**http://bit.ly/1ULy6G6**). The result is a grouping with more LEDs than our original array (19 versus 16) that occupies a smaller (1.5-inch diameter) footprint. Also, this is where we had a bit of a brainwave – we re-created the cone that sits on top of the pixels using crushed glass and clear epoxy (Fig.3).

As you can see, this provides 'random' with regard to both intensity and duration. And, even though it's really simple, it actually provides a reasonably interesting effect as you can see in this YouTube video: **http://bit.ly/1RSDXDH**. However, although this looks OK when the ambient light is low, it's almost impossible to see in regular lighting conditions.

The solution is to use more and brighter LEDs. Yes, of course I'm talking about NeoPixels. Having said this, another consideration with the above code is that, although the delay is random, all of the pixels change at the same time, resulting in a less-than-optimal effect when you are using a bunch of LEDs.

GLOW, SPARK and DARK modes

To cut a long story short, we implemented a simple time wheel where each 'tick' occupies one millisecond. We also decided that each pixel would randomly adopt one of three modes – GLOW, SPARK, or DARK – where these modes are 'weighted' such that GLOW is the most common.

In the case of the GLOW mode, that pixel's color – red, orange, or yellow – is randomly selected (weighted so that red is more prevalent than orange, which is more prevalent than yellow). Also, the intensity and duration values for the pixel are randomly selected. By comparison, SPARK mode adds more colors (white and purple) and pixel flares up and fades away. Last but not least, in DARK mode the pixel is turned off for some random duration. The end result is that each pixel can be 'doing its own thing' completely independent of all of the other pixels (you can access the entire Arduino program here: **http://bit.ly/1Xk6E0d**).

The result of having 19 NeoPixels means that the fire is more than visible even in bright ambient light. Meanwhile, as you can see in this YouTube video (**http://bit.ly/1YhHmjs**), the crushed glass cone reflects and refracts light like you wouldn't believe.

When you are watching the video, observe the occasional flashes of white and purple light; these are from the SPARK mode. Although you may think all of this is a bit 'over the top,' remember that we're going to place charred 'logs' around the glass cone, so you'll only be able to see the 'fire' through the chinks in these logs.

As you'll see from our code, everything is fully parameterised. Thus far, we're pretty much using the original parameter values we threw into the mixing pot – I think we'll be able to achieve increasingly realistic effects by varying these parameters. If you decide to build one of these to play with yourself, we'd love to hear your thoughts on the optimal parameter settings.

Future developments

Now we're about to start work on the time portal, which we're hoping to have working by yesterday – perhaps even the day before if we're lucky. I will report further details in a future *Cool Beans* column. Until then, have a good one!

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

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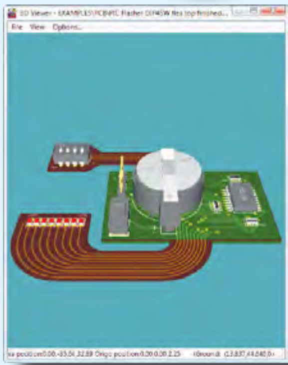

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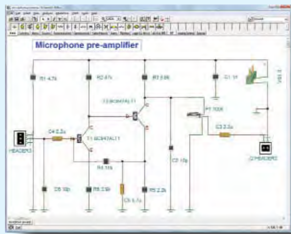

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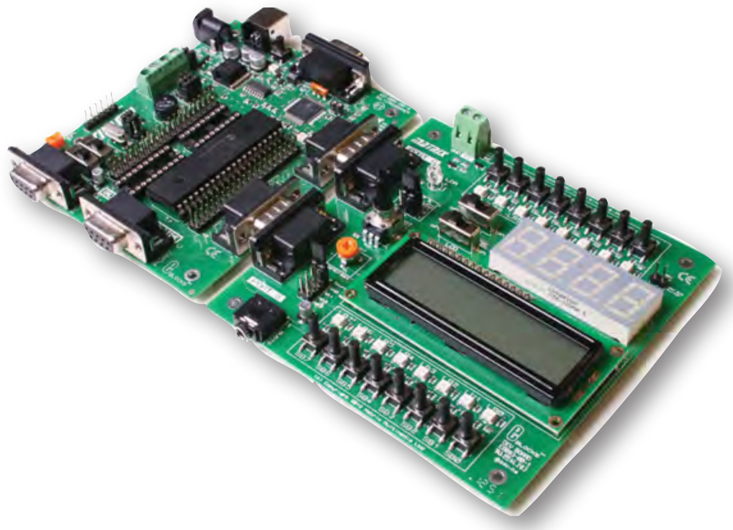

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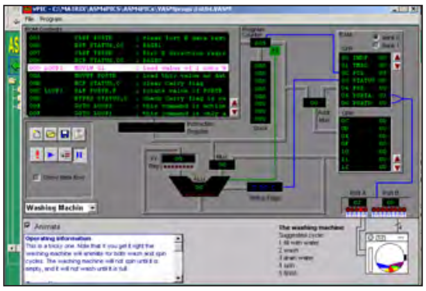

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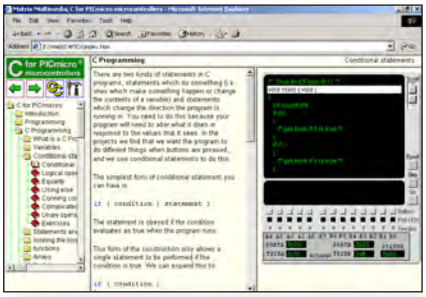

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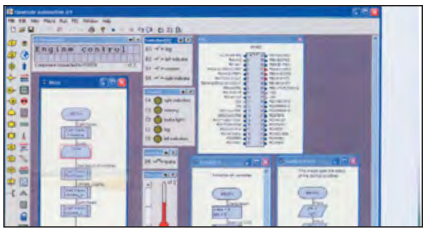

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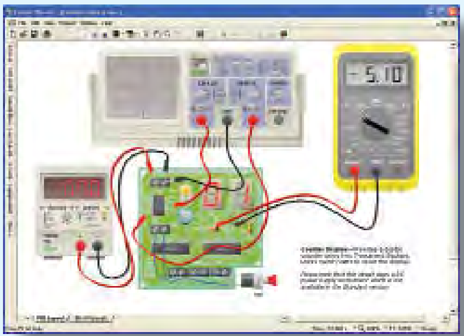

This software can be used with the *Jump Start* and *Teach-In 2011* series (and the *Teach-In 4* book).

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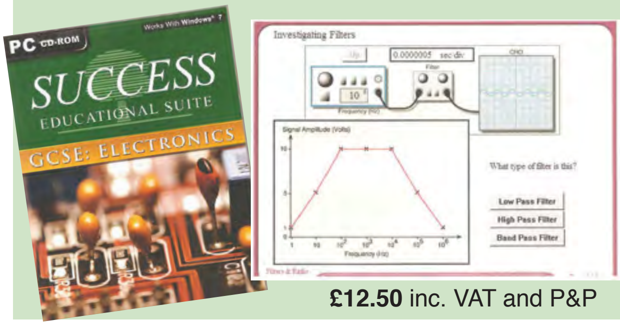

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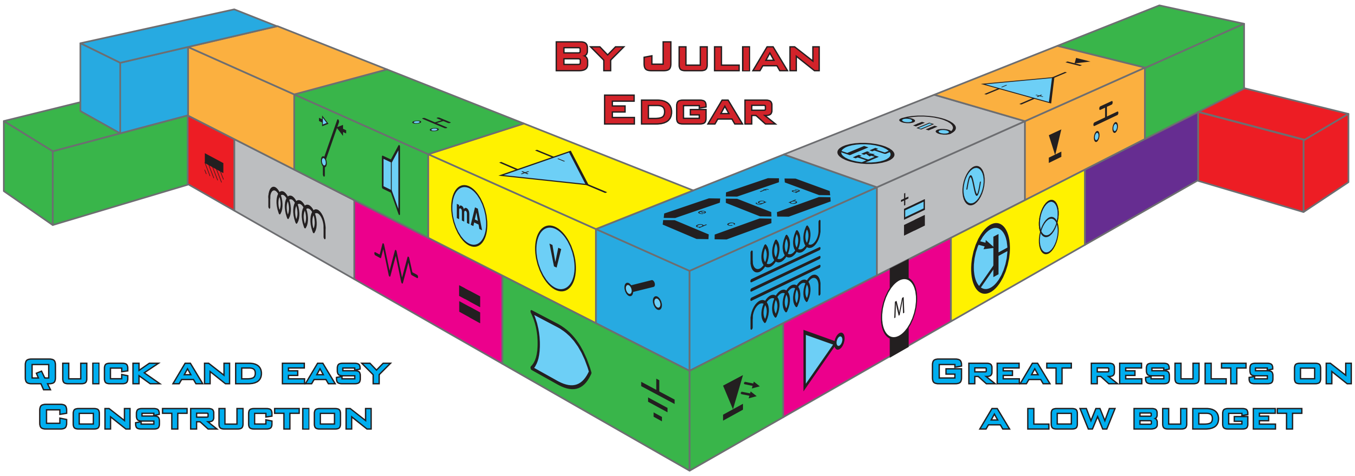
Electronic Building Blocks



By Julian Edgar

Quick and easy construction

Great results on a low budget

USB Boost Charger

Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be... FAST! These projects range from around £15 to under a fiver... bargains!

Charge a USB device from lower voltages

Here's a cheap module that will provide a charging source for any USB-charged device – a phone, tablet, even a rechargeable torch. The beauty of this device is that it is a boost converter, so it can do this charging while using an input voltage well below 5V.

Tiny but mighty

A tiny 33 × 18 × 13mm, the module is claimed to work at input voltages from 0.9 to 6V and output up to one amp. In real-world use on typical USB-charged devices, we found that indeed an output current of up to 1A was available. However, the unit showed good voltage regulation only with input voltages from 1.5 to 5.5V.

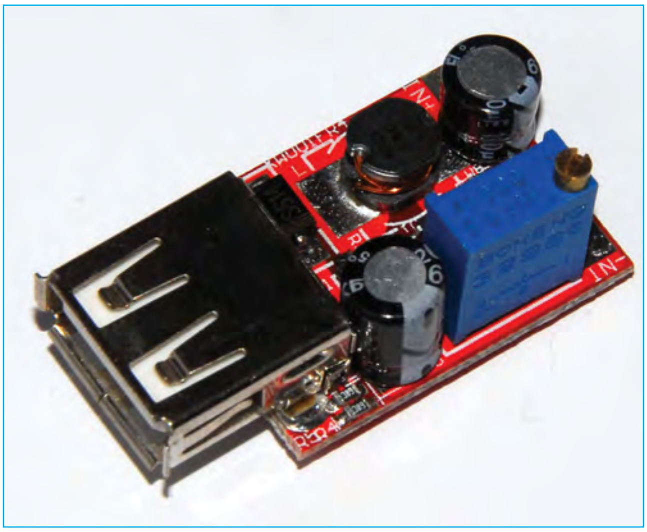


Fig.2. A normal USB cable plugs into the on-board socket, while power and ground feeds need to be soldered to pads located at the other end of the board.

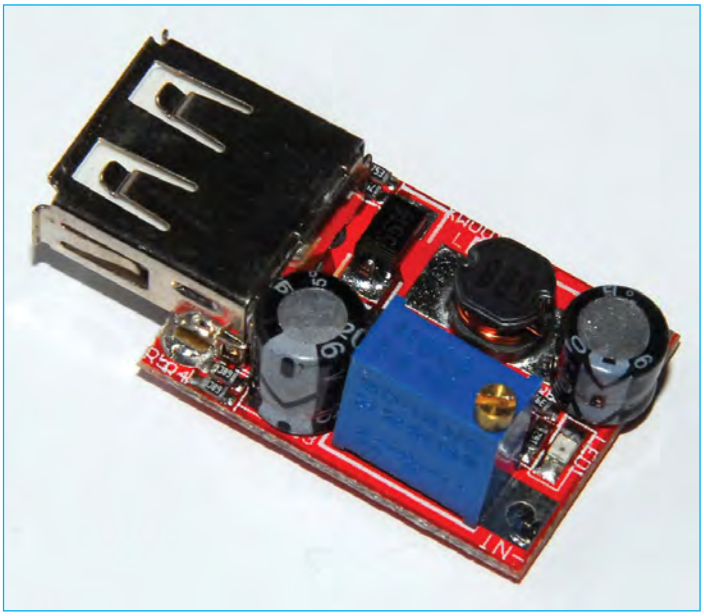


Fig.1. This tiny module is able to charge your phone or other USB-charged device while being powered from voltages well below the 5V USB nominal output.

Control and efficiency

The module features a pot that allows you to adjust the output voltage to precisely 5V, with an adjustable output range of 3.3 to 9V.

Conversion efficiency is claimed to be 94 per cent and while we did not directly measure this, in operation the module stayed quite cool.

Use with flat batteries

So what use is this device? Well, the major use is as an emergency charger for a phone. Place the module in a small box along with a dual AA cell holder, add a switch and you have an emergency supply that can be used to charge a phone, using only readily-available AA cells.

Another use is if you get sick of throwing away batteries that, while down a bit in voltage, are not fully discharged. This can be the case if you use devices that freeze if the voltage drops too far – so you end up with a bunch of cells still showing 1.3 or 1.4V. What a waste to throw them away!

Place two cells in series and this module will charge a USB device – even when the series cells' voltage is down to just 2V!

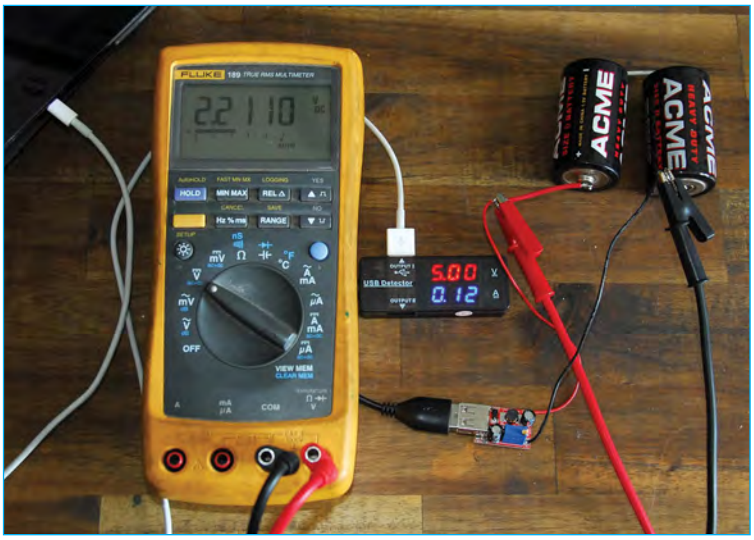


Fig.3. Here's the charging module in action. Being powered by two near-flat D cells (series voltage of the pair is just 2.2V, as shown on the multimeter), the module is charging an iPad Air at 120mA and 5.0V. The tiny module is nearly lost from sight in this pic – it's at the middle, bottom of the photo.

However, there's a qualification that needs to be made. Batteries in most modern USB-charged devices have a lot of capacity. Charging via a couple of AA cells (or even two D cells!) isn't going to take your iPad from empty to full – the cells don't have enough stored energy capacity. But as an emergency charge if you're back-packing or hiking, sure.

While we didn't try it, this may also be a useful module to use with solar cells developing less than 5V.

Not all of them are the same...

Not all of these *USB boost converters* are the same! This one, also purchased, proved to have poor performance. In real-world charging use we were unable to gain a greater output than 240mA and output voltage regulation was poor.

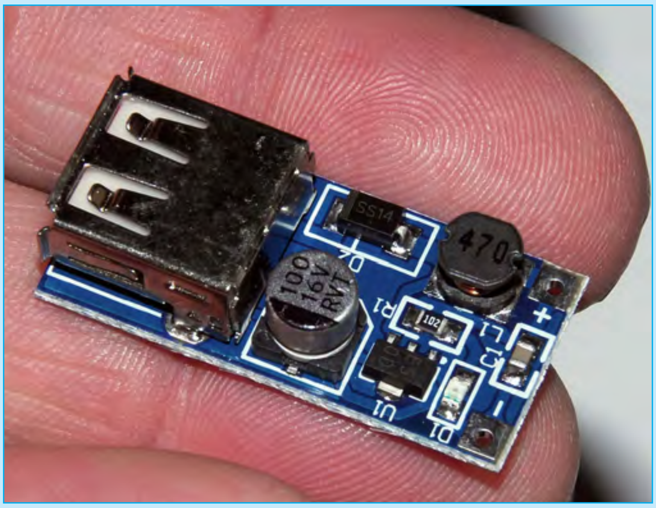


Fig.4. A 'dud' – be careful what you buy!

Sourcing

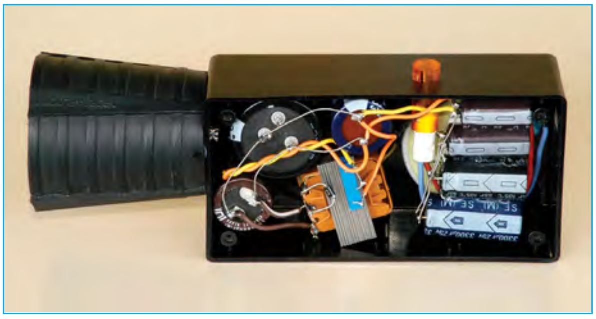
And what will the module cost you? Well under £2, delivered to your letter box!

At the time of writing, it could be found on eBay by searching for item No. 141662415264.

You may also be able to find it by searching under 'USB Solar Boost DC-DC 3V-5V Adjustable Power Supply Voltage Converter Module NEW', or variants of that phrase.

Next month

Here's a project that is not just good fun, but you end up with a useful torch that will never get flat batteries and will last a very long time.



Next month – Build your own hand-powered LED torch!

PCB SERVICE

CHECK US OUT ON THE WEB

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

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

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

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

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Teach-In 2015 – Part 1 Pre-Amp	905	£9.33
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A Rubidium Frequency Standard For A Song	04105141	£8.02
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Teach-In 2015 – Part 3	906	£8.75
MAY '15		
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Please check price and availability in the latest issue.
A large number of older boards are listed on, and can be ordered from, our website.

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

EPE SOFTWARE

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

PCB MASTERS

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

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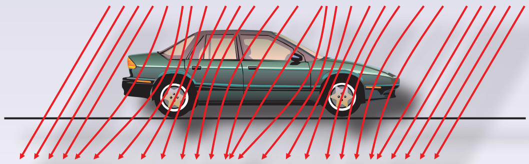
Next Month

Content may be subject to change



Driveway Monitor – Part 1

Based on a Honeywell magneto-resistive sensor, this *Driveway Monitor* provides an audible and visual indication when a vehicle is detected. Alternatively, it can be made to activate a remote-controlled mains switch to turn on lights for a preset time.

Install USB charging points in your car

New cars often have more than one USB socket for charging phones and other devices, but older cars have none. This tiny PCB will let you add one or two USB sockets and the total charge current can be up to 2.5A, more than enough for phones, satnavs or dash cameras.

Intelligent Charger for Nicad and NiMH Batteries

Cheap chargers supplied with original equipment can – and often do – damage the battery. Proper chargers are usually expensive. This cheap and easy-to-build Nicad/NiMH charger is suitable for automatically charging a wide range of batteries.

Teach-In 2016 – Part 6

In July's *Teach-In 2016* we examine how an Arduino can communicate wirelessly. *Arduino Workshop* will introduce wireless modules and *Arduino World* will look at short-range wireless systems to send data between Arduinos. *Coding Quickstart* introduces the RadioHead Packet Radio library for embedded microprocessors, and the *Get Real* project will be a simple wireless-linked rain alarm.

PLUS!

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

JULY '16 ISSUE ON SALE 2 JUNE 2016

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