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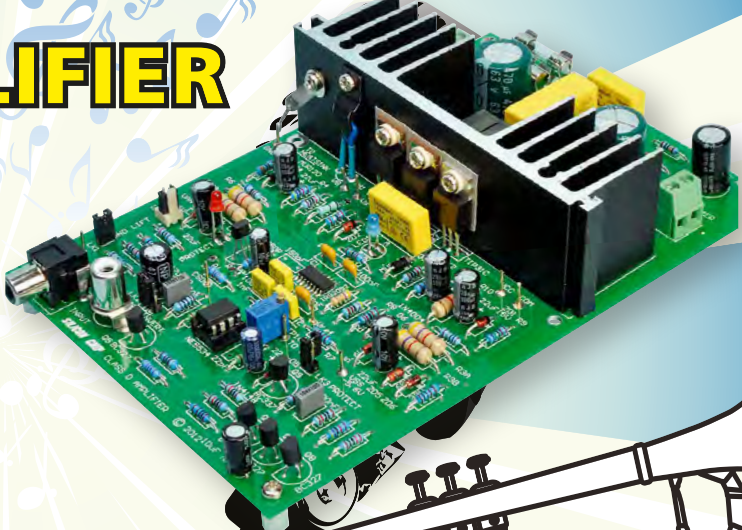

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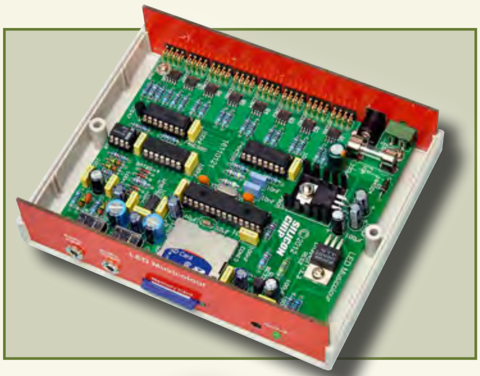

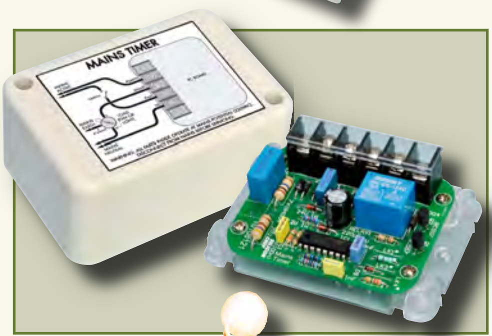

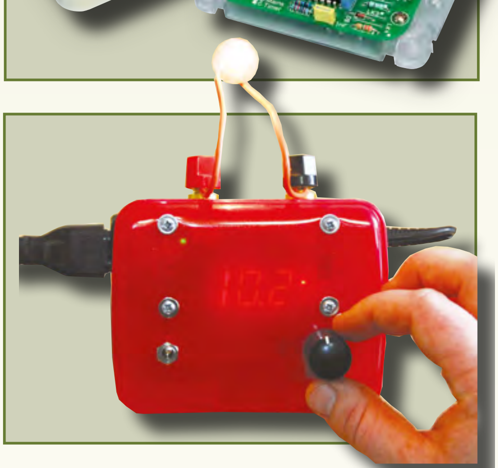

Our December 2013 issue will be published on Thursday 7 November 2013, see page 72 for details.

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- PCB: 70 x 57mm

KA-1119

£10.25*

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Plug this kit inline with a USB device to display the current that is drawn at any given time. Check the total power draw from an unpowered hub and its attached devices or what impact a USB device has on your laptop battery life. Displays current, voltage or power, is auto-ranging and will read as low as a few microamps and up to over an amp. Kit supplied with double sided, solder masked and screen-printed PCB with SMD components presoldered, LCD screen, and components.

- PCB: 65 x 36mm

KC-5516

£21.75*

Laptop not included

Independent Electronic Boost Controller Kit

It can be used in cars fitted with factory electronic boost control using the factory control solenoid, or cars without electronic boost control using a solenoid from a wrecker etc. It has two different completely programmable boost curves. This is ideal for switching between say, a race/street mode, or a performance/wet weather mode. Each boost map has 64 points able to be adjusted in 1% duty cycle increments. Boost curve selection is via a dashboard switch, and it is all programmed using the Handheld Digital Controller available separate - **KC-5386** £24.75. Kit supplied with PCB, machined case, and all electronic components.

- Suitable for EFI and engine management systems only.

KC-5387

£29.00*

TEACH KIDS ELECTRONICS

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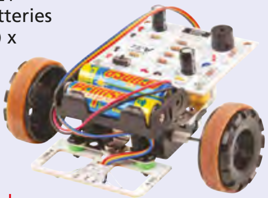
Learn about robotics and programming with this line tracer kit. Run it in line tracer mode by drawing a thick dark line on paper for the robot to follow.

- Suitable for ages 12+
- Requires 2 x AA batteries
- Size: 120(L) x 64(W) x 55(H)mm

KJ-8906



£11.00*

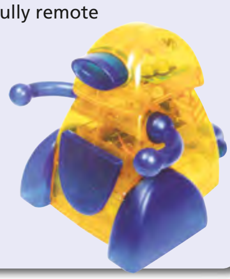
Batteries not included

Remote Control Robot Kit

This robot kit includes a collection of components ready to assemble on the kitchen table. Once complete you will have a fully remote controlled robot unit.

- Suitable for ages: 8+
- Requires 6 x AAA batteries in total
- Size: 125(H)mm approx.

KJ-8952



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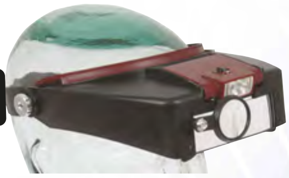
- 1.5x, 3x, 8.5x or 10x magnification
- Requires 2 x AAA batteries

QM-3511



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- Display: 4000 count
- Size: 150(H) x 70(W) x 50(D)mm

QM-1327

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NEW 2013

- 3.7V output for a single Li-Po cell
- Micro-USB jack
- "Charge" and "Standby" LEDs
- Size: 27(W) x 16(H) x 10(D)mm

XC-4243

£4.75*

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Connects to the USB port on your computer and acts as a virtual serial port, converting the USB signals to either 5V or 3.3V logic level serial data.

- Size: 46(W) x 26(D) x 10(H)mm

XC-4241

£8.50*

NEW 2013

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NEW 2013

- Size: 56(L) x 46(W) x 22(H)mm

XC-4237

£9.25*

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An ultra compact 6-way 12VDC touch control panel to control devices in automotive, camping, or marine applications. The 6 buttons on the switch panel control 6 relays in the separate control box with an included 1m long ribbon cable. This resulting a completely waterproof (IP67) switch panel.

NEW 2013

- Built-in resettable fuses
- Max current: 10A per channel, 35A total
- Touch Panel size: 70(L) x 63(W) x 1(H)mm
- Membrane Control Box size: 135(L) x 90W) x 33(H)mm

SP-0900

£44.90*

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Let your CCD camera see in the dark! This infrared light is powered from any 12-14VDC source and uses 32 x infrared LEDs to illuminate an area of up to 5m (will vary with light conditions).

- Kit is supplied with silkscreened/ gold plated/ solder-masked PCB, 32 x Infrared LEDs and all electronic components
- PCB: 74 x 55mm

KG-9068

Note: Not suitable for colour CMOS cameras

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C-9701 Cebek Module £7.89
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CD-9 Cebek Module £12.99
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Red 7 Segment display in attractive enclosure, automatic time base selection, battery back-up, 12 or 24Hr modes.
Power: 9Vac or dc
MK151 Velleman kit £15.09
Nixie Clock Kit
Gas filled nixie tubes with their distinctive orange glow. HH:MM display, automatic power sync 50/60Hz
Power: 9-12Vac 300mA
K8099 Velleman kit £64.96
1.8W Mono Amplifier
Compact mono 1.8W RMS 4Ω power stage, short circuit & reverse polarity protection. 30-18kHz, Power: 4-14Vdc 150mA
E-1 Cebek Module £5.87
Proximity Card Reader Kit
A simple security kit with many applications. RFID technology activates a relay, either on/off or timed. Supplied with 2 cards, can be used with up to 25 cards. Power: 9Vac or dc
MK179 Velleman kit £14.25
Mini USB Interface Board
New from Velleman this little interface module with 15 inputs/outputs inc digital & analogue in, PWM outputs. USB Powered 50mA, Software supplied
VM167 Module £26.80
20W 2 Channel Amplifier
Mono amplifier with 2 channels (Low & High frequecy), 20W RMS 4Ω per channel, adjustable high level. 22-22kHz, short circuit & reverse polarity protection.
Power: 8-18Vdc 2A
E-14 Cebek Module £22.11
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Powered by two subminiature motors, this robot will run towards any light source. Novel shape PCB with LED eyes.
Power: 2 x AAA Batteries
MK127 Velleman kit £9.02
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Power: 12Vdc 100mA
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Stereo power stage with 5W RMS 4Ω, 30-18kHz, short circuit & reverse polarity protection.
Power: 6-15Vdc 500mA
ES-2 Cebek Module £21.54
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A high quality audio power amp, 200w music power @ 4Ω 3-200kHz Available as a kit without heatsink or module including heatsink.
K8060 Velleman kit £12.85
Heatsink for kit £9.95
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Single rail regulated power supply complete with transformer. 130mA max, low ripple, 12Vdc with adjustment.
FE-103 Cebek Module £13.16
MP3 Player Kit
Plays MP3 files from an SD card, supports ID3 tag which can be displayed on optional LCD. Line & headphone output. Remote control add-on. Power: 12Vdc 100mA
K8095 Velleman kit £39.99
Velleman PC Scope
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PCSU1000 Velleman £249.00
1-180 Second Timer
Universal timer with relay output. Time start upon power up or push button. LED indication. 5A Relay
Power: 12Vdc 60mA
I-1 Cebek Module £12.92
DC to Pulse width Modulator
A handy kit to accurately control DC motors etc. Overload & short circuit protection. Input voltage 2.5-35Vdc, Max output 6.5A.
Power: 8-35Vdc
K8004 Velleman kit £9.95
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PC Based USB controlled 2 channel oscilloscope AND Function generator. Software included. See web site for full feature list.
PCSGU250 Velleman £113.67
Cyclic Timer
Universal timer with relay output. Time start upon power up or push button. On & Off times 0.3-60 Seconds, LED indication. 5A Relay
Power: 12Vdc 80mA
I-10 Cebek Module £14.12
Audio Analyser Kit
A small spectrum analyser with LCD. Suitable for use on 2, 4 or 8Ω systems. 300mW to 1200W(2Ω) 20-20kHz Panel mounting, back-lit display. Power: 12Vdc 75mA
K8098 Velleman kit £31.65
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TL-5 Cebek Module £14.64
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5A Relay
Power: 12Vdc 60mA
I-4 Cebek Module £13.98
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Power: 12Vdc 60mA
I-6 Cebek Module £13.08
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K8055 Velleman kit £24.80
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An electronic lock with up to ten 4 digit codes. Momentary or timed (1-60ec/1-60min) output. Relay 5A
Power: 12Vdc 100mA Keypad included.
DA-03 Cebek Module £54.26
Thermostat
A temerature controlled relay. Adjustable between -10 to 60°C Sensor on remote PCB. Connector for external adjustment pot. 5A Relay
Power: 12Vdc 60mA
I-8 Cebek Module £12.80
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K8090 Velleman kit £39.95
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EVERYDAY PRACTICAL ELECTRONICS

Analogue, digital or simply electronic?

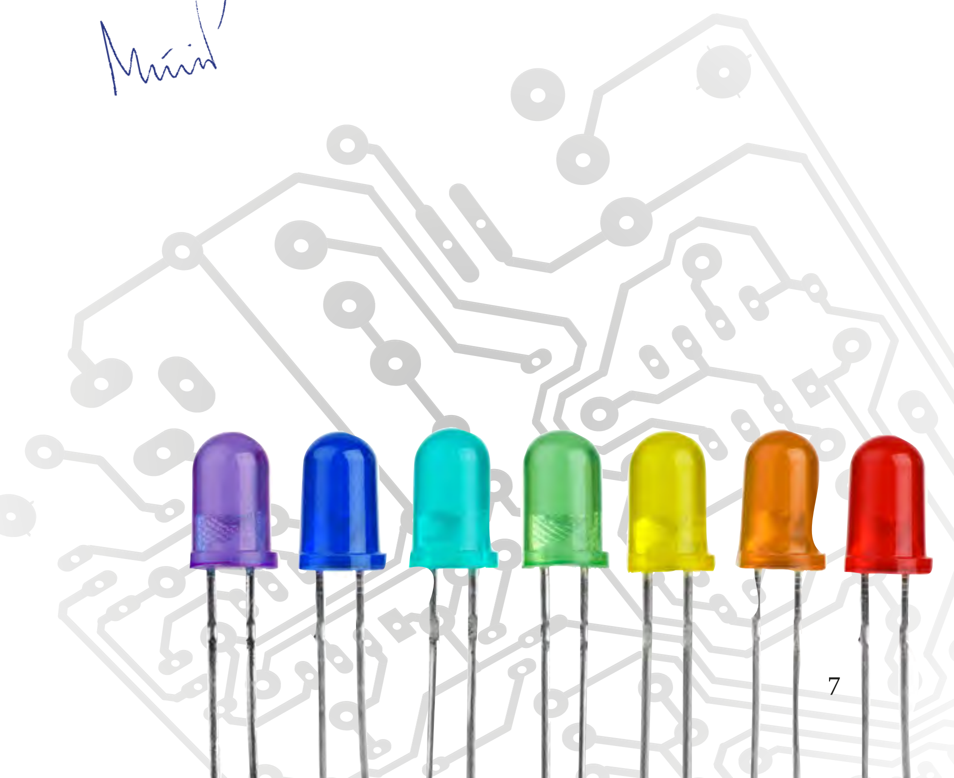
In our electronics world, it is often tempting to divide our activities into the eternally separate domains of analogue and digital. People often identify with building amplifiers or designing PIC-based projects. It's as if the choice is exclusively flip-flops or op amps, but does that really make sense? The building blocks in both are generally silicon-fabricated diodes and transistors – both bipolar and field effect. The truth is, analogue and digital are really just opposites sides of the same coin, something nicely revealed in one of this month's projects – the *CLASSiC-D amplifier*.

What could be 'more analogue' than an audio amplifier? It's the kind of project many of us have cut our teeth on. Also, since we usually start off with a Class-A design we also learn the meaning of efficiency thanks to the inevitable heatsinks hanging off the back of any design that puts out more than a dozen watts. More ambitious, higher-power designs usually meant graduating to Class B – better efficiency, but then we faced all the fun of eliminating cross-over distortion in push-pull designs.

Audio amps are a great way to learn about design, but there was always a nagging feeling that surely there must be a great way to amplify music that doesn't double as a room heater! Enter our Class-D amplifier. This type of amplifier uses pulse-width modulation, filters and borrows a very useful design concept from digital electronics – keep your transistors fully on or fully off for maximum efficiency. Above all, avoid the linear region, which is where the large heatsinks lurk!

The truth is, if you want to get the most out of digital or analogue electronics then it really does pay to know what's going on in the 'other camp'. I remember wasting half a day at university troubleshooting a digital project because I had failed to treat a basic digital building block as an electronic circuit rather than a 'piece of Lego'. I had failed to spot my device had open-collector outputs and needed to be treated in part as an analogue device that required a pull-up resistor. A mistake that's all too easy to make when you divide the world into uncommunicative camps.

So, my tip for November is: 'don't live in an electronic silo' – see yourself as an electronics hobbyist, not an analogue nor digital one.



NEWS

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

4K TV dominates IFA Berlin – by Barry Fox

As expected, IFA in Berlin this year centred on 4K Ultra HD – the next big hope for the TV industry after 3D, which (wholly predictably) flopped, and Connected TVs that often remain unconnected to the Internet because they are so awkward to use.

HDMI Ver 2.0

What everyone has been waiting for is the new version of the HDMI standard (Ver 2.0) that enables a 4K TV to connect with a future 'Full 4K' source such as a next generation Blu-ray player, and displays 60 full 4K pictures a second. The current HDMI standard, Ver 1.4, with a maximum data rate of 10.2Gbps, can only handle 30 pictures per second.

HDMI Ver 2.0, with a data rate of 18Gbps, was due in January – 'at the latest' – but has been repeatedly delayed. At the launch press conference in Berlin, Steve Venuti, president of the HDMI Licensing Organisation, said 'growing pains' were to blame. The pains came because in October 2011 the seven-member HDMI Founders Group morphed into the 88-member HDMI Forum – including Apple, a supporter of the rival DisplayPort connection system, and some new members inexperienced in the political game of standards setting.

On the face of things the HDMI 1.4 chips in current TVs cannot handle 4K Ultra HD at 60p (pictures per second); so, existing 4K Ultra HD sets are potentially obsolete without hardware upgrading.

Upgrade kits from Samsung and Philips

Ahead of IFA, Samsung had promised to update existing 4K Ultra HD TVs, with a plug-in extension kit. This is a large, heavy module that runs hot (signifying a high component count) that Samsung will sell for 299 euros.

Philips TP Vision will make an HDMI 2.0 'upgrade kit' available early next year for consumers who buy this year's 9000 series Ultra HD TVs with HDMI 1.4 capability, announced Scott Housley, global head of product, strategy, marketing and design, explaining: 'Basically, we'll create, for lack of a better word, a connected device based on HDMI 2.0, which will connect to the TVs and enable them to have HDMI 2.0 source through to the TV.'

Behind closed doors on the Philips booth, head TV designer Danny Tack was explaining how this will work. An upgrade kit box will sit beside the TV, taking in 4K signals through an HDMI 2.0 connector and connecting to an existing TV by its existing HDMI 1.4 socket. The HDMI chip in the TV set will be disabled so that the HDMI 1.4 connection is used simply as a dumb cable feed. The dumb connection will be carrying an unprotected signal, so Philips will have to do something to stop digital copying, Tack acknowledges. 'But we will handle that' he assures.

'By having a separate box we can handle any future developments, for instance HEVC H.265 decoding,' adds Tack. 'Some people are trying to run ahead. And they could run into big trouble.'

The Sony and Panasonic approach

Sony and Panasonic kicked off the show with competing announcements. Panasonic, which has so far held back on selling 4K TVs, will start 4K marketing with a 65-inch set that has both HDMI 2.0 and Display Port 1.2a connectors. The 65-inch WT600 will cost £5500 and be available at the end of September.

Sony countered by pledging that a firmware upgrade, available free over the Internet before the end of the year, would upgrade existing Sony TVs, without the need for any hardware modifications. 'Upgradeable to HDMI 2.0 – 4K/60p' promised the publicity labelling.

How can they do that, many asked – including Sony's competitors.

4K from HDMI Ver 1.4?

The first clue to the answer came from an engineer working for LG, the company which initially supplied raw 4K LCD panels to Sony, but now bitterly competes with Sony.

'There are no HDMI 2 chips available,' he told me. 'They aren't expected until next year. So we will need to change the main circuit board. We don't think it is possible for anyone to upgrade to HDMI 2.0 with just a firmware change – unless perhaps Sony is compromising with 4.2.0 colour coding. That would let them offer 60p but with the lower data rates that can be handled by HDMI 1.4 chips'.

Because the human eye is less sensitive to colour or chroma detail than to luma or black and white brightness detail, it is common practice to reduce broadcast or recording data rates by coding the chroma content of a TV or video signal less precisely that the luma. There are several different ways of doing this 'chroma subsampling'.

Instead of digitising the luma and chroma at the same full sampling rate and same full resolution (denoted by the shorthand term 4:4:4), the chroma signals can be sampled at half the luma rate (4:2.2) or at a quarter the rate (4:1:1) or asymmetrically (4.2.0) with higher horizontal resolution than vertical resolution. Inevitably, the lower rate codings reduce theoretical quality, and the practical effect is subjective and open to debate.

Sony had not mentioned the use of the latter option, 4.2.0, at its briefing sessions ahead of the HDMI event. However, the HDMI Forum's president Robert Blanchard, who happens to be a Sony employee, confirmed the situation when quizzed by the press on how Sony could promise a firmware upgrade to HDMI 2.0 without replacing the HDMI 1.4 chips in its sets and with no HDMI 2.0 chips currently available.

'I cannot speak here for Sony, but I'd like to share with you what Sony experts have told me' said Blanchard. 'It is possible to do 4K at 60p – without new hardware required – by using 4.2.0 pixel coding'.

The use of 4:2:0 permits the use of 4K at 60p without the need for higher data rates – enabling the use of existing HDMI 1.4 chips; but it opens the door to accusations of compromised picture quality and paves the way for a whole new hot topic of perceivable differences between differing colour codings.

The industry looks all set now to split between those offering new TVs and upgrades with 'Full 4k' and those arguing that '4K Lite' is good enough.

Pico Technology adds to PC scope range

Pico Technology has launched a new PC oscilloscope with up to 500MHz bandwidth on four channels, and an industry-leading two giga-samples of buffer memory. The new PicoScope 6000 Series has both the performance and the advanced analysis capability to speedily debug modern, complex electronic designs.

The 6000 Series employs hardware acceleration and a USB 3.0 interface to acquire and display many mega-samples of data per screen update without slowing down. Users can observe large portions of their design's electrical behavior at one time, and in great detail, which helps to reduce debug cycles and enables electronic design projects to be completed on schedule.

Pico provide a suite of advanced debugging tools, included as standard with the scopes, so that engineers who are developing complex electronic systems will find all the functions they need.

All models include an integrated function generator or arbitrary waveform generator (AWG), advanced triggering, automatic measurements with statistics, an FFT spectrum analysis mode, comprehensive waveform maths, mask limit testing, and serial decoding for popular industry standards such as I^2C, SPI, UART, CAN, LIN and FlexRay.

The PicoScope 6000 Series scopes are compact and include a five-year warranty as standard. Prices start at £1995 for the 250MHz model with function generator, through to £4495 for the 500MHz model with arbitrary waveform generator and two giga-samples of buffer memory. A set of four high-quality matched probes is supplied with every scope.

More information can be found at: **www.picotech.com**

Enigma veterans' Bletchley Park reunion

Veterans of Bletchley Park, Britain's wartime cryptography and computing centre, gathered in early September for their annual Enigma Reunion.

Veterans of Britain's greatest codebreaking endeavour – cracking the German Engima code (Photo: mubsta.com)

They were given updates on the progress of the £8 million Heritage-Lottery-Funded restoration of Bletchley Park and the oral history project, which is gathering memories for future generations. You can hear about the veterans' visit and other Bletchley material at the Bletchley Park Podcast website: **https://audioboo.fm/Bletchleypark**

SOLDERING TOOL KIT

Parallax has launched its 'Pro Soldering Tool Kit'. The ensemble is a complete set of soldering tools that includes a Panavise circuit board holder, Hakko #FX888D soldering station, small pair of diagonal cutters, tip cleaning pad, roll of (leaded) solder, hand-held vacuum solder sucker, four rubber mounting feet, a standoff holder for the solder roll, and mounting hardware – all supplied in a handy carrying crate. All you need to add is Alan Winstanley's excellent *Basic Soldering Guide* ebook available for Kindle.

More details at: **www.parallax.com** (Item code 700-10018, $199).

Raspberry Pi

RasWIK

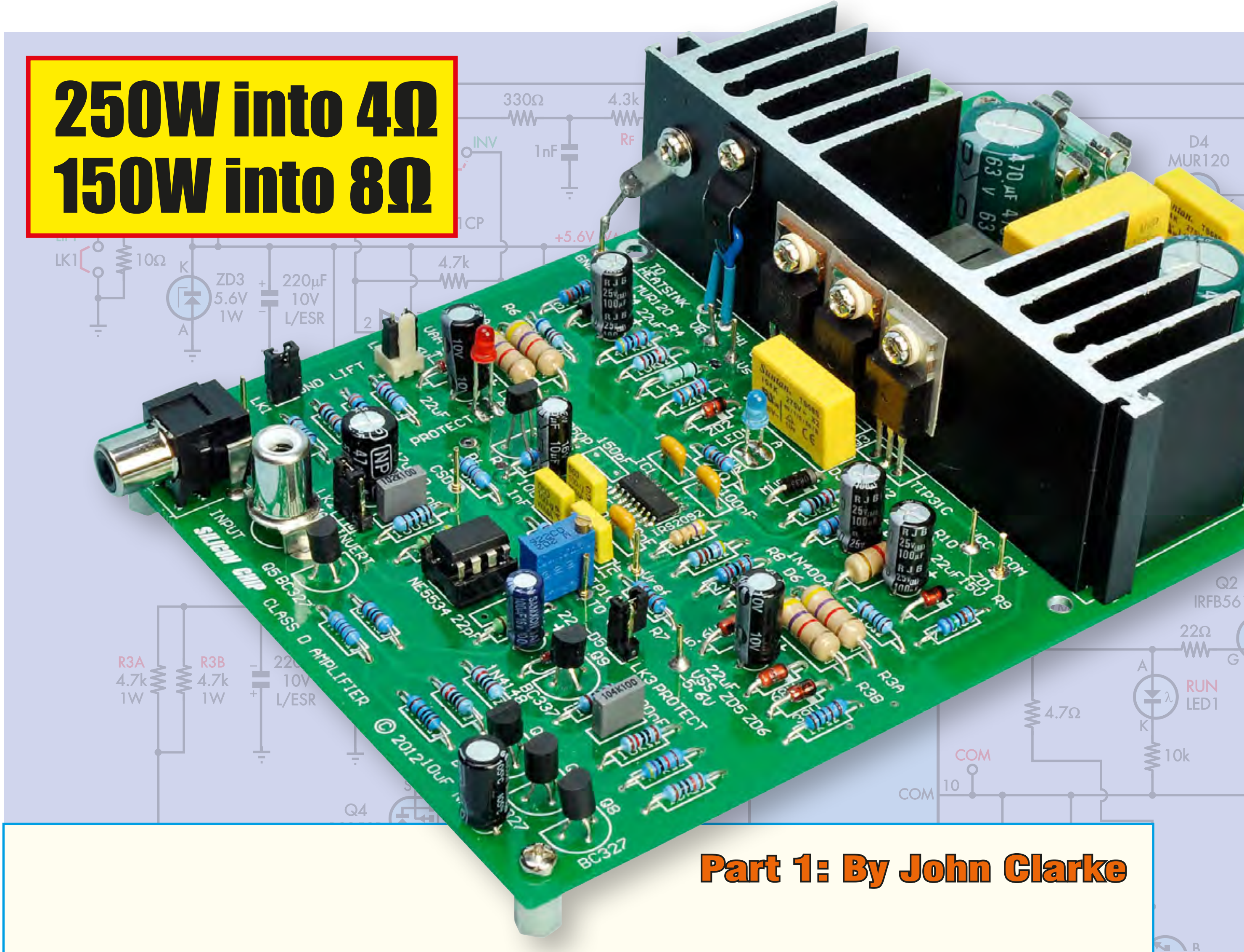
Ciseco has announced a Raspberry Pi 'Wireless Inventors Kit' (RasWIK). The 88-piece kit provides everything for a series of step-by-step projects to create wireless devices; without the need for configuration or even writing code. RasWIK has been designed to be highly accessible, enabling anyone with basic computing skills to build wireless Pi projects. See: **http://shop.ciseco.co.uk/resellers**

RPi programming challenge

The PA Consulting Group is challenging teams from schools and universities to put their technology skills, ingenuity and creativity to the test in its second Raspberry Pi programming competition. PA wants entrants to use the Raspberry Pi to develop a computer program that will help the environment.

Teams of up to six students may use a Raspberry Pi, additional hardware up to the value of £100 and any software modules available as source code. PA will supply the first 100 teams to enter the competition with a starter kit of equipment worth £75, including a Raspberry Pi computer.

To register and to view a video of last year's winners, visit PA's website: **www.paconsulting.com/raspberrypi**



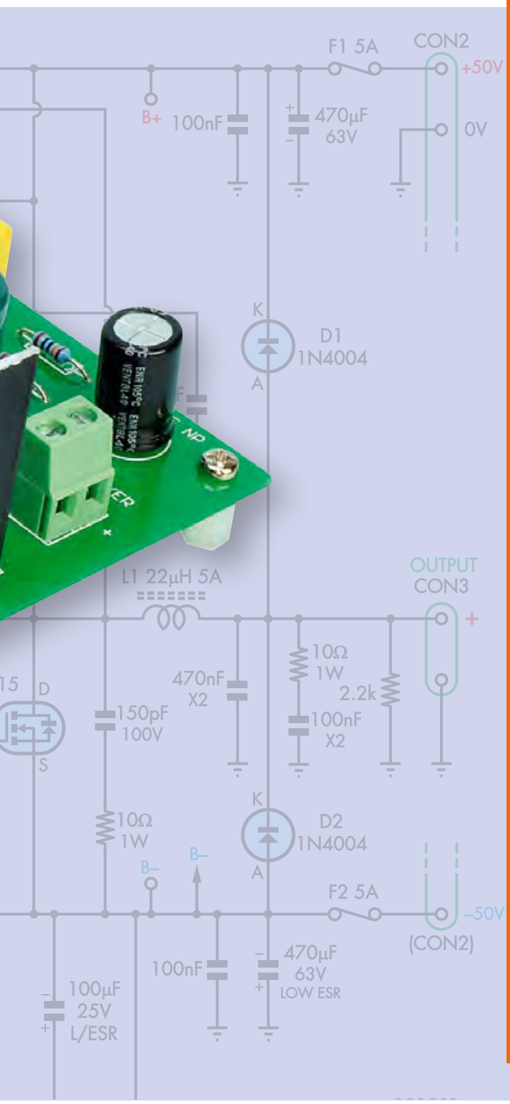
250W into 4Ω
150W into 8Ω

Part 1: By John Clarke

CLASSiC-D Amplifier

World's first DIY high-power high-performance Class-D amplifier: 250W into 4Ω, 150W into 8Ω

You asked for it and now we are finally delivering it! Over the years we have worked on a number of Class-D amplifiers, but they never saw the light of day because they were simply too difficult to build and were unreliable. We kept blowing 'em up! But now we have succeeded, and as a bonus, this design has high power, very low harmonic distortion and is very quiet.



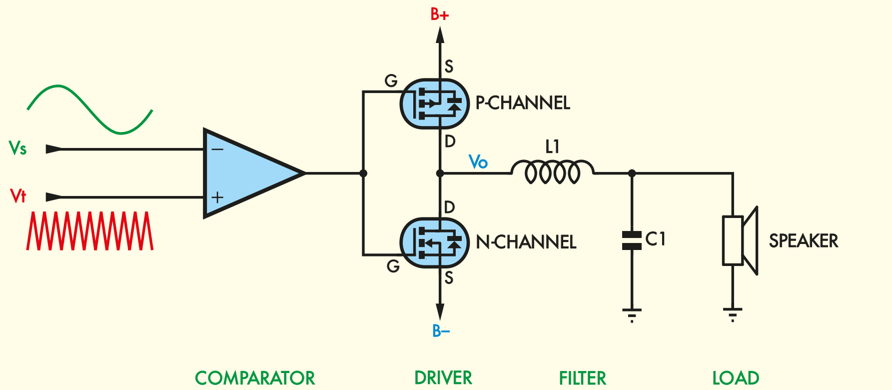


Fig.1: simplified circuit of a Class-D amplifier. The incoming analogue waveform (Vs) is compared to a high-frequency triangle wave (Vt) and the comparator then drives a pair of MOSFETs to generate a PWM waveform. This then passes through an LC low-pass filter before being delivered to the speaker.

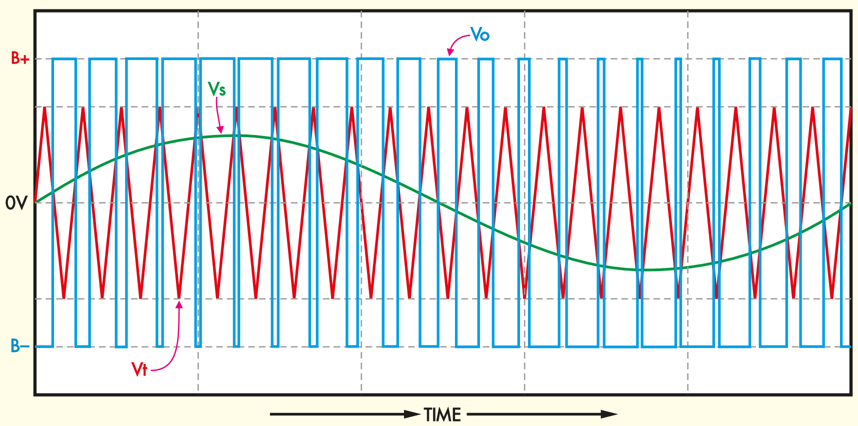


Fig.2: this diagram shows the two input waveforms fed to the circuit of Fig.1, along with the PWM output (V_O). Note how the duty cycle is longer when Vs is high and shorter when Vs is low. The output of the filter will be quite similar in shape to Vs.

CLASS-D OR SWITCHING amplifiers are made by the squillions and used in countless TV sets, home audio systems and a host of other applications ranging from iPod players and phones to large amplifiers in commercial applications. So they are obviously reliable when they are mass produced.

However, in the past when we have taken a typical Class-D chipset and tried to adapt it to a do-it-yourself design, we have been lamentably unsuccessful. Inevitably, the chipsets were surface-mount devices and some employed quite critical heatsinking for the main amplifier itself. And inevitably again, we consistently blew devices as we tried to devise a reliable DIY design.

Despite the frustration, time heals all wounds and eventually we came up with this design. Yes, it does use a surface-mount driver chip, but the pin spacing is quite reasonable for hand-soldering. More particularly, the main switching MOSFETs are conventional TO-220 devices that are easy to solder and heatsink. All the other components are conventional leaded devices and the result is that this Class-D amplifier is easy to assemble.

That's its first big advantage. Its second big advantage is ruggedness and reliability. It delivers heaps of power and has all sorts of protection built in, so we have not blown up a succession of devices during development. Well, back up a minute, we did blow some in the early stages – but those problems have all been sorted out!

Efficiency is the third big advantage, in common with all Class-D switching amplifiers. Efficiency is around 90% and that means that this amplifier will deliver considerably more power from a given power supply than would be possible with a typical linear amplifier.

High-quality sound is the final advantage of this design and this is its outstanding feature. Most Class-D amplifiers are only average in this respect and this applies to the vast majority of sound equipment used in homes today.

What is Class-D?

So what is a Class-D amplifier and how does it differ from a conventional amplifier? Put simply, conventional audio amplifiers are either Class-A, Class-B or Class-AB (a combination of the first two). These amplifiers have their output driver transistors (or MOSFETs) operating linearly. If you trace the signal through them, you will find that its shape is unchanged, but increased in amplitude as it passes through successive stages to the output.

Class-D amplifiers operate in an entirely different mode, the output MOSFET or bipolar transistors operate as switches rather than in their linear

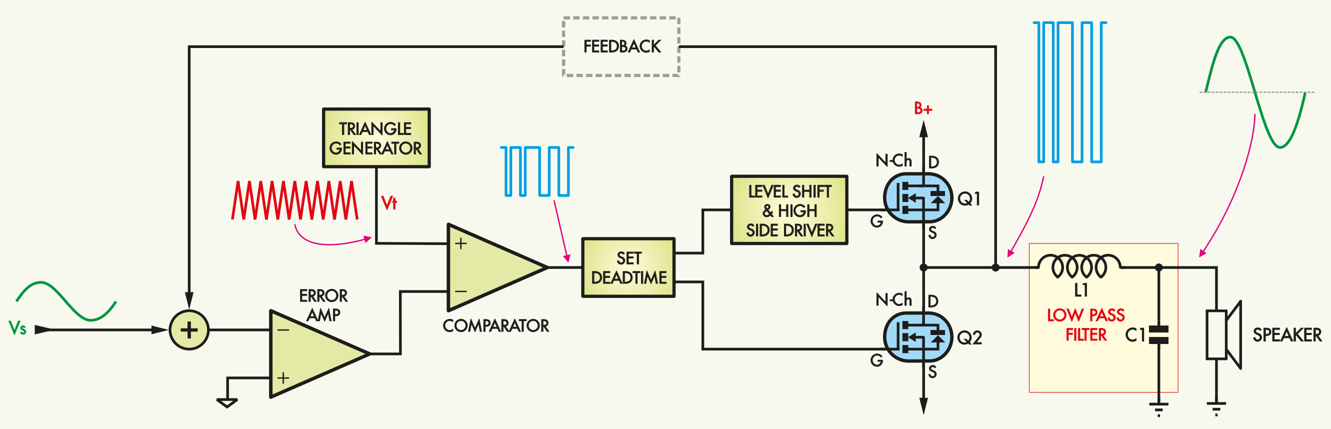


Fig.3: a more complete block diagram of a Class-D amplifier. This adds an error amplifier that provides some feedback from the output, reducing distortion. The output arrangement is improved too, with a pair of N-channel MOSFETs. With this arrangement, the upper MOSFET must be driven from a floating gate supply and a dead-time generator is used to prevent cross-conduction which would otherwise waste power and increase dissipation.

region and are either fully switched on or fully switched off. When switched on (or off), the power losses within the MOSFETs (or output transistors) are almost zero. Thus, a Class-D amplifier is far more efficient and generates much less heat than linear Class-A, Class-B and Class-AB designs.

In a Class-D amplifier, the output devices are switched at a very high frequency and the duty cycle is varied by the input audio signal. This technique is called pulse-width modulation (PWM). After filtering to remove the high-frequency switching from the output, the result is an amplified version of the input signal.

Note that with Class-D it is often (mistakenly) assumed that 'D' stands for digital. Not true. It was called Class-D because the previous amplifier classes were A, B, AB and C. So when switching amplifiers were first devised many decades ago, it was natural to call them Class-D.

Features

- High efficiency
- High power
- Low distortion and noise
- Bridging option for driving 8Ω loads with two modules
- Over-current protection
- Over-temperature protection
- Under-voltage switch-off
- Over-voltage switch-off
- DC offset protection
- Fault indicator
- Amplifier running indicator
- Optional speaker protector module

Class-D basics

Fig.1 shows the simplified arrangement of a Class-D amplifier. It consists of a comparator that drives a complementary MOSFET output stage with balanced supply rails (B+ and B–).

The comparator compares a fixed-frequency triangle wave against the incoming analogue signal. Its output swings low, to B–, when the input signal voltage is more positive than the triangle waveform and swings high, to B+, when the signal voltage is below. The output stage shown here is inverting, so the common drain (Vo) has the correct sense, ie, high when the input signal voltage is above the triangle voltage and vice versa.

Fig.2 shows the switching waveform produced by this circuit as well as the triangle wave input. The triangle wave (Vt) is at a much higher frequency than the input signal (Vs) and the resulting PWM output is shown as Vo.

A second-order low-pass filter comprising inductor L1 and capacitor C1 converts the PWM signal to a smoothly varying voltage. The result is an amplified version of the input signal, which is then applied to the loudspeaker, reproducing the input waveform as sound.

Fig.3 shows a more practical Class-D audio amplifier. This includes negative feedback from the PWM output to an error amplifier. The feedback reduces distortion at the amplifier's output and also allows a fixed gain to be applied. The input signal is applied to the error amplifier at the summing junction and its output is applied to the following comparator, which acts in the same way as in Fig.1, comparing a triangle waveform with the error amplifier output.

Note that because feedback comes from before the LC filter, the filter must be very linear for the output distortion to be low. In other words, we are assuming that the output filter does not add much distortion since there is no feedback around it and therefore if it does, that distortion will not be automatically compensated for. We don't want to add feedback around the output filter because it introduces a significant phase shift to the signal and that would adversely affect amplifier stability.

Fig.3 employs two N-channel MOSFETs and so the driving circuitry is more complicated. It includes a 'dead-time' generator that prevents one MOSFET switching on before the other has switched off. Without dead-time, each time the output switches, there would be massive current flow as both MOSFETs would simultaneously be in a state of partial conduction.

The MOSFET driver also includes a level shifter and high-side gate supply voltage generator, so that MOSFET Q1's gate can be driven with a higher voltage than its source (as is necessary to switch on an N-channel device). N-channel MOSFETs are generally more efficient than P-channel types, and since it can be the same type as Q2, the switching times are better matched.

It is important that MOSFETs Q1 and Q2 have similar characteristics so that the switching and dead-time can be optimised. Their desirable characteristics include: low on-resistance ($R_{DS(ON)}$) for minimal dissipation, a low gate capacitance to reduce switching losses and minimise switching times, and low gate resistance and reverse recovery times. These allow for a fast switching speed with short dead-times. Increased dead-time generally means increased distortion, so the shorter the better.

In practice, our new Class-D amplifier works in a slightly different way to that depicted in Figs.1, 2 and 3 since it uses a scheme known as 'second-order delta-sigma modulation'. In this, the triangle wave is produced by an integrator which is connected as an oscillator and its frequency varies with the output duty cycle.

This integrator also effectively forms the error amplifier and as with the simpler scheme described above, its output is fed to the comparator which controls the MOSFETs. In terms of actual circuit complexity, the delta-sigma scheme probably uses fewer components, and from our tests, it gives surprisingly good performance. So it's a clear winner compared to the traditional approach explained above.

Specifications

THD+N: typically <0.01%; see Figs.8-10

Power output: up to 150W into 8Ω and 250W into 4Ω, depending on power supply

Power output, bridged, 8Ω only: 450-500W, depending on power supply

Efficiency: typically 90% at full power for 8Ω and 83% for 4Ω

Signal-to-noise ratio: 103dB with respect to full power

Input sensitivity: 2V RMS (4Ω), 2.2V RMS (8Ω)

Frequency response: ±1dB, 10Hz-20kHz

Power requirements: ±40-60VDC, 50-55V nominal

Over-temperature cut-out: 75°C

Under-voltage threshold: +40V

Over-voltage threshold: +75V

DC offset protection threshold: > ±4VDC

Over-current threshold: 29A

Idling (no signal) frequency: ~500kHz (adjustable)

MOSFET dead time: 45ns

Full circuit details

Fig.4 shows the full circuit of the *CLASSiC-D Amplifier.* It's based on an International Rectifier IRS2092S Class-D audio amplifier IC (IC1). This incorporates the necessary integrator, comparator, MOSFET drivers and fault protection logic.

It also includes the level shifting and high-side driver required for the two N-channel MOSFETs (Q1 and Q2).

The over-current protection thresholds for each output MOSFET and the dead-time delay are set by external resistors on IC1's CSH, OC_{SET} and DT pins. The IC also has a fault input/output pin (C_{SD}) to allow external sensing of supply rail under-voltage and over-voltage conditions, as well as heatsink thermal limiting. This is used to shut down the amplifier if one of these fault conditions has occurred.

Other components in the circuit are included to regulate and filter the various power supplies, while inductor L1 and a 470nF capacitor form the low-pass output filter.

As shown on Fig.4, the main ±50V (nominal) supplies (B+ and B–) are fed in via fuses F1 and F2. These rails are then filtered by 470µF low-ESR capacitors that are bypassed with 100nF capacitors. The B+ rail connects to the drain of MOSFET Q1, while B– connects to the source of Q2 and to the common (COM) of IC1 at pin 10.

There is no direct B+ connection to IC1. Instead, the Vcc supply at pin 12 is relative to and derived from the B– supply via zener diode ZD1 and transistor Q3. In operation, current flows through ZD1 via a 7.5kΩ resistor (R9), so ZD1's cathode is at B– plus 15V. This voltage is buffered by Q3 and bypassed using 100µF and 1µF capacitors to derive the Vcc rail (ie, 15V above B–).

This voltage is applied to pin 12 of IC1 and is the supply rail for the low-side driver inside IC1. This drives MOSFET Q2's gate via the pin 11 (LO) output.

When pin 11 is low (ie, at COM or B-), MOSFET Q2 is off. Conversely, when the LO output goes high to Vcc, Q2's gate-source voltage is around +15V and so Q2 switches on.

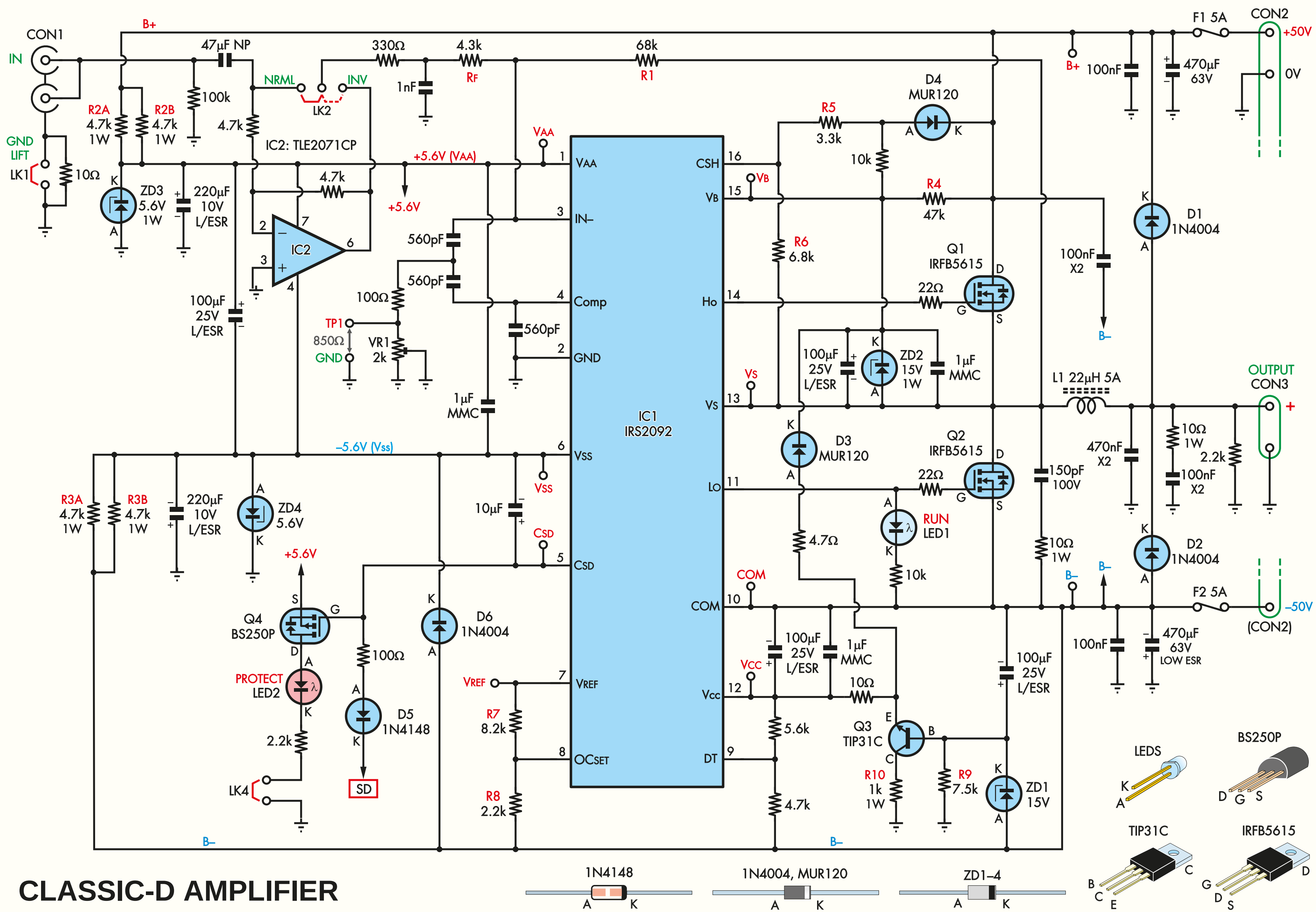
Similarly, Q1's gate must be at least 12V above its source in order to switch it fully on. Its source is connected directly to the output inductor (L1) and this can swing up to B+ (or very close to this) when Q1 is on. Conversely, this side of the output inductor goes to B– when Q1 is off and Q2 is switched on.

This means that the voltage supply for Q1's gate drive must 'float' on top of the output rail. Fig.5 shows a simplified version of the basic arrangement.

When the output at the junction of Q1 and Q2 is low, D3 is forward biased and this charges the 100µF and 1µF capacitors in parallel across ZD2 from the 15V Vcc supply. Conversely, when this output goes high, D3 is reverse biased, but the two capacitors retain charge for long enough to keep Q1's gate high (via V_B and HO of IC1) and thus Q1 switched on until the next negative pulse.

When both MOSFETs are switched off (eg, when power is first applied or during a fault condition), the voltage at Vs (pin 13 of IC1) is held near ground by current flowing through the speaker load at CON3 or, if no speaker is attached, the parallel 2.2kΩ resistor. Since D3 is reverse-biased in this condition, resistor R4 (47kΩ) is included to provide a small amount of current to keep the capacitors across ZD2 charged, so that Q1 can be quickly switched on once conditions have stabilised.

The current through R4 produces a small DC offset at the amplifier's output, but it's not sufficient to cause any problems. With no load attached, the output offset will be +1.56V, due to current flowing through R4, ZD2 and the 2.2kΩ resistor at the output. This drops to 5.7mV with an 8Ω loudspeaker load (or half that for a 4Ω load).



CLASSIC-D AMPLIFIER

Fig.4: the main circuit for the *CLASSiC-D Amplifier* module (without the protection circuitry shown in Fig.6). It's based on IC1, an IRS2092 Digital Audio Amplifier which contains the error amplifier/triangle wave generator, comparator, dead-time generator, level shifter, MOSFET drivers and protection logic. Op amp IC2 provides the signal invert option, while MOSFETs Q1 and Q2 form the output stage. The main supply rails are B+, GND and B–, while IC1 has four additional supply rails: +5.6V (V_{AA}), –5.6V (V_{SS}), B– + 15V (V_{CC}) and a 15V floating supply (V_B/V_S).

Input circuit

The input/analogue section of IC1 is powered from a pair of separate ±5.6V rails. These are connected to pin 1 (V_{AA}, +5.6V) and pin 6 (V_{SS}, –5.6V) and are referenced to GND (pin 2). They power IC1's internal error amplifier/integrator and comparator circuits and they also power op amp IC2.

The ±5.6V rails are derived from the main B+ and B– rails via paralleled 4.7kΩ resistors and zener diodes ZD3 and ZD4. A 220µF capacitor filters each supply, while a 100µF electrolytic and 1µF MMC capacitor in parallel bypass the total supply between V_{AA} and V_{SS}.

The amplifier's signal input is applied to one of the two RCA sockets at CON1 – one vertical, the other horizontal so that you have a choice when it comes to making the connection. Having a second input socket also allows the input signal to be daisy-chained to a second amplifier module if you want to operate two modules in bridge mode.

The RCA socket shields are either connected directly to ground via link LK1 or via a 10Ω resistor. This resistor is typically included in a multi-channel amplifier and prevents hum by reducing the current flowing between the signal ground connections. It can also improve channel separation.

As shown in Fig.4, the input signal is fed via a 47µF capacitor to jumper block LK2. This allows you to select whether the input is inverted by op amp IC2 or not. If you are using just one module, then LK2 would be installed in the normal (NRML) position.

The invert mode is useful for bridging two amplifier modules. In that case, the first module is set to normal mode and the second to invert. The same input signal is then fed to both amplifiers and the speaker connected between the two outputs.

Supply bus pumping

You can also use the invert mode for one channel of a stereo amplifier. Basically, it's a good idea to invert the output signal of one amplifier relative to the other. The correct phase is then maintained by swapping the output terminals of the inverted amplifier module. This prevents a problem with Class-D amplifiers whereby the power supply can be raised above its normal voltage by a process called 'supply bus pumping'.

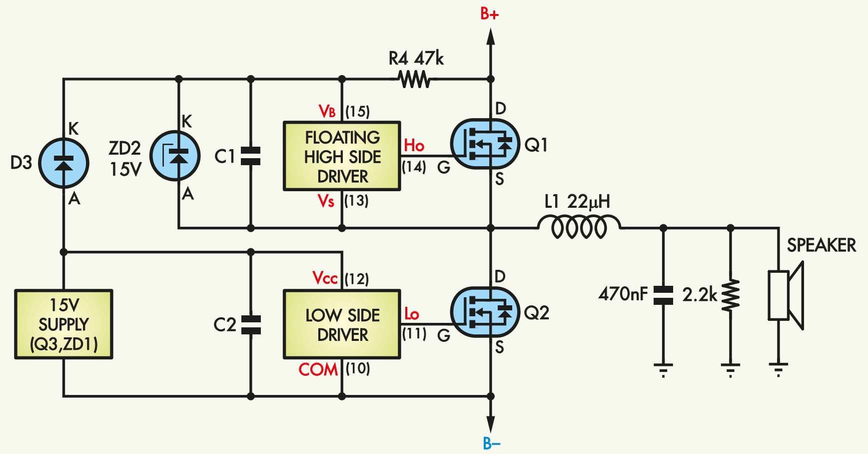


Fig.5: a simplified version of the floating supply arrangement. C1 is charged to 15V, which is limited by ZD2. When the output (Vs) is low, C1 charges from C2 via D3. C1 partially discharges (due to gate drive current) when Vs is high and recharges on the next low cycle. R4 charges C1 when both Q1 and Q2 are switched off (eg, when power is first applied).

Supply bus pumping is caused by the energy stored in the inductance of the output filter and speaker winding(s) being fed back into the supply rail via the output MOSFETs. This is primarily an issue for signal frequencies below 100Hz, ie, the ripple frequency of the main supply capacitors.

When one amplifier is driven out of phase to the other, the supply pumping effect is cancelled out, assuming the low-frequency signal is more or less evenly split between the two channels. In bridge mode, this is automatically the case, so the effect doesn't occur.

From LK2, the signal is fed through a low-pass filter comprising a 330Ω resistor and 1nF capacitor which prevent RF signals from entering the amplifier. This filter also prevents high-frequency switching artefacts at the output from being fed back to the input via resistors R1 and R_F.

Following the low-pass filter, the audio signal is fed to the inverting input (IN–) at pin 3 of IC1. R_F (4.3kΩ) and R1 (68kΩ) set the gain of the amplifier, with feedback via the 68kΩ resistor also applied to the IN– input. The gain with the component values shown is 68kΩ ÷ (4.3kΩ + 330Ω) = 14.7 or 23dB.

The 560pF capacitor between the COMP input (pin 4) and GND (pin 2) rolls off the open-loop gain of the amplifier, to ensure stability. Two more 560pF capacitors between the COMP and IN– pins, together with a 100Ω resistor and trimpot VR1, set the oscillator frequency. This RC network forms the second-order delta-sigma differentiator.

Output filter

The switching amplifier output is filtered using 22µH inductor L1 and a 470nF X2 polypropylene capacitor. The inductor is a special type chosen for its linearity, so as to minimise distortion, especially at higher frequencies.

This type of LC low-pass filter has second order characteristics, ie, after the –3dB point it rolls off at around 12dB/octave. The switching frequency is around 500kHz and the filter's –3dB point is set to 1 ÷ (2π x √(22µH × 470nF)) = 49.5kHz. This gives $\log_2$(500kHz ÷ 49.5kHz) × 12dB + 3dB = 43dB attenuation of the nominally 50V RMS switching waveform.

Thus, we expect a high-frequency signal of about 0.4V RMS to remain after the filter – which is very close to that measured.

A snubber network comprising a 10Ω resistor and series 100nF capacitor is also connected across the output following the filter to prevent oscillation. Similarly, there is a 150pF/10Ω 1W snubber at the switching output to limit the rise and fall times and so reduce EMI (electromagnetic interference). D1 and D2 clamp any output excursions that would otherwise go beyond the B+ and B– supply rails (eg, due to the speaker coil inductance).

Fault protection

When power is first applied or if a fault occurs, the shutdown input (C_{SD}) at pin

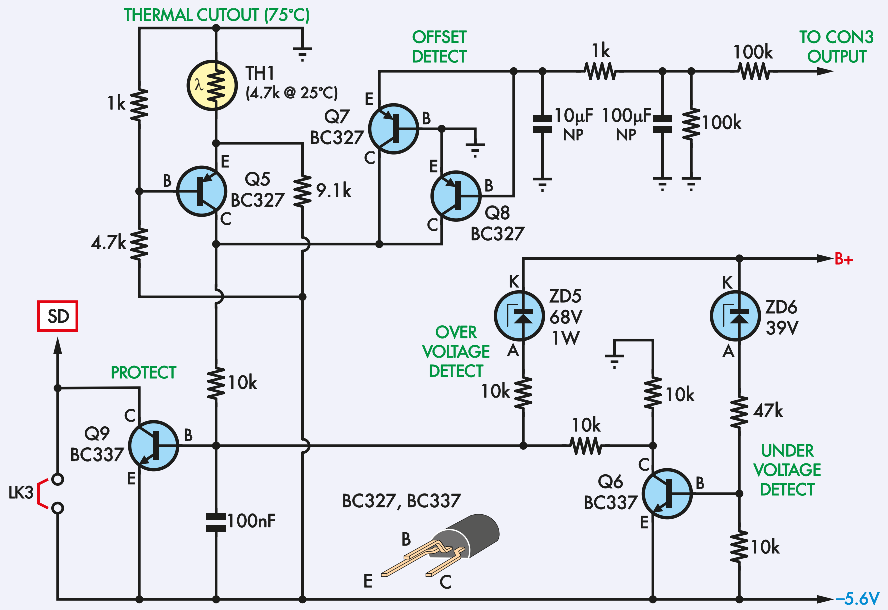


Fig.6: additional protection circuitry on the amplifier PCB. TH1 provides over-temperature protection, ZD5, ZD6 and Q6 provide over and under-voltage protection, and Q7 and Q8 provide DC offset protection. If any of the fault conditions is met, Q9 turns on and pulls the C_{SD} pin of IC1 to –5.6V via D5 and a 100Ω series resistor (shown in Fig.4).

5 is held at –5.6V (or close to it). In that case, MOSFETs Q1 and Q2 are both off and switching is disabled. And with no gate drive for Q2, LED1 is off too.

IC1 is held in this state until the V_{AA}, V_{SS}, V_{CC} and V_B supplies reach sufficient voltage for it to operate.

In addition, IC1 can be shut down by external protection circuitry when its C_{SD} pin (pin 5) is pulled low via D5. The additional protection circuitry on the PCB is shown in Fig.6. When C_{SD} is low, P-channel small-signal MOSFET Q4 turns on and this lights LED2 (PROTECT), provided link LK4 is installed.

Shutdown also occurs if either Q1 or Q2 passes excessive current, eg, due to a shorted output. In operation, the output current is measured by monitoring the voltage across each MOSFET during the period it is switched on. The MOSFETs specified (IRFB5615) have a typical on-resistance of 35mΩ at 25°C.

In the case of Q2, the current threshold before shutdown is set by resistors R7 and R8, at pins 7 and 8 of IC1. Pin 7 is the reference (5.1V), while pin 8 (OCSET) is the over-current threshold input. This is set at 1.08V by the 8.2kΩ and 2.2kΩ resistors, and this in turn sets the current shutdown at about 30.8A (ie, 1.08V ÷ 0.035Ω) at 25°C (or slightly less as Q2's temperature rises during operation).

The high-side current limit is set by divider resistors R5 and R6 on IC1's CSH input (pin 16). This circuit works in a different manner to the low-side current-limiting circuit. In this case, diode D4 provides a reference voltage that's about 0.6V above B+. That's because V_B is 15V above B+ and is applied to D4's anode via a 10kΩ resistor.

This reference voltage is applied to the top of the divider, the bottom end of which goes to the Vs rail (pin 13). As the current through Q1 increases, so does the voltage across it and so V_S drops in relation to B+. As a result, the voltage at the CSH pin rises relative to V_S until there is about 1V across Q1, at which point the over-current protection kicks in (for more detail on this, refer to International Rectifier application note AN-1138 at **www.irf.com/technical-info/appnotes/an-1138.pdf**).

The dead time for Q1 and Q2 (ie, the delay between one switching off and the other switching on) is set by the two divider resistors (5.6kΩ/4.7kΩ) on DT (pin 9). For this design, it is set at 45ns, the second-fastest option out of four.

More protection

Additional protection circuitry (see Fig.6) is used to prevent the amplifier from running should it overheat or develop a large DC offset, or if the supply voltage goes outside the normal operating limits. In any of these events, transistor Q9 switches on and pulls IC1's CSD input low via diode D5 and a series 100Ω resistor.

Jumper link LK3 provides forced shut-down of the amplifier. It's there to allow the supply voltages to be checked after construction, before the amplifier is allowed to run. Once the supplies have been checked out, LK3 is removed.

The over-temperature cut-out is provided using thermistor TH1. This thermistor has a resistance of 4.7kΩ at 25°C, dropping to about 690Ω at 75°C.

Thermistor TH1 is monitored by transistor Q5. This transistor's base is biased to 982mV below ground (ie, –5.6V × 1kΩ ÷ (4.7kΩ + 1kΩ)), while its emitter is 1.9V below ground with TH1 at room temperature.

Q5's emitter will rise to 0.6V above its base when TH1's resistance drops to 690Ω, ie, when TH1's temperature rises above a critical point. At that point, Q5 switches on and supplies current to Q9's base via a 10kΩ current-limiting resistor, thereby turning on Q9 and shutting down the amplifier.

Q6 and ZD6 make up the under-voltage detection circuit. If the supply voltage drops much below 40V, ZD6 no longer conducts and Q6 turns off. This allows current to flow into Q9's base via the 10kΩ pull-up resistor and a further 10kΩ series resistor and so Q9 turns on and shuts the amplifier down.

By contrast, the over-voltage protection kicks in at around 60V, when ZD5 begins to conduct. This again supplies current to Q9's base to shut the amplifier down.

DC offset protection

Q7 and Q8 monitor the amplifier's output DC offset. As shown, the amplifier's output is fed through a low-pass RC filter consisting of two 100kΩ resistors and a 100µF NP capacitor, to remove frequencies above 0.3Hz. This prevents normal AC signal excursions from tripping the circuit.

A second filter consisting of a 1kΩ resistor and 10µF capacitor follows. This is required to prevent false triggering due to high-frequency signals finding their way into Q7 and Q8.

If the amplifier's output has a positive DC offset, Q7's emitter is pulled 0.6V above its base (ground). As a result, Q7 turns on and so Q9 also turns on and the amplifier shuts down as before. Similarly, for a negative DC offset, Q8's base is pulled 0.6V below its emitter and Q8 and Q9 turn on.

Parts List: CLASSiC-D Amplifier

1 PCB available from the *EPE PCB Service,* code, 01108121, 117mm × 167mm
1 heatsink, 100 × 33 × 30mm
1 22µH 5A inductor (L1) (ICE Components 1D17A-220M [X-ON, Mouser] or Sagami 7G17A-220MR)
1 chassis-mount 45° 6.4mm single spade terminal (to secure TH1)
3 TO-220 insulating washers and bushes
1 solder lug
4 M205 PCB-mount fuse clips
1 NTC thermistor 4.7kΩ at 25°C (TH1)
2 5A fast blow M205 fuses (F1,F2)
1 vertical PCB-mount RCA socket (CON1) and/or
1 horizontal PCB-mount RCA socket (CON1)
1 3-way PCB mount screw terminal (5.08mm pin spacing) (CON2)
1 2-way PCB mount screw terminal (5.08mm pin spacing) (CON3)
2 2-way pin headers (2.5mm spacing) (LK1,LK3)
1 3-way pin header (2.5mm spacing) (LK2)
1 polarised 2-way header (2.54mm spacing) (LK4)
2 3/16-inch × 20mm-long machine screws (secure heatsink to PCB)
5 M3 × 10mm machine screws
11 PC stakes
1 50mm length of 0.7mm tinned copper wire
4 jumper shunts (shorting links)
4 M3 × 9mm tapped nylon spacers
4 M3 × 5mm machine screws
1 8-pin DIL IC socket
1 25-turn 2kΩ trimpot (VR1)

Semiconductors
1 IRS2092S Digital Audio Amplifier IC [SOIC-16] (IC1)*
1 TLE2071CP op amp (IC2)*
2 IRFB5615 150V 25A N-channel digital audio MOSFETs (Q1,Q2)*
1 TIP31C NPN transistor (Q3)
1 BS250P P-channel DMOS FET (Q4)
3 BC327 PNP transistors (Q5,Q7,Q8)
2 BC337 NPN transistors (Q6,Q9)
1 3mm blue LED (LED1)
1 3mm red LED (LED2)
3 1N4004 1A diodes (D1,D2,D6)
2 MUR120 super-fast diodes (D3,D4)
1 1N4148 diode (D5)
2 15V 1W zener diodes (ZD1,ZD2)
2 5.6V 1W zener diodes (ZD3,ZD4)
1 68V 1W zener diode (ZD5)
1 39V 1W zener diode (ZD6)

Capacitors
2 470µF 63V or 100V low-ESR PCB-mount electrolytic
1 100µF 50V non-polarised PCB-mount electrolytic
2 220µF 10V low-ESR electrolytic
4 100µF 25V low-ESR electrolytic
1 47µF 50V non-polarised PCB-mount electrolytic
1 10µF 16V PCB-mount electrolytic
1 10µF non-polarised PCB-mount electrolytic
3 1µF MMC
1 470nF 250VAC X2 MKP
2 100nF 250VAC X2 MKP
3 100nF 100V MKT
1 1nF 100V MKT
3 560pF MKT (Rockby 35636 or 32733) (supplied with PCB)
1 150pF 100V (minimum) ceramic or MKT

Resistors (0.25W, 1%)
3 100kΩ
1 68kΩ (R1)
1 47kΩ (R4)
1 47kΩ
7 10kΩ
1 9.1kΩ
1 8.2kΩ (R7)
1 7.5kΩ (R9)
1 6.8kΩ (R6)
1 5.6kΩ
4 4.7kΩ
4 4.7kΩ 1W 5% (R2A, R2B, R3A, R3B)
1 4.3kΩ (Rf)
1 3.3kΩ (R5)
2 2.2kΩ
1 2.2kΩ (R8)
1 1kΩ 1W 5% (R10)
2 1kΩ
1 330Ω
2 100Ω
2 22Ω
2 10Ω 1W 5%
2 10Ω
1 4.7Ω

Speaker Protector
1 PCB, available from the *EPE PCB Service,* code, 01108122, 76mm × 66mm
2 5-way PCB-mount screw terminal block or 2 × 2-way and 2 × 3-way (CON1,CON2)
2 polarised 2-way headers (2.54mm pitch) (Input1 and Input2)
1 DPDT 24V 10A PCB-mount relay (RLY1)
1 200mm length of medium-duty red hookup wire
1 200mm length of medium-duty black hookup wire
4 M3 × 9mm tapped nylon spacers
4 M3 × 5mm machine screws

Semiconductors
2 4N28 optocouplers (OPTO1, OPTO2)
1 STP16NE06 MOSFET (Q10)
2 1N4148 diodes (D6,D7)
1 1N4004 diode (D8)
1 15V 1W zener diode (ZD7)
1 3mm red LED (LED3)

Capacitors
1 4.7µF 16V PC electrolytic

Resistors (0.25W, 1%)

1 1MΩ	3 1kΩ
1 100kΩ	1 820Ω 5W
1 10kΩ	1 22Ω
1 4.7kΩ 1W	

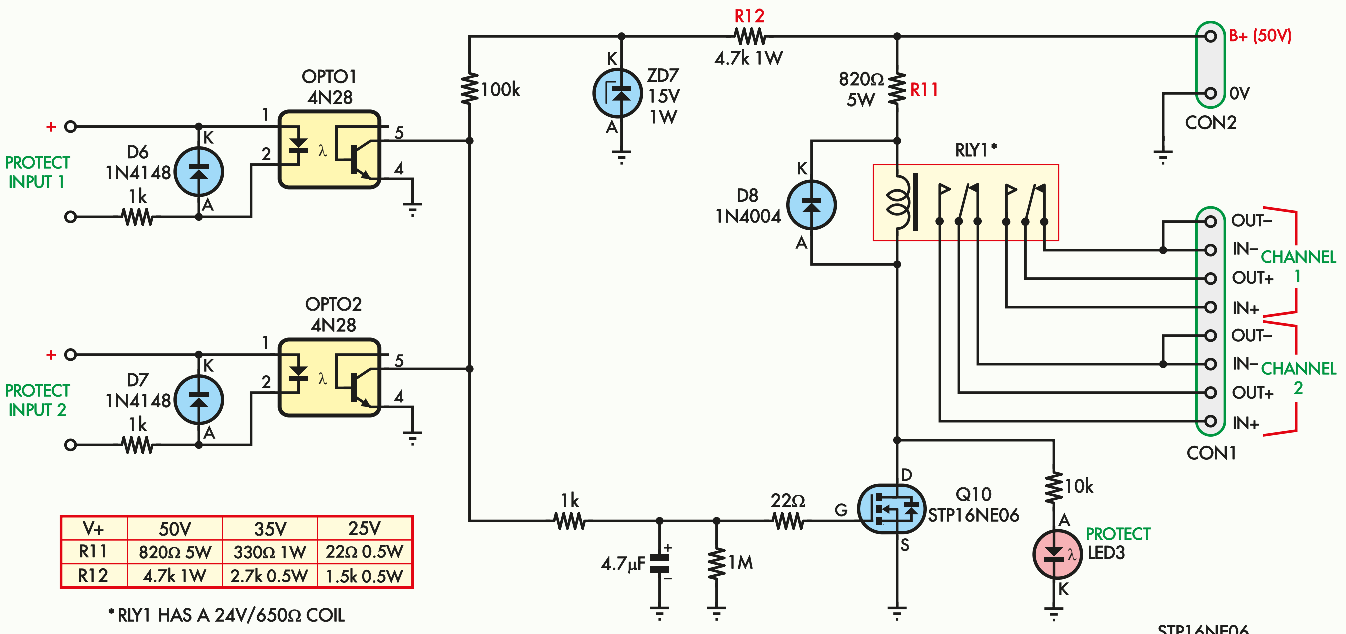
* These parts are available from element14, Mouser and Digi-Key

* A kit of parts for this project is available from Jaycar Electronics

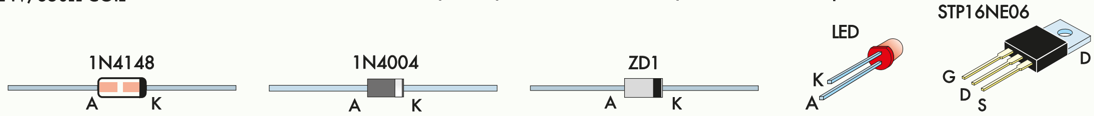
Speaker protector
Note that even though IC1 turns off its driver outputs should a significant DC offset occur, this will not necessarily save the connected loudspeaker. That's because if one of the output MOSFETs fails and goes short circuit, IC1 will be unable to turn it off and the full supply voltage will be applied to the loudspeaker, causing its voice coil to overheat and possibly catch fire.

To deal with this possibility, we have produced an additional small PCB which acts in conjunction with one or two *CLASSiC-D Amplifier* modules to protect the speaker(s), even if an output MOSFET fails. It uses a relay

CLASSiC-D Loudspeaker Protector



V+	50V	35V	25V
R11	820Ω 5W	330Ω 1W	22Ω 0.5W
R12	4.7k 1W	2.7k 0.5W	1.5k 0.5W



CLASSIC-D AMPLIFIER – SPEAKER PROTECTOR

Fig.7: the *CLASSiC-D Amplifier* speaker protection circuit suits mono, stereo or bridged mono amplifiers. If either fault input is triggered, it pulls the gate of Q10 low via its associated optocoupler and 1kΩ resistor. This turns off RLY1, disconnecting the speaker(s) and lights LED3. Once the fault(s) clear, Q10 turns on after a delay, switching RLY1 on (and LED3 off) and connecting the speaker(s) to the amplifier module(s).

THE SPEAKER PROTECTOR MAKES USE of the fact that whenever the amplifier is in protection mode, the Protect LED (LED2) is lit. By monitoring this, the Protector circuit can disconnect the speaker from the amplifier whenever LED2 lights up. Since there is a delay after power-up before LED2 turns off and since it turns back on for a short time when you switch the unit off, it also provides a 'de-thump' feature.

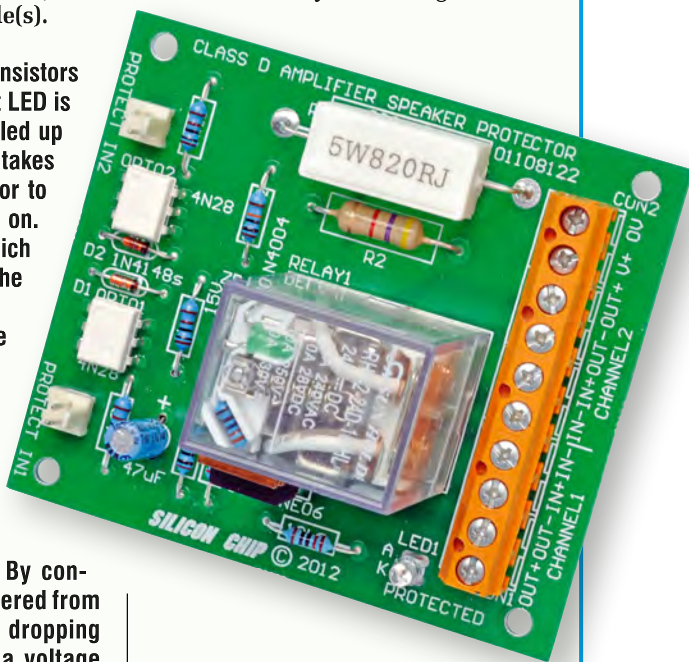
Fig.7 shows the stereo speaker protector circuit. For each module, an optocoupler (OPTO1 and OPTO2) connects in series with the protect LED of each amplifier module via LK4, which acts as a connector. When the protect LED turns on, the relevant optocoupler LED is also lit and this switches on the internal phototransistor.

This in turn pulls the gate of MOSFET Q10 low via a 1kΩ resistor and 22Ω gate resistor. As a result, Q10 turns off and this turns the relay off, opening its COM and NO contacts and disconnecting the speaker from the amplifier.

Conversely, if both phototransistors are off (ie, no amplifier protect LED is lit), MOSFET Q10's gate is pulled up to 15V via a 100kΩ resistor. It takes about 4s for the 47μF capacitor to charge, after which Q10 turns on. This then turns on the relay which connects the speaker(s) to the amplifier module(s).

Note that if there is only one amplifier module, the second input on the Loudspeaker Protector is left unconnected.

The +15V supply rail for the optocouplers is derived from the B+ rail using 15V zener diode ZD7 and a 4.7kΩ 1W current-limiting resistor. By contrast, the 24V relay coil is powered from the 50V supply via an 820Ω dropping resistor. This resistor forms a voltage divider with RLY1's coil resistance to limit the coil voltage to about 24V. Diode D8 is included to quench any back-EMF spikes that may be generated when the relay switches off.



LED3 turns on when Q10 and the relay are off (eg, if there is a fault condition). Conversely, when Q10 and the relay are on, there is virtually no voltage across LED3 and it turns off.

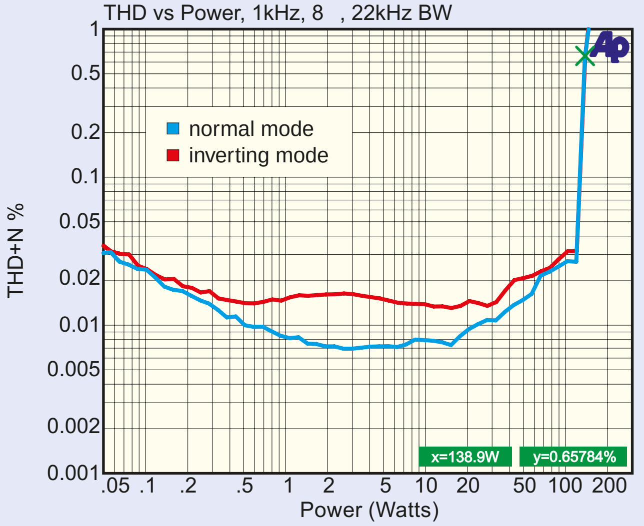


Fig.8: THD+N plotted against power level into an 8Ω resistive load. The power supply was set at ±55V and we used an Audio Precision AUX-0025 Switching Amplifier Measurement Filter in addition to a 20Hz-22kHz bandpass filter in the Audio Precision System Two.

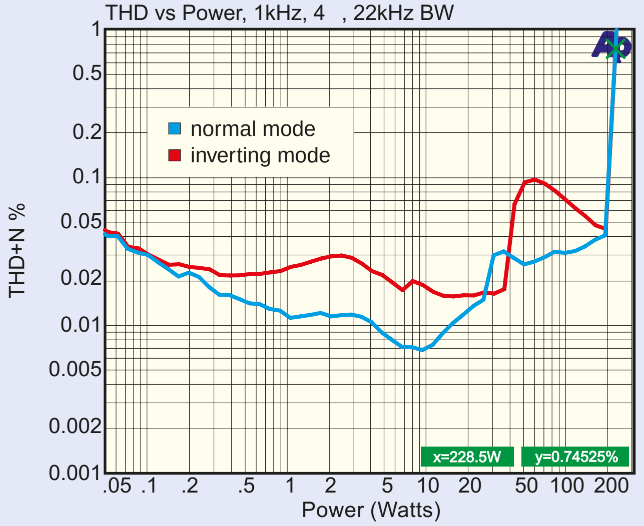


Fig.9: THD+N plotted against power level into a 4Ω resistive load (conditions otherwise identical to Fig.8). Note that in both cases, there is higher distortion across most of the audio band in inverting mode compared to normal mode. This is due to op amp IC2.

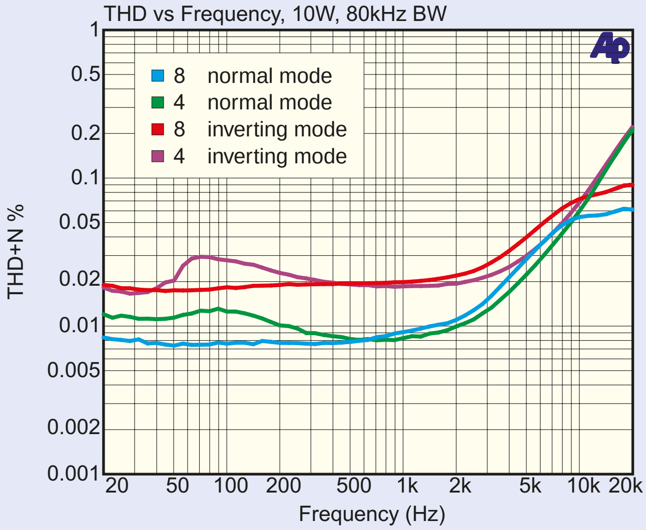


Fig.10: distortion versus frequency at 10W for 4Ω and 8Ω loads. As you would expect, distortion increases above the baseline for frequencies above about 1kHz. The 8Ω performance is better than 4Ω below 600Hz and above 10kHz, but they are quite similar otherwise.

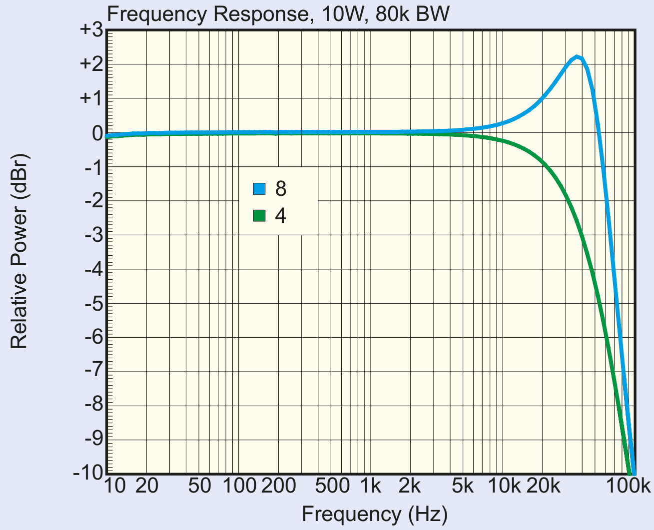


Fig.11: frequency response for the two most common load impedances. The input signal level and reference level is identical for both plots, so this also demonstrates the relatively low output impedance of the amplifier. The difference is due to the output LC filter.

to break the connection between the failed module and the speaker.

The speaker protector circuit and its operation are described in the panel on the previous page (see Fig.7).

Power supply

The *CLASSiC-D Amplifier* module is designed to operate from nominal ±50V supply rails, but it will operate over the range of ±40-60V. For testing, we used the *Ultra-LD Mk.3 Power Supply*. (**See note on this page!**). This uses a 300VA 40V-0-40V toroidal transformer, a 35A bridge rectifier and 15,000µF filter capacitor banks across each rail.

While this has a nominal output of ±57V, it's perfectly suitable for use with this amplifier module and will give higher output power than from a ±50V supply. A supply of ±57V will give an output power of about 150W into 8Ω and 250W into 4Ω with 1% THD + N. On the other hand, you could quite easily substitute a 35V-0-35V transformer (which is a bit easier to obtain) to get close to ±50V from the same supply module with slightly reduced output power.

IMPORTANT NOTE!
Project power supply

EPE has a project-sharing relationship with the Australian magazine *Silicon Chip*. Occasionally, as with the CLASSiC-D Amplifier, we will need to refer to projects not used in *EPE*. The 'Ultra-LD Mk.3 Power Supply' referred to here has not been published in *EPE* – however, full construction and wiring details will be included in next month's *EPE*.

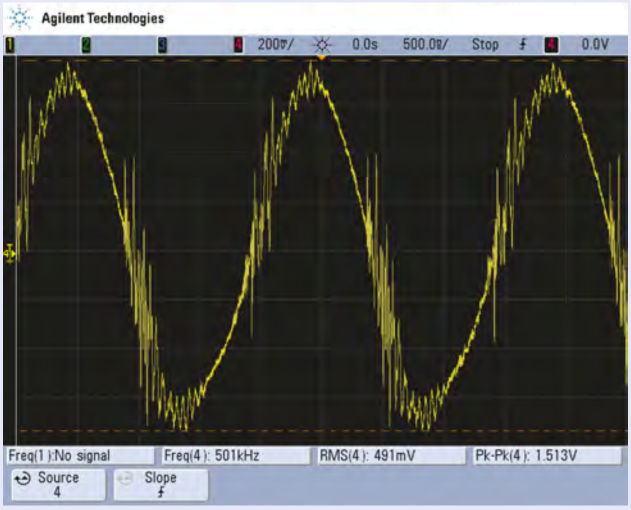


Fig.12: output waveform at idle (ie, no signal applied). This shows the switching frequency of around 500kHz and the residual amplitude of about 0.5V RMS. Note that the filter has converted the square-wave output into something resembling a sinewave.

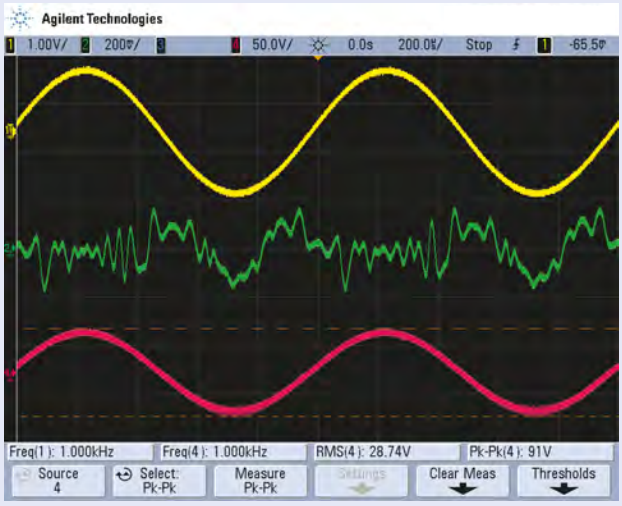


Fig.13: the filtered output of the amplifier (yellow, top) along with the distortion residual (green) at 100W into 8Ω (THD+N 0.026%). The red trace shows the output of the amplifier after the LC filter but with no additional filtering; you can just see the high frequency 'fuzz'.

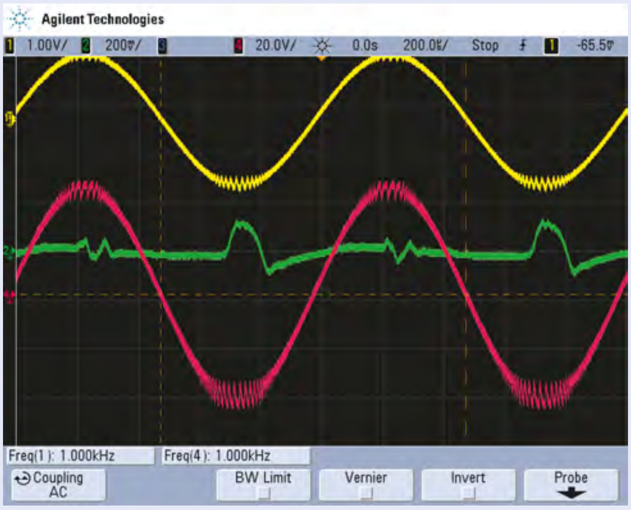


Fig.14: clipping behaviour at >230W into 4Ω (±55V) Note how the self-oscillation frequency drops at the output extremes and so the output tends to "bounce" off the rails when driven this hard. The distortion waveform is shown in green and is quite similar to that of a Class-AB design.

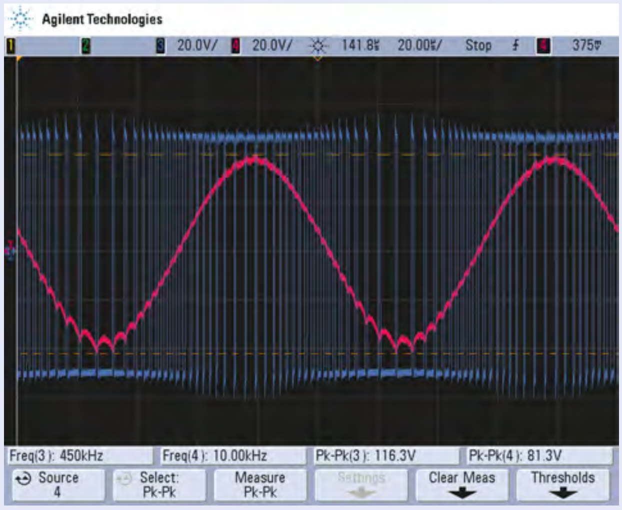


Fig.15: this scope grab shows the switching output of the amplifier with a 10kHz sinewave input (blue) and the reconstructed waveform after the LC low-pass filter (red). Again note how the frequency shifts as the duty cycle changes, with it being highest around the zero crossing.

We wouldn't go any higher than ±57V. The filter capacitors on the *CLASSiC-D Amplifier* module are only rated for 63V (like the capacitors in the *Ultra-LD Mk.3 Power Supply*) and due to mains voltage variations, they may already operate close to that limit with a 40V-0-40V transformer.

If you want to build two (or even four!) modules into one case, you can have them share a single power supply, although that will reduce the continuous output power available (more so with 4Ω loads than 8Ω loads). It won't affect the music power much though.

Alternatively, you can use separate power supplies or a bigger transformer with a larger filter capacitor bank. For example, if you want to bridge two *CLASSiC-D Amplifier* modules to get 500W into 8Ω and run them off a single power supply, you will need a transformer rated at 500VA or more.

If you want to run the module from a lower voltage supply, you can do so, but it will deliver less power. In addition, several components need to be changed if the supply voltage will be below 40V (more in Part 2 next month).

That's all for now. Next month, we will present the two PCB overlays and give details on how to build, set-up and test the amplifier module.

References and links

1. IR Application Note AN-1138 (IRS-2092S) – **www.irf.com/technical-info/appnotes/an-1138.pdf**
2. IRS2092 Data – **www.irf.com/product-info/datasheets/data/irs2092.pdf**
3. *Introduction to Electroacoustics and Audio Amplifier Design, Second Edition* – **http://users.ece.gatech.edu/mleach/ece4435/f01/ClassD2.pdf**
4. AN-1071 Class D Amplifier Basics – **www.irf.com/technical-info/appnotes/an-1071.pdf**

Location, location, location...

TechnoTalk

Mark Nelson

No matter how pleased you are with your smartphone, manufacturers want you to ditch it. If you're totally satisfied, there'll be no market for their next models! Mark Nelson details the next big thing that will make current smartphones as outdated as wind-up gramophones.

IF you're a smartphone user you need to know about 'indoor location', the must-have feature when you next upgrade. The good news is that you can carry on using your existing phone for now, but after 2018 it'll be toast!

Hybrid indoor location

According to technology analyst and trend forecaster ABI Research, more than a billion new smartphones will incorporate indoor location technologies in 2018. 'We see a significant trend towards hybridization, with Wi-Fi and sensor fusion,' commented ABI's senior analyst, Patrick Connolly. 'By 2014, hybrid solutions will have already surpassed standalone indoor location technologies on smartphones, with Wi-Fi and sensor fusion hybrid solutions reaching over 900 million units in 2018. Longer term, technologies around optical light, object recognition and LTE-direct are all forecast to offer differentiation.'

Most smartphones already include location features based on GPS satellites, which can locate you to within a few metres. This is fine if you are outdoors, but not in an 'urban canyon' where your smartphone cannot 'see' the satellites. When you're indoors, which most people are for most of the time, you're often out of luck.

Of course, you probably know where you are – but not with great precision. If you are shopping deep inside a vast mega-mall such as London's Westfield or a multi-storey car park and a fire breaks out, then you'll need to call the emergency services. How can you describe your precise location? You probably don't even know the name of the street outside or the name of the car park. But, a smartphone with indoor location could tell you. Given that Google Maps already has indoor floor plans of several major shopping centres, airports and museums, you can see how handy indoor location would be for pinpointing exact locations.

They're after your money

There are plenty of commercial applications planned for this new facility. Indoors is where business is carried out, where we meet up with friends and crucially, where we spend money. In supermarkets and department stores you could enter a product name and your smartphone would tell you which floor you'll find it on, or even in which aisle. For products and services that interest you, the smartphone could alert you to special offers, offer discount coupons or deliver targeted advertising based on your interests.

At work, this indoor location facility could enable management to track down where staff are hiding (pernicious!). In hospitals, airports, railway stations and supermarkets it would put an end to those constant 'colleague announcements' made when someone is needed urgently. The function would be a boon to emergency response teams, undercover police staff and store detectives.

Why hybrid?

GPS is one of several technologies that smartphones can use for determining your location, but the weak signals from GPS satellites do not penetrate indoors. However, there are a number of other signals that do, such as Wi-Fi, NFC (near field communications), Bluetooth and cellular radio (more on these in a moment).

The number and variety of these different technical systems means that only a hybrid or combined approach can be certain of capturing and evaluating all available data. Consequently, application developers will have to support all of these approaches and use whichever signals happen to be available at a user's current location.

Triangulation, measuring the signal strength and the round-trip signal time from three different cellphone base stations is a remarkably accurate means of plotting position. A comparable technique can be used with Wi-Fi signals, especially as databases (that are updated regularly) exist of known Wi-Fi hotspots. 'Wi-Fi fingerprinting' is another facility – your smartphone activates Wi-Fi for a couple of seconds to get a 'Wi-Fi fingerprint', which it can associate with a particular location and then compare with a database of known fingerprint and location pairs. It is used frequently in conjunction with check-in services such as Google Places: **www.google.co.uk/business/placesforbusiness** and by FourSquare: **https://foursquare.com**

Proof positive

Proof that indoor location is the next 'killer app' came earlier this year when Apple confirmed that that it had spent $20 million acquiring WiFiSlam, a two-year-old start-up company that has developed a technology for smartphones to fix their position to an accuracy of 2.5m. 'Slam' stands for 'Simultaneous Localisation And Mapping'; WiFiSlam has asserted its aim to 'engage with users at the scale that personal interaction actually takes place', foreseeing its target as 'step-by-step indoor navigation to product-level retail customer engagement, to proximity-based social networking' (sorry, no real English translation available). Fortunately, you can watch WiFiSlam's presentation at: **http://youtu.be/OGdvjvla1Tc**

The technology revealed in this video is illuminating. Although the individual sensors in people's smartphones are not sufficiently accurate to provide truly meaningful information, if you aggregate the date gathered by all of the sensors – and add WiFiSlam's proprietary pattern recognition and machine learning technologies then you can create correlations between all of the data gathered and start to create accurate maps of indoor locations.

If Apple can sort out the accuracy of its maps, this might become a marriage made in heaven, although smartphone users may not embrace the technology if it invades their privacy or becomes overtly commercial.

Loo Wee Teck, Euromonitor's global head of consumer electronics research, observed on ZDnet that Apple's purchase of WiFiSlam merely brought the company's map system to a par with Google's indoor Google Maps, adding that the 'unassailable' lead of Android-based smartphones over iPhones would not change with Apple's acquisition of WiFiSlam. He also asserted that in an arena where companies like Google and Facebook were providing free services (naturally with the intention of making profit from data mining and other practices), consumers could hardly expect free use while demanding total privacy and anonymity. 'Users have to make their own judgment when using them, while companies have to tread a tightrope to ensure they do not enrage the users,' he stated.

Regardless of these qualifications, the global market for indoor location, positioning and navigation is already worth $448 million, according to forecaster Reasearchandmarkets.com. Over the next five years it will grow to $2.60 billion per annum.

The new LED Musicolour makes building a spectacular light and music show easier than ever. In this second and final instalment, we explain how to build and test the unit and also detail how you can control it.

WE'LL GET onto the construction of the *LED Musicolour* shortly. Before we do, let's quickly look at a few more design details.

One aspect of the unit's operation that we didn't mention in Part 1 is the automatic gain control (AGC). This applies when you are feeding audio into the unit via the audio line input socket (CON11). The problem is that line level signal amplitude can be quite variable and we don't want the lights to be driven dimly simply because your signal source has a low peak voltage.

To solve this, we constantly monitor the peak voltage at the audio inputs and apply an asymmetrical low-pass (smoothing) function to it. The output of this function remains close to the long-term peak of the audio signal, even though the amplitude won't be constant. We do this by allowing the detected peak voltage value to increase rapidly, but only decrease slowly.

Given this detected peak amplitude, we can then 'normalise' the audio data by computing a gain value which is the inverse of this peak amplitude, ie, the lower the amplitude, the higher the gain. This gain is applied before the Fast Fourier Transform (FFT) function is applied to the audio data. The output of the FFT then gives a consistent brightness level over a range of input signal amplitudes from around 500mV RMS up to a little over 2V RMS.

When we describe the configuration options later, you will see that there are a few options which control the rate at which the AGC level changes and the maximum gain setting available. We've chosen defaults that work well in most circumstances, so you won't normally need to change these.

Memory cards

Throughout these articles we have generally referred to the memory card as an 'SD card'. There are actually several different types of SD card. These days, most cards sold are actually SDHC (high capacity) cards in the range of about 4GB-32GB. We have successfully tested the largest of these cards in the *LED Musicolour*.

It should also support the older MMC cards, even though they are basically obsolete now. We haven't tested SDXC (64GB+) cards, but in theory, they should work too as they still support the 1-wire SPI interface we are using to communicate with the memory card.

Construction

Building the main PCB is relatively straightforward and should take just a few hours. Fig.3 shows the parts layout. The board is coded 16110121 and measures 103 x 118mm.

The 11 SMD components are mounted first, ie, the eight dual MOSFETs (Q1-Q8), audio DAC IC2, the 10µF ceramic capacitor for IC1 and the SD card socket (CON13).

Start with MOSFETs Q1-Q8, which are in 8-pin SOIC packages. In each case, the pin 1 dot goes towards the lefthand side of the PCB. Place a small amount of solder on one pad, line up the IC and slide it into place while heating that solder. If it isn't positioned correctly on its pads, reheat the solder and reposition it. Make sure it's sitting flat on the board, then solder the remaining pins. Finally, add some more solder to the first pin.

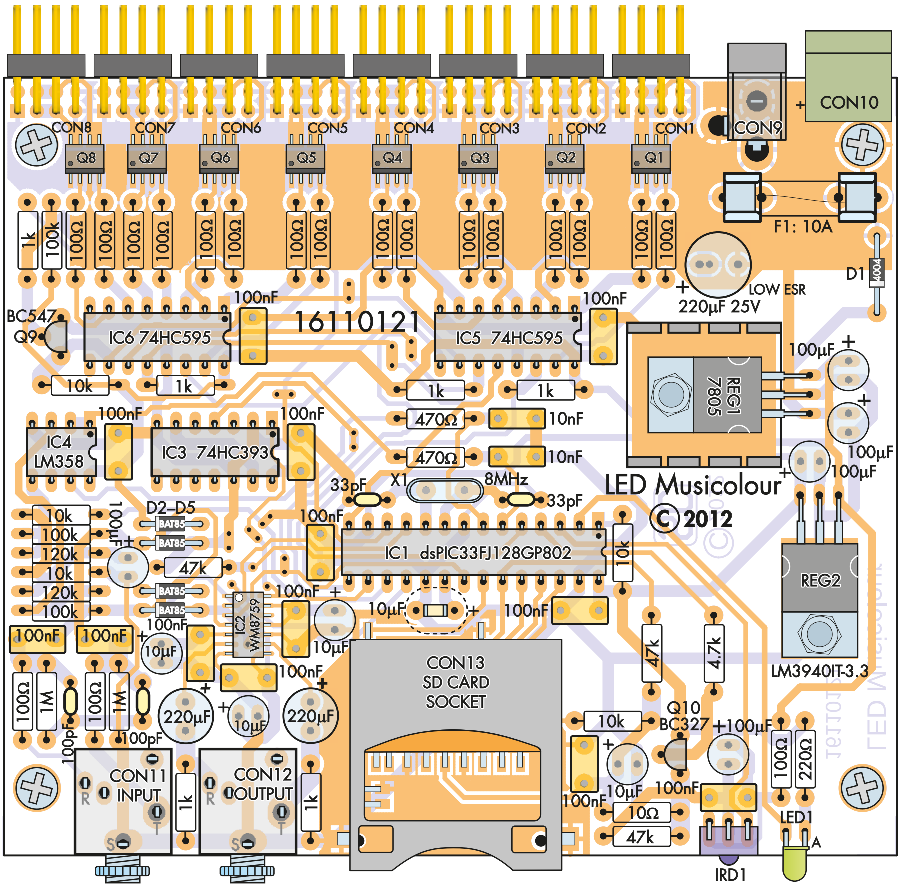


Fig.3: install the parts on the PCB as shown in this diagram, starting with the SMD components. The off-board LED strips are connected to pin headers CON1-CON8 via matching header sockets. Note that infrared receiver IRD1 is installed upside down (see text and photo).

That done, check that there are no bridges between the pins. If there are, use solder wick to clean them up. That's best done by first adding a little liquid flux paste (no-clean type) along both rows of pins and then removing any excess solder using the solder wick. You can clean up the flux residue with isopropyl alcohol if you like.

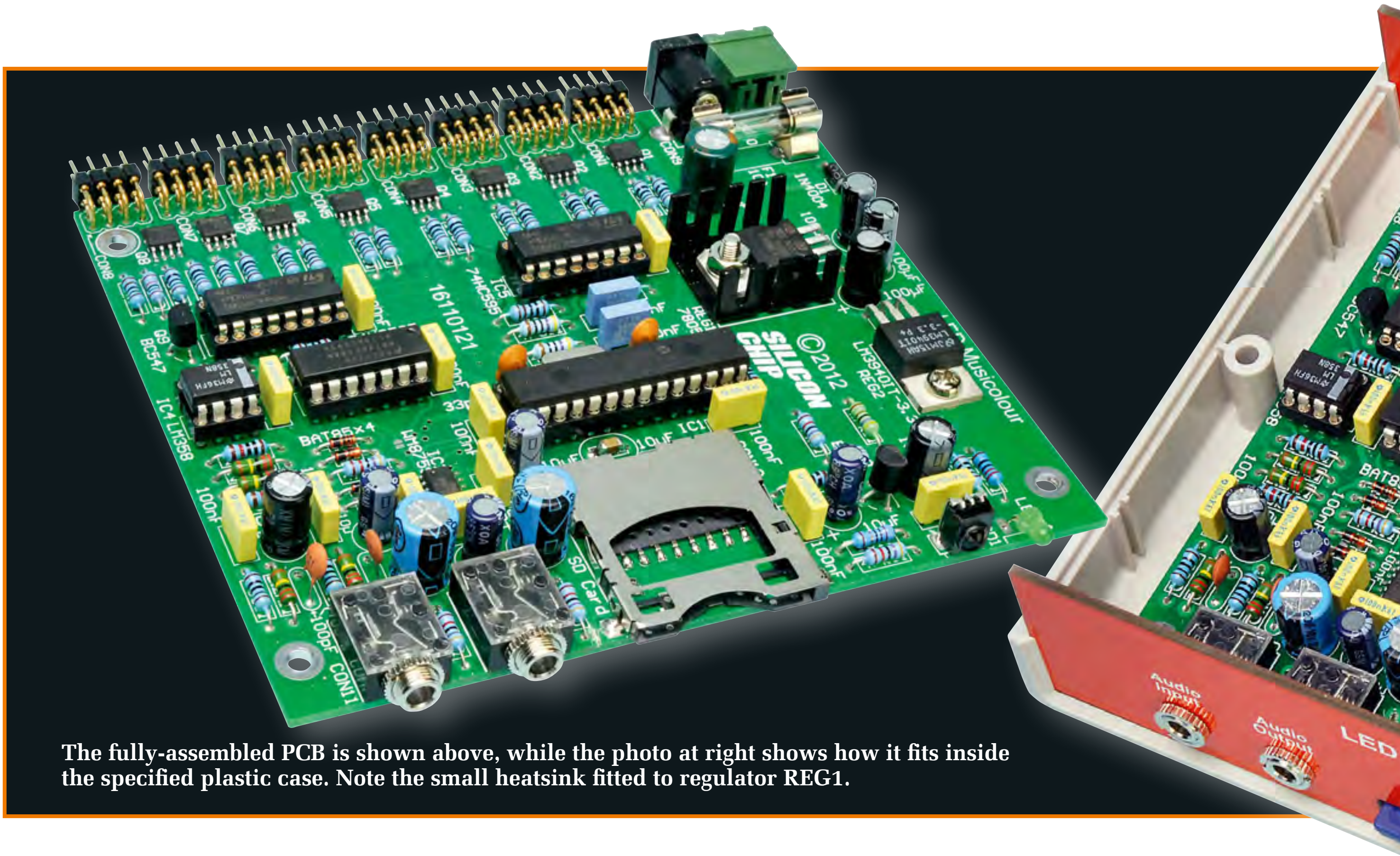
Note that for each of Q1-Q8, two pairs of pins share a single, larger pad. These are the two MOSFET drains.

Table 2: Capacitor Codes

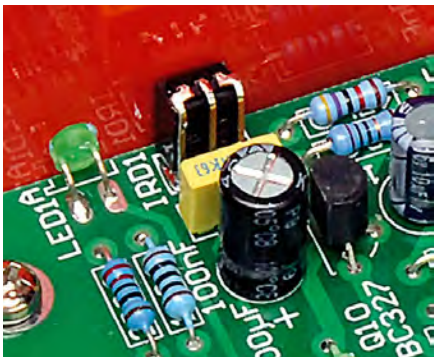
Value	µF Value	IEC Code	EIA Code
100nF	0.1µF	100n	104
10nF	0.01µF	10n	103
100pF	NA	100p	101
33pF	NA	33p	33

Table 1: Resistor Colour Codes

❑	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❑	2	1MΩ	brown black green brown	brown black black yellow brown
❑	2	120kΩ	brown red yellow brown	brown red black orange brown
❑	3	100kΩ	brown black yellow brown	brown black black orange brown
❑	3	47kΩ	yellow violet orange brown	yellow violet black red brown
❑	5	10kΩ	brown black orange brown	brown black black red brown
❑	1	4.7kΩ	yellow violet red brown	yellow violet black brown brown
❑	6	1kΩ	brown black red brown	brown black black brown brown
❑	2	470Ω	yellow violet brown brown	yellow violet black black brown
❑	1	220Ω	red red brown brown	red red black black brown
❑	19	100Ω	brown black brown brown	brown black black black brown
❑	1	10Ω	brown black black brown	brown black black gold brown



The fully-assembled PCB is shown above, while the photo at right shows how it fits inside the specified plastic case. Note the small heatsink fitted to regulator REG1.



These two photos show the mounting details for the infrared receiver (IRD1). It must be mounted upside down (so that its lens lines up with the adjacent LED), with its leads run down the back of its body.

Obviously you don't have to worry about these being bridged, although you should check that the two drains are not accidentally shorted.

Fit the rest of the SMD parts using the same method, with the exception of the SD card holder. This has two plastic posts which go into holes on the PCB, holding it in position. You then solder the larger mounting tabs, followed by the signal pins. There are 15 in all; remove and discard the plastic insert before soldering those inside the socket.

Through-hole parts

Now mount the resistors, checking each value with a DMM first. You can refer to the colour code table, but the multimeter is more reliable. Follow with diode D1 (1N4004) and then the four smaller Schottky diodes, D2-D5. In each case, ensure that the cathode stripe is oriented as shown.

Solder crystal X1 in place next, then fit the IC sockets or, if you are not using a socket at any location, the IC itself. It's a good idea to use a socket for IC1, but the rest are optional. Either way, make sure the pin 1 notches are all oriented towards the righthand side of the PCB, as shown on the overlay.

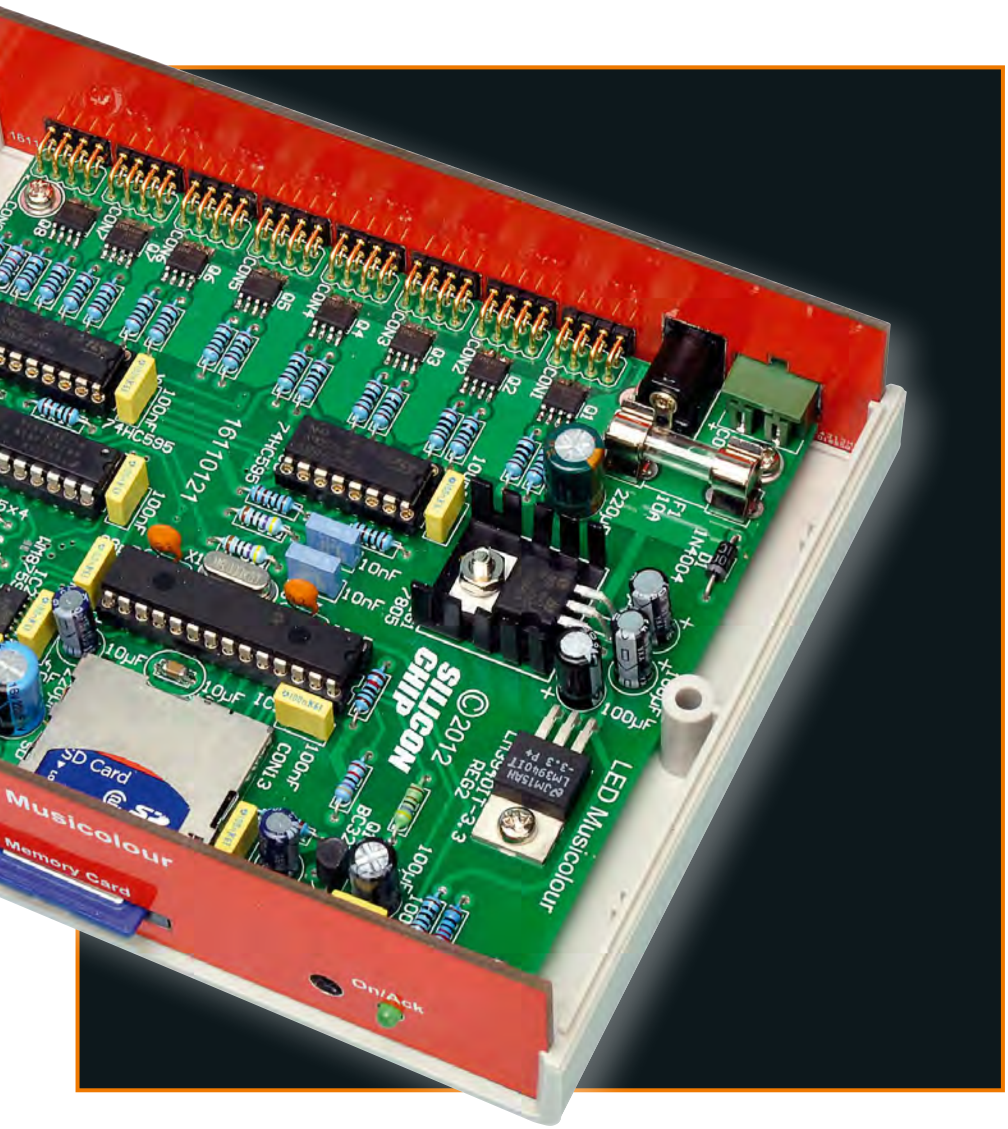
Next, bend REG2's leads down through 90° about 7mm from its tab, then use an M3 × 6mm machine screw, shakeproof washer and nut to fasten it to the board. Do the screw up tight, then solder and trim the leads.

That done, install the two 3.5mm stereo jack sockets. These must sit flush against the PCB and must be correctly aligned with its edge. Follow with the two small-signal transistors, taking care not to get them mixed up. Bend their leads with small pliers to suit the pad spacing on the board.

Pin headers CON1-CON8 can now go in. If you can't get 8-pin dual row right-angle pin headers, make them from longer, snappable headers. Do this carefully using pliers and file off any burrs. Check that each header fits through the hole in the rear panel before soldering it to the PCB. When doing so, take care that the projecting pins are parallel to the surface of the PCB and at right-angles to the edge.

If one of the headers won't fit through the rear panel, a few strokes with a needle file will generally take off enough plastic to fix it. This is easier to do before the header is soldered to the board. It's also a good idea to check the alignment of each header once you have soldered a couple of its pins.

With the pin headers in place, you can then mount CON9 and CON10, again checking that they are aligned correctly to fit through the rear panel hole. Follow with the two fuse clips;



push them down all the way onto the PCB and check that the end-stops are on the outside.

The MKT and ceramic capacitors go in next, in the locations shown on the overlay diagram. Follow with the electrolytic capacitors, ensuring that in each case, the longer lead goes into the hole marked with a '+' on the overlay diagram.

That done, bend the green LED's leads down 2mm from its lens so that when fitted, its anode (longer lead) will go towards the right. Solder it in place with the horizontal portion of the leads 3mm above the PCB. Don't trim the leads too short in case you need to adjust it later.

Infrared receiver

IRD1 is installed in an unusual manner – basically upside-down, so that the centre of its lens is aligned with the other front panel connectors and the LED. This means the leads run down the back of the receiver and the top of the housing sits on the surface of the PCB.

We used a plastic-encapsulated type, but some infrared receivers have a metal shield. **Because the leads run near the body of the device and because of the exposed pads on the PCB, you will have to place an insulating layer (eg, electrical tape) over the back and top side of the receiver.**

There's a bit of a trap here because you might expect that this is unnecessary for IR receivers which have a plastic case. In fact, many of these use a conductive type of plastic (for shielding) so you should put some insulation along the rear and top of these as well. Make sure the body can't make contact with the leads or PCB pads. If it does, the receiver won't work.

Once you're ready, bend the leads through 180°, against the insulation layer on the rear of the receiver, then push it down all the way onto the PCB and solder it in place. The accompanying photos show how we did it.

Now bend regulator REG1's leads down through 90° in a similar manner as for REG2. This device is then fastened to the PCB, along with a mini-U heatsink using an M3 × 10mm machine screw nut and flat washer. Tighten the screw firmly before soldering and trimming REG1's leads.

The PCB assembly can now be completed by fitting the 10A fuse and plugging the ICs into their sockets. Make sure that the pin 1 notch or dot of each IC goes towards the righthand side of the PCB – see Fig.3.

Putting it in the case

Before fitting the PCB into the case, first you must cut off or file down the four inner plastic posts in the base, ie, the ones which don't correspond with the PCB corner mounting holes. That done, push the rear panel onto the PCB connectors until it sits against the edge of the board. It should be a tight fit.

If it won't go, carefully use a needle file to slightly enlarge the offending cut-out and try again.

With the rear panel in place, you can then unscrew the nuts for the two 3.5mm stereo sockets and slip the front panel on. It should fit easily – but again, if it doesn't, a little filing should fix it. Check that LED1 and infrared receiver IRD1 are properly aligned with their holes and if not, adjust them. Once the panel is in place, refit the two nuts to the sockets to hold it in place.

You can now slip the whole assembly down into the channels in the bottom of the case and attach the board to the integral stand-offs using four self-tapping screws.

Testing

It's best to test the unit initially without the LED strips plugged in. You can use a 7.5-24V DC plugpack if you have one handy. Alternatively, use the 12-24V power supply you will be using later.

Plug in the supply and switch on. Check that LED1 lights immediately. If it doesn't, switch off and check for faults (make sure IC1 has been programmed correctly). If all is well, measure the outputs of REG1 and REG2. Connect the negative lead of a DMM to the tab of either regulator and then, with the board oriented as in Fig.3, measure the voltage on the top pin of REG1 and the lefthand pin of REG2. You should get readings in the range of 4.8-5.2V for REG1 and 3.2-3.4V for REG2.

Table 1 – Infrared Remote Control Commands		
Button	**Command**	**Description**
Play	play	Starts or resumes playback
Stop	stop	Stops playback; pressing it twice resets the unit
Pause	pause	Pauses or resumes playback
Down arrow	next_folder	Play first file in next folder
Up arrow	prev_folder	Play first file in previous folder
Right arrow	next_file	Play next file in this folder (will skip to next folder on last file)
Left arrow	prev_file	Play last file in this folder (will skip to previous folder on first file)
Channel +	next_mode	Changes light display mode; see Table 2
Channel –	prev_mode	Changes light display mode; see Table 2
Volume +	volup	Increases volume in ~1dB steps (default is 0dB)
Volume –	voldn	Decreases volume in ~1dB steps (minimum is about –30dB)
Mute	mute	Toggles mute mode
Fast forward	forward	Skip ahead 10 seconds
Rewind	back	Skip back 10 seconds
0-9	0-9	Goes to a specific light display mode; see Table 2
Power	reset	Resets device to initial settings
Record	order	Cycles file order through sorted shuffle and directory (see text)

Table 2 – Light display modes	
Mode	**Description**
0	16 frequency bands, 40Hz-4kHz, combining both channels (default)
1	Two sets of 8 frequency bands, 40Hz-4kHz, one for each channel
2	16 frequency bands, 40-750Hz, combining both channels
3	16 frequency bands, 750Hz-4kHz, combining both channels
4	16 frequency bands, 40Hz-4kHz, left channel only
5	16 frequency bands, 40Hz-4kHz, right channel only
6	16 frequency bands, 40-750Hz, left channel only
7	16 frequency bands, 750Hz-4kHz, left channel only
8	16 frequency bands, 40-750Hz, right channel only
9	16 frequency bands, 750Hz-4kHz, right channel only

If you plan to use an infrared remote control, you can point a universal remote set for a common Philips device code (TV, VCR) and press some buttons. The green LED should flash in response. If not, try a different code and failing that, check that the left and right pins on the infrared receiver are not shorted to ground (possibly via the case). In the quiescent state, these pins should both measure at least 3V.

If you have an SD card, copy a 44.1kHz or 48kHz 16-bit stereo WAV file to its root folder and plug it in. The green LED should flash a few times and if you now connect the *LED Musicolour's* line output to a stereo amplifier, you should hear the audio file being played back. Remove the SD card when you have finished.

You can also test the audio input. It's simply a matter of connecting it to a signal source such as a DVD player, MP3 player or computer sound card, and again feeding the output into a stereo amplifier.

Finally, with no SD card inserted and nothing plugged into the audio input or output jacks, plug in one or more LED strips (it's OK to do this while the unit is running). Within 30s of switching on, the unit should go into a test mode where the LED strips fade up and down in brightness, in a pattern moving from output 1 through to output 16 and then repeating.

You can use this test mode to verify that all the LED outputs are working properly and that you have the strips connected in the right sequence. When you do, the light should appear to move smoothly from one side of the display to the other.

If it all checks out, you can put the lid on the case. If any of the tests fail, switch off and check the PCB carefully for faults. Inspect the SMD and through-hole solder joints and verify that the correct components are installed in each location. Check also that all polarised components (diodes, electrolytic capacitors, ICs) are the right way around.

Wiring the LED strips

You may be able to purchase LED strips with 4-pin female connectors already attached, but many strips come with bare wires or just pads on the end of the flexible PCB. In this case, you will need to connect a length of 2-way or 4-way cable with a pin header at the end.

The easiest way is to buy pre-made cables with 4-pin female headers at each end and chop them in half. These are available from various online retailers. It is possible to crimp your own connectors, but this is a fiddly task without a specialised crimping tool. The plugs are available from element14 (eg, Cat. 865620 and 1022220) and Futurlec (HDCONNS4 and HDPINF).

Using it

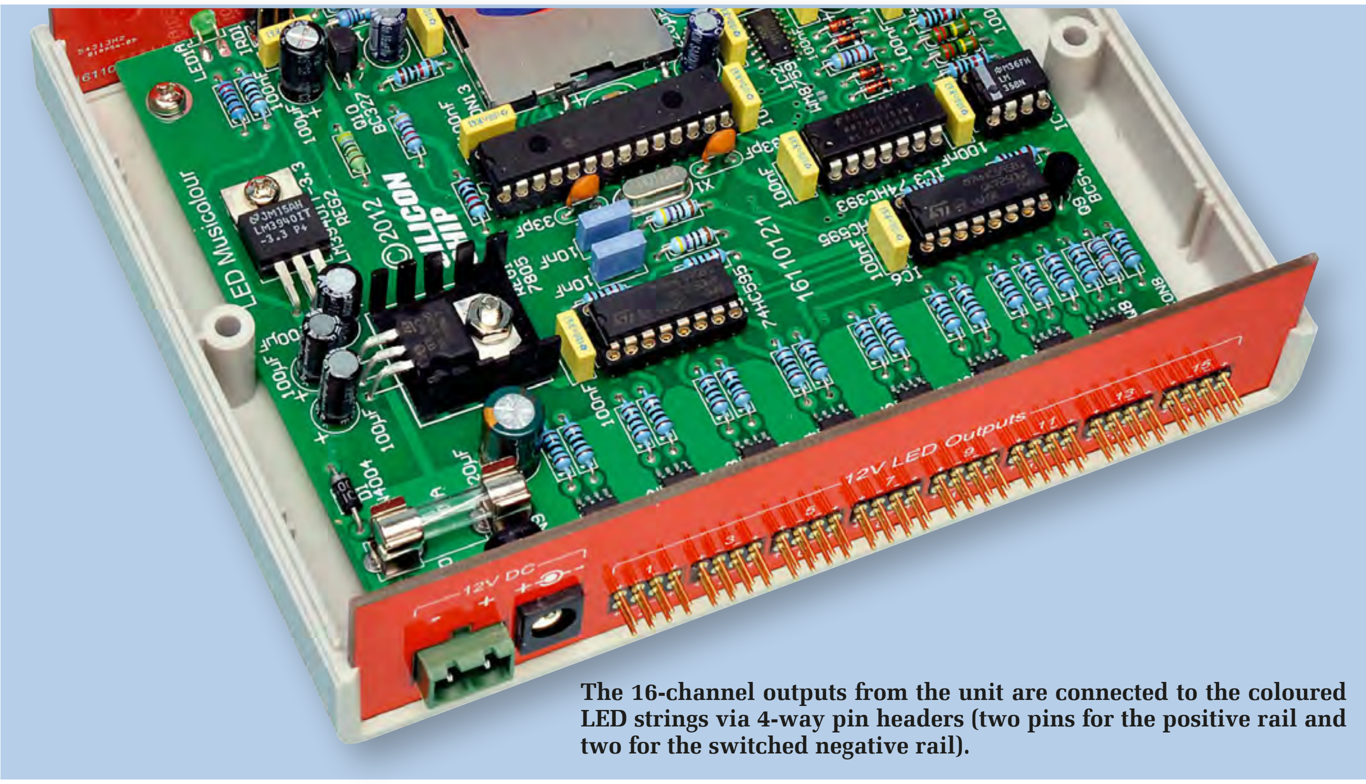
At this point, you may plug everything in, turn it on, sit back and watch. However, you may want to do some additional configuration or learn how to use the remote control commands.

If you are going to use a universal infrared remote, the Jaycar AR1726 should be set to TV code 102 and the AR1723 to code 0348. The Altronics A1012 should be set to TV code 156. Other universal remotes should work, but you may have to try multiple Philips TV codes before you find the right one.

Refer to Table 1 to see which button does what. Note that the IR command codes can be changed – see below.

Play, stop, pause, mute, fast forward/rewind and volume up/down are all self-explanatory. If you only want to play a few audio files, you can place them all in the SD card's root folder or a sub-folder and then simply use the left and right arrow buttons (*next* and *previous* file commands) to skip between them.

However, given the high capacities of SD cards that are available today (64GB or more), you can put a lot of WAV files onto one card and skipping



The 16-channel outputs from the unit are connected to the coloured LED strings via 4-way pin headers (two pins for the positive rail and two for the switched negative rail).

through them individually can be a chore. So you can instead organise them into separate folders.

The *next* and *previous* file commands will still skip through the whole lot, but you can also use the *Up* and *Down* arrows on the remote to skip to the previous or next folder respectively. That way, you can quickly locate the folder with the file(s) that you want to play back and then use the *Left* and *Right* arrows to select the desired file. Each folder can contain one CD's worth of audio files, or you can organise them however you want (eg, by genre, by performer).

Normally, the order in which files and folders are played is alphabetical. You can change this to random (shuffle) or directory order (the order the file entries are stored on the card). This is done either by pressing the Record button on the remote control or with the configuration file, as explained below.

Lighting modes

The lighting modes available are shown in Table 2. The default is mode 0. In this mode, the audio data from the left and right channels is mixed to form a mono signal and this is then split up into 16 frequency bands, more or less equally spaced over the six or so octaves from 40Hz to 4kHz. The audio energy in each band then determines the brightness of the corresponding LED strip, where LEDs1 corresponds to the lowest band (~0-40Hz) and LEDs16 corresponds to the highest band (~3.5-4kHz).

With mode 1, the difference is that the channels are processed separately and are used to drive LEDs1-LEDs8 (left) and LEDs9-LEDs16 (right). Each band therefore covers a larger range of frequencies.

Modes 2-9 are similar to modes 0 and 1, but are intended for use when

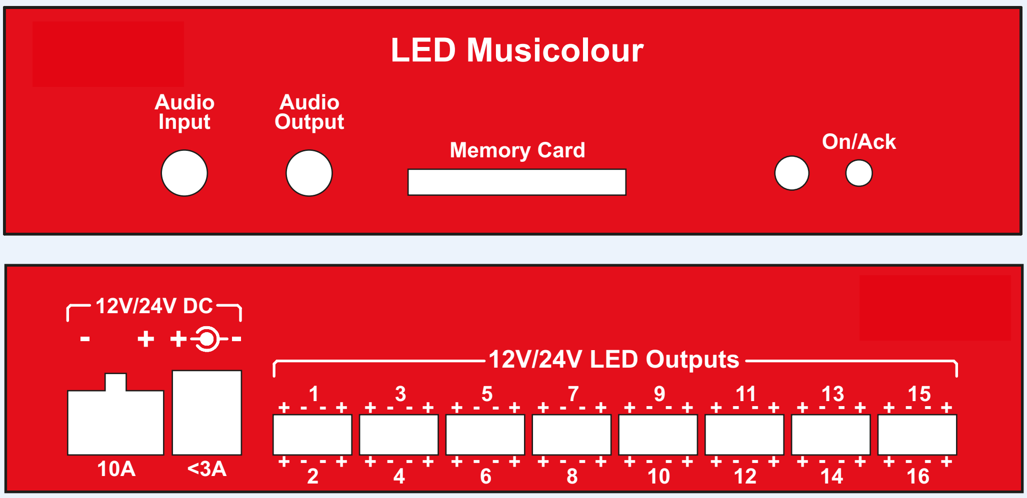
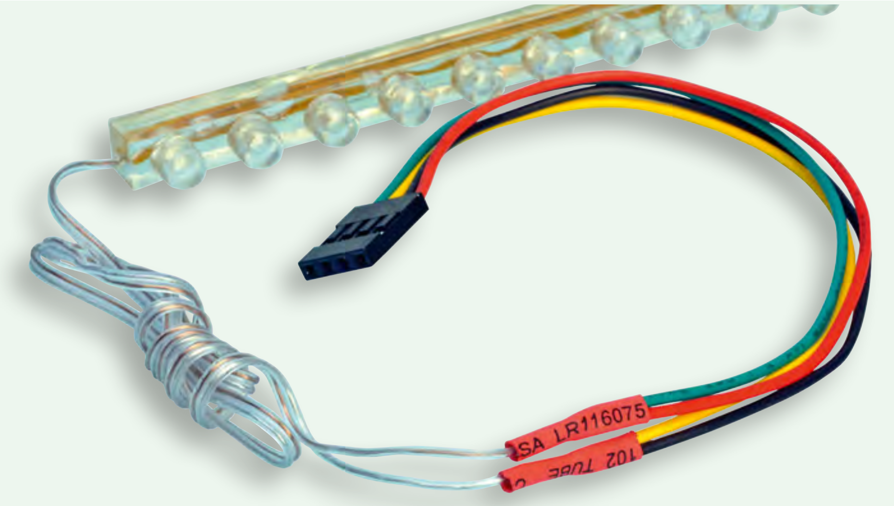


Fig.4: the front and rear panel designs for the *LED Musicolour*. Cutting the plastic end-panels provided with the case is very difficult given the number and shape of the cut-outs, so you can order pre-made PCB panels with screen-printed labels from www.siliconchip.com

Table 3 – Configuration commands		
Setting	**Valid options**	**Description**
mode	0-9	Which light display mode the unit starts up in (default=0)
spectrum attack	0-255	If set below 255, limits the rate at which LED brightness can increase (default=255)
spectrum decay	0-255	If set below 255, limits the rate at which LED brightness can decrease (default=255)
min brightness	0-255	Brightness level below which a strip remains off (default=8)
default playback order	sorted,shuffle,directory	Which order WAV files and folders are processed (default=sorted)
default volume	0-100%	The initial sound output volume (default=100%)
start playback automatically	yes,no,true,false	If yes/true, playback starts immediately
default repeat all	yes,no,true,false	If yes/true, when the last file is finished playing, it starts again with the first (default=yes)
agc filter coefficient	0-65535	AGC low-pass filter coefficient, lower values give slower gain changes (default=16)
agc max error	0-65535	Amount by which AGC output is allowed to deviate from nominal before gain changes (default=256)
agc max	0-65535	Maximum allowable AGC gain, multiplied by 4096 (default=16384, ie, gain of four)
agc delta limit	0-65535	Maximum change in AGC gain in a single step (default=4)
remote code <command>	RC5(0x????)	Changes the 16-bit RC5 code assigned to a given command; number can be decimal or hexadecimal as shown. See Table 1 for command names.
infrared logging	on,off	If set to on, valid RC5 remote control codes detected are written to a log file on the SD card (default=off)



This view shows how the LED strips are wired to the 4-way header sockets. The two outer leads go to the positive rail, while the inner leads go to the negative rail, so the socket can be plugged into a header either way around.

you have more than one *LED Musicolour* unit. For two units, you feed them the same audio and then use either modes 2 and 3, with each unit processing half the frequency bands, or modes 4 and 5, with each unit processing one channel. With four units, set them to modes 6-9.

Of course, if you prefer the way one of these other modes looks with a single *Musicolour*, there's nothing stopping you from using it that way too.

Configuration file

So that you don't have to change the settings with the remote control each time you power the unit on, you can record them in a configuration file in the root folder of the SD card. This works even if you don't want to use the SD card to play back audio; if you don't put any WAV files on the card, the unit will instead utilise its audio input, just as if there was no card inserted.

This file must be called 'LED Musicolour.cfg' and contains one line per setting. Each line starts with the name of that setting, then has an equals sign ('=') and then the value. The options are shown in Table 3. Any settings not specified remain at the default value.

There are some options to control parameters that you can only set using the configuration file. For example, if you want to simulate a 'peak hold' spectrum analyser, you can set the spectrum decay setting low (say, to 8). This means that an LED strip driven at full brightness will stay on for 256 ÷ 8 = 32 window periods or about 1.5 seconds. You can play around with the attack and decay settings to see if you prefer the effect achieved.

As you can see from the table, there are quite a few settings, although many of them are provided for people who really want to tweak the way the unit works. Most of the settings can simply be left at their defaults.

SD card bootloader

In case of bugs in the firmware, we have incorporated a 'bootloader'. This checks for the presence of a certain HEX file in the root folder of the SD card when power is first applied. If it exists and its contents differ from the micro's flash memory, the bootloader re-flashes the micro.

During this process, LED1 flashes. From then on, the microcontroller will run using the new firmware from that HEX file.

The file must be called 'LED Musicolour.hex'. If we release an updated version of the firmware, it will probably have a different file name so you will need to rename it after copying it to the memory card. Once the unit has successfully been re-flashed, you should delete the file from the SD card.

That's it; enjoy the show!

EPE EXCLUSIVE

Win an MPLAB Starter Kit for Digital Power

EVERYDAY PRACTICAL ELECTRONICS is offering its readers the chance to win an MPLAB Starter Kit for Digital Power (#DM330017). This starter kit allows the user to easily explore the capabilities and features of the dsPIC33F GS Digital Power Conversion family. It is a digitally controlled power supply board that consists of one independent DC/DC synchronous buck converter and one independent DC/DC boost converter. Each power stage includes a MOSFET-controlled 5W resistive load. The kit features an on-board in-circuit debugger/programmer via USB, LCD display for voltage, current, temperature and fault conditions and an on-board temperature sensor.

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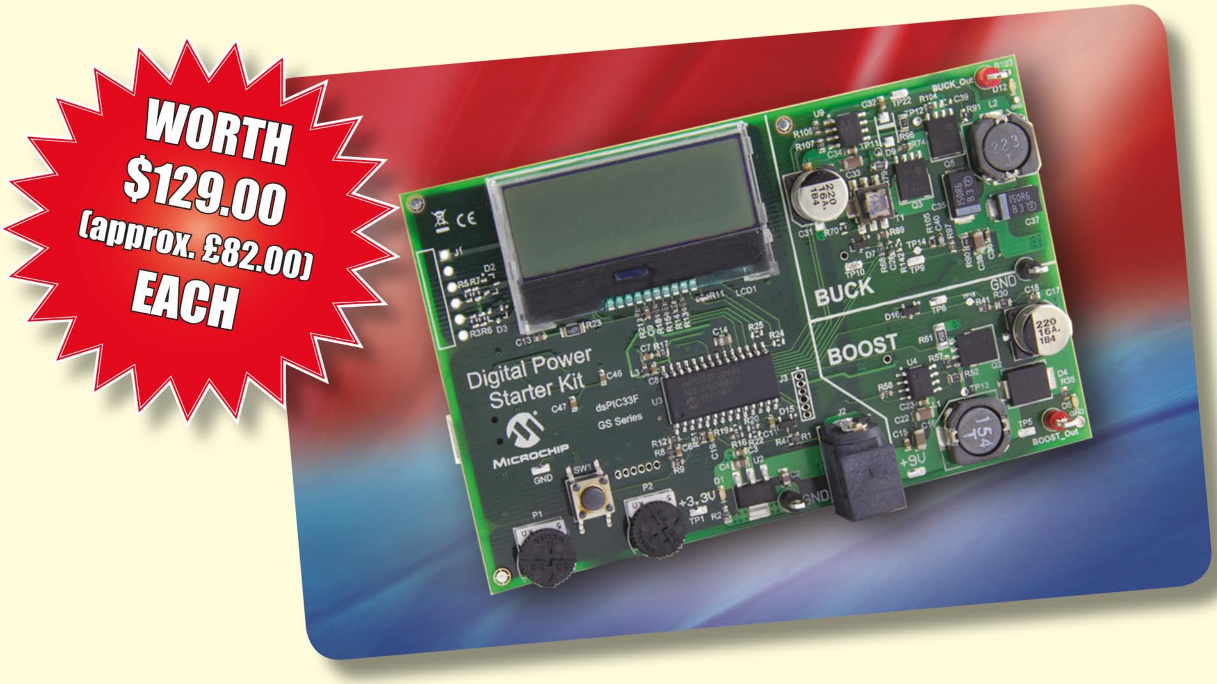

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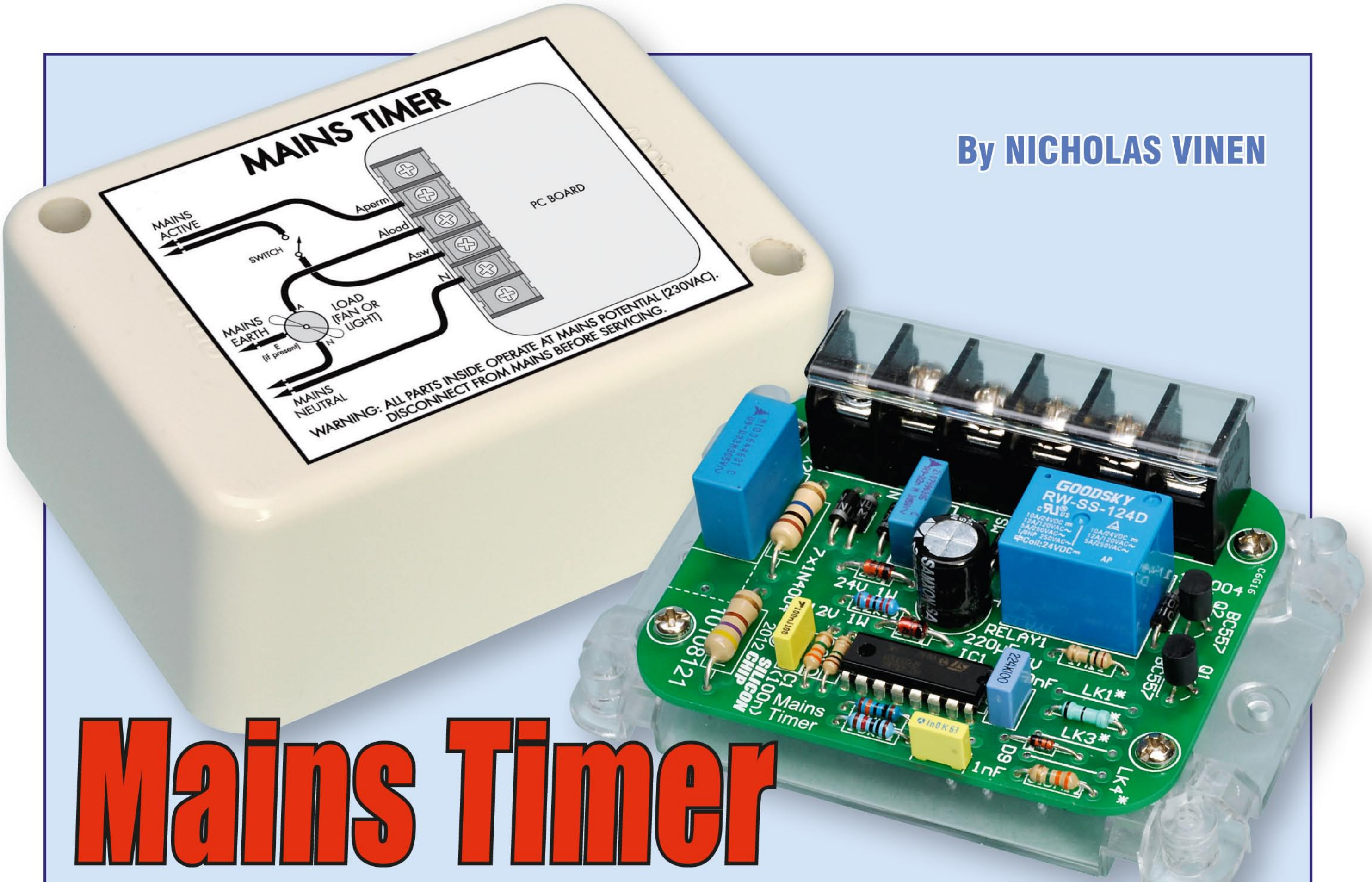


By NICHOLAS VINEN

Mains Timer
for fans or lights

This simple circuit provides a turn-off delay for a 230V AC light or a fan. It can be used to make a bathroom fan run for a set period after the switch has been turned off or it can be used with a pushbutton to turn a light on for a specific time. The timer circuit consumes no standby power when the load is off.

BATHROOMS and toilets need an exhaust fan to vent humid air or odours outside. It's a good idea to have the fan running while you shower and then for a little while afterwards, to prevent condensation and mould. This unit makes it easy, by automatically running the fan for a preset period after the wall switch has been turned off and then switching itself off.

And while this timer was designed specifically with bathroom or toilet fans in mind, it is equally applicable to exhaust fans in kitchens where cooking odours need to be vented outside. Of course, cooking also produces large amounts of water vapour, so a fan is desirable to avoid condensation on the walls which can lead to mould.

It has other applications too. For example, many apartment buildings have lights in the foyer or stairwell with pushbuttons to turn them on. This allows people on any level to turn the lights on for long enough to get into or out of the building without the possibility of them being left on for long periods. This unit can perform that task too, when combined with mains-rated momentary pushbuttons or spring-loaded switches.

Or do you forget to turn off outdoor lights after visitors have departed? This timer will avoid that problem.

You can easily set the time-out from five seconds to one hour by changing an on-board link and possibly a capacitor. The whole thing fits in a junction box (Arlec 9071 or equivalent) for ease of installation. And as noted above, it has no standby power so it's quite 'green' (well, the PCB is anyway).

Commercial units to do these jobs are available, but can be hard to get and expensive. This design has relatively few parts and it can handle loads of up to 5A/1250VA.

Improvements

We have published many projects which one way or another control

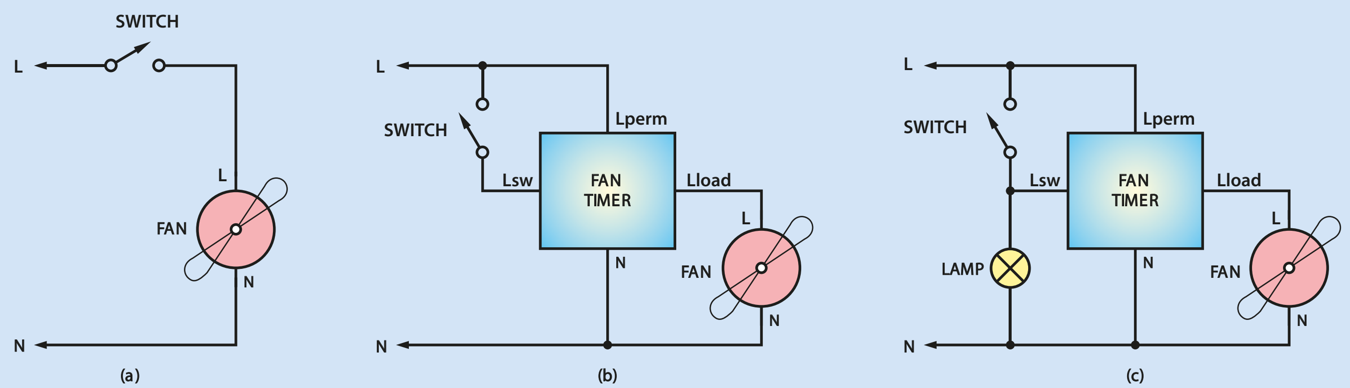


Fig.1(a) at left shows how a fan (or light) is normally connected, while Fig.1(b) shows how the wiring is changed so the *Timer* controls the fan, in conjunction with the switch. Fig.1(c) shows the circuit with the ceiling light in place, where the light and the fan share a common switch.

mains power. Often, these controllers have used a PIC microcontroller and/ or a triac to regulate power. While these often have some fancy features, their standby power was typically-several watts, which is something of a drawback these days. Also, use of a triac makes a circuit incompatible with some compact fluorescent lamps (CFLs).

This new design dispenses with the need for a micro, so there is no need for programming. Instead, it is based on a cheap and commonly available CMOS oscillator/counter IC. There is no triac either, as the load switching is done by a mains-rated relay.

Connections

The *Mains Timer* is designed to be added to an existing fan or light installation with minimal fuss. Fig.1(a) shows how a typical fan is wired up (this also applies to lights). The 3-core mains cable is normally run in the ceiling cavity with the live line splitting out to run down to the power switch, mounted on the architrave or wall below. The switched live line then runs back up into the ceiling to connect to the fan. Neutral and possibly earth are permanently connected to it.

Fig.1(b) shows how the *Mains Timer* would be connected into the circuit. As before, neutral and earth wires run straight to the fan. The timer is connected in-line with the switched live, with the wire from the switch going to its 'Lsw' terminal and the wire to the fan coming from its 'Lload' terminal.

Two additional wires, 'Lperm' and 'N', are run back to the live and neutral supply. For the sake of convenience, the junction of the two neutral lines may be made on the *Mains Timer* PCB.

The additional live line (Lperm) is necessary to power the fan or light after the mains switch has been turned off. The neutral line is used to power the timer circuitry without affecting the voltage delivered to the load.

Finally, Fig.1(c) shows how you can add an exhaust fan to a room which only has a light switch, using the one switch to turn on both the fan and the light. When the switch is turned off, the light goes off immediately, but the fan runs for the preset time before it too goes off. All you have to do is run the switched live line from the light to the Lsw terminal on the timer and then run the live, neutral and load (fan) wires as shown.

Circuit description

Fig.2 is a simplified diagram of the *Mains Timer*, showing how its power supply works. This configuration allows it to have zero standby power. Initially, the mains switch (S1) is off and so is Relay1. So the circuit has

> **Warning!**
>
> This circuit is directly connected to the mains and all parts operate at 230VAC. As such, contact with ANY part of the circuit could be fatal!
>
> DO NOT operate this circuit unless it is fully enclosed in the specified junction box and DO NOT touch any part of the circuit while it is connected to the mains.
>
> Note that unless you have the requisite skills and experience, this unit should be connected to the house wiring by a qualified electrician.

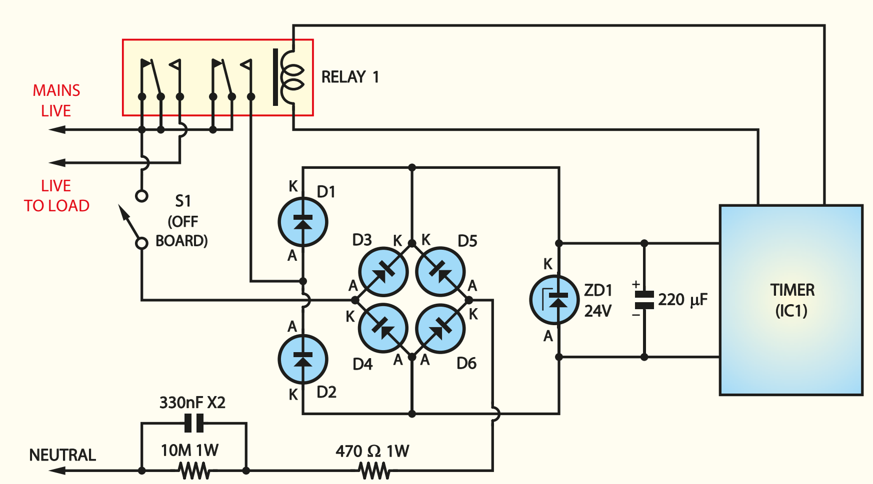
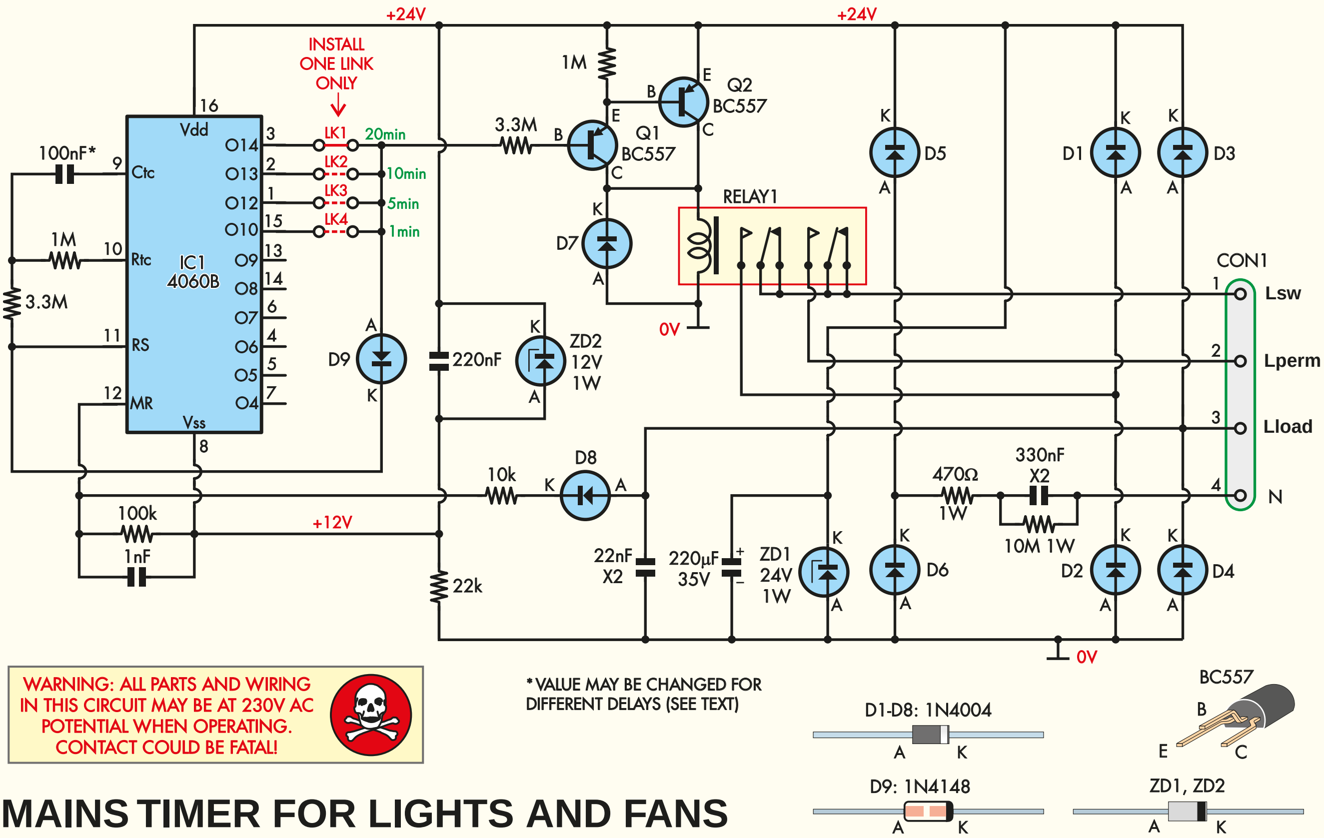


Fig.2: simplified circuit of the timer power supply. The mains is rectified by diodes D3-D6, filtered with a 220µF capacitor and regulated by 24V zener diode ZD1. A 220nF X2 capacitor in the neutral leg limits the mains current. Diodes D1-D2 work in conjunction with Relay1 to supply power for the circuit after switch S1 is turned off, until the off-timer period expires.



MAINS TIMER FOR LIGHTS AND FANS

Fig.3: the full circuit of the *Mains Timer*. IC1 is a 4060 CMOS oscillator/counter which provides the time delay. It controls Relay1 to switch power to the load as well as the circuit's power supply (refer to Fig.2). Diode D8 allows the timer to sense when the mains switch is turned off; while it is on, the timer is held in reset as IC1's MR input (master reset, pin 12) is held high.

no live connection until switch S1 is closed.

When S1 is closed, the mains voltage is applied across the bridge rectifier formed by diodes D3-D6. The output is limited to 24V DC by zener diode ZD1 and filtered by a 220µF capacitor. The mains input current is limited in the neutral leg by a series 330nF X2 capacitor with a parallel 10MΩ bleed resistor and a series 470Ω resistor for in-rush current limiting.

Once the 220µF capacitor has charged up, the timer circuitry energises the coil of Relay1 and its contacts switch over. The incoming mains live is then connected to the junction of diodes D1 and D2 via the relay and these are effectively in parallel with diodes D3 and D4 in the bridge rectifier. But when switch S1 is turned off, the circuit remains powered, via the relay contacts and the bridge rectifier formed by D1, D2, D5 and D6.

The circuit remains powered until the timer runs its course, at which point Relay1 is switched off and the 24V supply collapses, bringing it back to the initial state, where it is not consuming any power.

Note that the circuit is powered directly from the 230V AC mains and floats at or near mains live potential, so it must be considered as hazardous (lethal) once it has been connected.

Also note that zener diode ZD1 dissipates little power as the 330nF X2 capacitor value has been chosen to limit the mains current to a value very close to that drawn by the relay.

Details

Now take a look at Fig.3, which shows the full circuit diagram. Besides showing the details of the timing circuitry (at left), this also reveals an additional diode (D8) which is connected to mains live via switch S1 (off board). This diode allows the timer to sense when S1 is turned off, and this is the reason we didn't simply arrange for Relay1's contacts to short out the switch when it turns on. If we had, there would have been no way to sense when S1 is switched off.

While switch S1 is on, D8 is forward-biased and so at the peak of each mains cycle, current can flow through it and its series 10kΩ current-limiting resistor to charge the 1nF capacitor between the MR (master reset, pin 12) and Vss (negative supply, pin 8) terminals of timer IC1. While S1 is on, MR is kept high and this holds the timer in its reset state, with its oscillator inhibited and its 13-bit counter reset to zero. While the counter is zero, all its outputs (O4-O10 and O12-O14) remain low.

Depending on how the timer is configured, one of the four outputs O10 or O12-O14 is connected to the base of PNP transistor Q1 via a 3.3MΩ resistor. That output being low, it sinks current from the base of Q1, turning it on. It in turn drives PNP transistor Q2, which energises Relay1's coil, turning it on. One of its set of contacts supplies mains power to the load and the other connects the mains to this circuit, as described earlier.

Note that Q1 and Q2 are in a PNP Darlington configuration. The 1MΩ resistor between Q2's base and emitter shunts any leakage current from Q1, preventing a false turn-on.

When switch S1 is turned off, current can no longer flow through D8 and so the 1nF capacitor is discharged by its parallel 100kΩ bleeder resistor. The 22nF X2 capacitor at the anode of D8 is necessary to suppress capacitively-coupled electrical noise and leakage current through S1 from keeping the MR pin high even when S1 is off. When MR goes low, IC1's internal oscillator starts running and incrementing the counter.

Oscillator frequency

The oscillator's frequency is set by the combination of the 100nF capacitor and 1MΩ resistor between pins 9 and 10 of IC1. The formula in the 4060 data sheet gives us 4Hz for these values, but we measured 7Hz on two different prototypes, so we use this measured value and assume that the formula must be inaccurate when such a high resistor value is used (even though it is within the specified range). So IC1's internal counter is incremented seven times per second.

The 3.3MΩ resistor minimises frequency variation with supply voltage by isolating the input capacitance of pin 11.

IC1's O10 output goes high after 512 (2^9) oscillations, or 512 ÷ 7Hz = 73s. Similarly, the O12 output goes high after 5 minutes, O13 after 10 minutes and O14 after 20 minutes. So, depending on which of links LK1-LK4 is installed, after the selected delay, Q1 and Q2 switch off. This de-energises the coil of Relay1 and diode D7 absorbs the resulting back-EMF.

This cuts power to the load and the *Mains Timer* also powers down as the 220µF capacitor discharges. If the mains switch is turned back on before the time-out (ie, while the load is still energised), the MR input of IC1 is pulled high and so the timer is reset. When the switch is turned off, the timer again starts counting from zero.

We need 24V to drive the relay coil, but IC1 has a maximum rating of 15V, so the supply from the 220µF capacitor is fed via a 22kΩ resistor to the 12V zener diode, ZD2. This limits the supply for IC2 to +12V.

So, while it might not be immediately apparent from the circuit of Fig.3, the *Mains Timer* has two supply rails: +24V and +12V. Note, however, that IC1 (4060B) is actually connected between the +24V and +12V rails.

Don't be fooled by those low DC voltages though – as stated, this whole circuit 'floats' at mains potential (230V AC) and is potentially lethal.

The 220nF capacitor and 22kΩ resistor also form a low-pass RC filter to remove much of the 100Hz ripple from IC1's supply.

You might be wondering about the purpose of diode D9. It stops the timer from running once the relay switches off. Normally, this isn't an issue, since the power supply then collapses. But without D9, if the delay was set short enough, it's possible the relay could come back on while the mains switch remained off.

Other uses

Up to now we have been describing how the timer circuit is used with a standard wall switch, and in that case, the timer provides an off-delay – ie, the load is powered whenever the switch is on, as well as for the preset period after it is switched off.

But this is no good if you want to use the *Mains Timer* to prevent the load from being accidentally left on after use, which can be a concern for both fans and lights. If that's your aim, you simply need to change the mains switch to either a momentary push-button or a spring-loaded momentary switch.

These are available from electrical suppliers. They may be sold as a bell-press button or similar. So, if you swap the switch over to a momentary pushbutton and wire in

Parts List

1 PCB, code 10108121, available from the *EPE PCB Service*, size, 60mm × 76mm
1 4-way PCB-mount (screw fix) terminal barrier (CON1)
1 5A 24V DC coil DPDT or DPST relay
1 junction box
2 M3 × 15mm machine screws and nuts
4 M3 shakeproof washers
4 No.4 × 9mm self-tapping screws

Semiconductors
1 4060B oscillator/counter (IC1)
2 BC557 PNP transistors (Q1,Q2)
1 24V 1W zener diode (ZD1)
1 12V 1W zener diode (ZD2)
8 1N4004 1A diodes (D1-D8)
1 1N4148 small-signal diode (D9)

Capacitors
1 220µF 35V/50V electrolytic
1 330nF 250VAC X2 MKT/MKP (Element14 Part No. 1215460)
1 220nF MKT polyester
1 100nF MKT polyester (see panel below)
1 22nF 250VAC X2 MKT/MKP
1 1nF MKT polyester

Resistors (1%, 0.25W unless stated)
1 10MΩ 1W 5%
2 3.3MΩ
2 1MΩ
1 100kΩ
1 22kΩ
1 10kΩ
1 470Ω 1W 5%
1 0Ω

* A kit of parts for this project is available from Jaycar Electronics

Changing the switch-off time delay

Four time delay options are available by default: one minute, five minutes, 10 minutes and 20 minutes. These are selected by installing one of links LK1, LK2, LK3 or LK4 respectively. If none of these suit, you can change the value of the 100nF MKT capacitor to give other time delays, as shown in Table 1 below. Simply select the appropriate value and then install the corresponding link to give the desired delay.

Note that these times are approximate and can vary by about ±20%, due to component tolerances and rounding errors.

Table 1: Setting the timing

C1	LK1	LK2	LK3	LK4
330nF	1 hour	30 minutes	15 minutes	4 minutes
220nF	45 minutes	20 minutes	10 minutes	2.5 minutes
150nF	30 minutes	15 minutes	7.5 minutes	2 minutes
100nF	20 minutes	10 minutes	5 minutes	1 minute
22nF	4 minutes	2 minutes	1 minute	15 seconds
15nF	3 minutes	1.5 minutes	45 seconds	10 seconds
4.7nF	1 minute	30 seconds	15 seconds	5 seconds

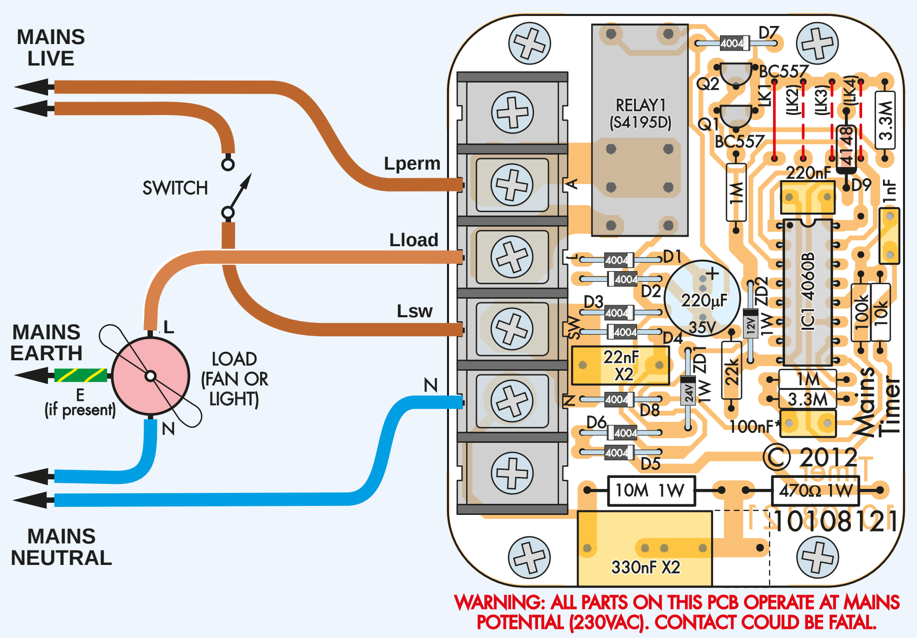
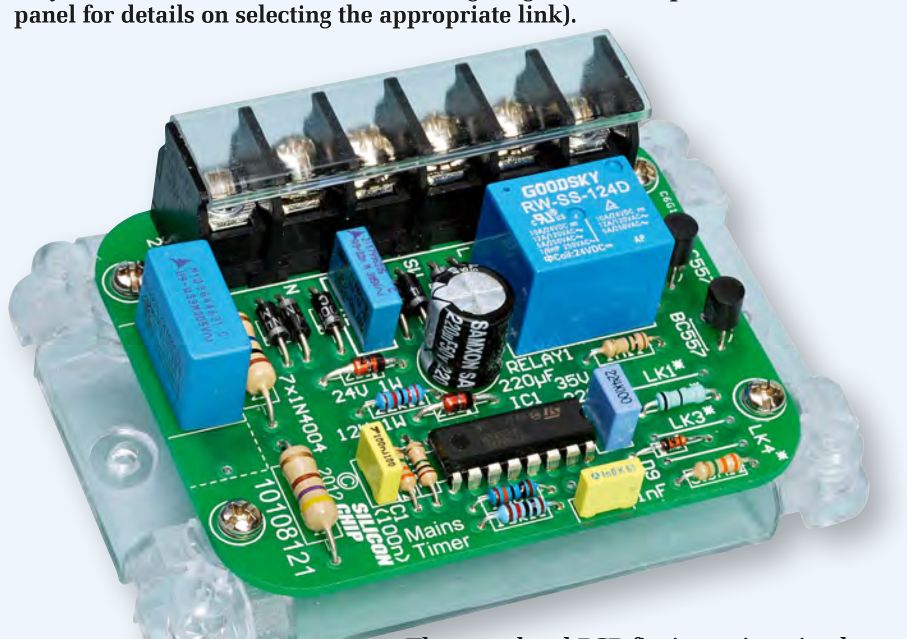


Fig.4: follow this layout and wiring diagram to assemble the timer board. Take care with the orientation of the diodes, the 220µF capacitor and IC1. Note that only one link (LK1 to LK4) is installed, giving four time options (see text and panel for details on selecting the appropriate link).



The completed PCB fits into a junction box. It's shown here mounted on the base.

the timer as shown above, the load will then turn on for the chosen period when the button is pressed and then automatically turn off again. The button can also be pressed any time the load is on, to reset the timer and keep it on for the preset period.

Construction

The *Mains Timer* is built on a PCB coded 10108121 (60mm × 76mm), which is available from the *EPE PCB Service.* This fits in a junction box (eg, Arlec 9071). But note that not all junction boxes are the same and you will need to check that the one you are purchasing has mounting holes in the same positions as those of the PCB.

While the PCB is notionally a single-sided design, we have made it double-sided and added parallel tracks on the top to improve its mains current-carrying capability. In the absence of a kit being available, we recommend you build the timer using one of our boards since they have a solder mask, which greatly reduces the chance of leakage paths developing and causing flash-over.

Referring to the PCB overlay diagram (Fig.4), start by installing all the small resistors. Use a DMM to check each as you go, since the colour codes can be hard to read accurately. The 0Ω resistor is used for one of LK1-LK4 and you must only install one of these. Refer to Table 1 and select your desired time-out, then fit the link (0Ω resistor or tinned copper wire) in the appropriate position.

Follow with the diodes, being careful with the orientation, and make sure the smaller 1N4148 diode goes in the top-right corner. **Note that the orientation of diodes D1-D6 and D8 alternates as you go down the board.** Install the two zener diodes (ZD1 and ZD2) also. These are in a larger glass-encapsulated package and both are oriented with the cathode stripe towards the top of the PCB.

Solder IC1 in place next, with the pin 1 notch or dot towards the top of the board as shown. Follow with the two 1W resistors – don't get them mixed up. You can then fit the smaller MKT capacitors. The 100nF capacitor can be a different value if you want to adjust the timing – see Table 1.

Now install the two transistors, bending their pins with a small pair of pliers to fit the pads provided. The flat faces are orientated as shown on the overlay diagram. You can then solder the electrolytic capacitor in place, with the longer (+) lead towards the top of the board.

Follow with the two X2 capacitors. Note that the larger X2 capacitor can have one of several lead pitches, so multiple pads have been provided to suit them all; its left-most lead should go in the left-most hole provided and the other into the best-fitting position. After that, solder the relay in place.

The terminal barrier is attached to the PCB using two 15mm M3 machine screws with a star washer under each screw head and nut. Check that the connector is straight and do the screws up tight before soldering the four pins. Use a hot iron to ensure that the solder joints form proper fillets.

Finally, attach the PCB to the junction box baseplate using four small self-tapping screws and you are ready to test it.

Testing

If you have a bench supply and would like to test the PCB before it is installed and connected to the mains, you can do so. Connect a DC supply, set to slightly less than 24V, across ZD1, with the positive lead to its cathode (striped end). The circuit should draw about 30mA, if it draws much more than this, switch off and check for faults.

The relay may or may not switch on initially; if it does not, apply 24V to the SW terminal of CON1 and it should turn on. After the delay you have selected, it should turn off again. Assuming it does, the unit is working correctly and you can power it down. Otherwise, carefully check the component orientation, component values and solder joints.

Installation

Note that unless you have the requisite skills and experience, this unit should be connected to the house wiring by a qualified electrician. Note also that ALL parts on this circuit operate at mains potential (230V AC), so do not touch any part of the circuit when power is applied.

It's a matter of following the wiring diagram (Fig.4) to make the connections. You must switch off the circuit before you start working on it, and check that it really is off before starting work.

Ensure that the junction box base-plate is securely anchored to a joist or ceiling batten using the supplied screws before doing the wiring. Note that you will need to knock out one or two panels in the junction box housing to allow the wiring to pass through.

The mains cables must be clipped or clamped to convenient beams or joists once you have finished. This keeps the ceiling space (or wherever the unit is installed) neat and prevents wires from being tripped over or accidentally yanked. It also makes it easier to trace the wires to see where they go.

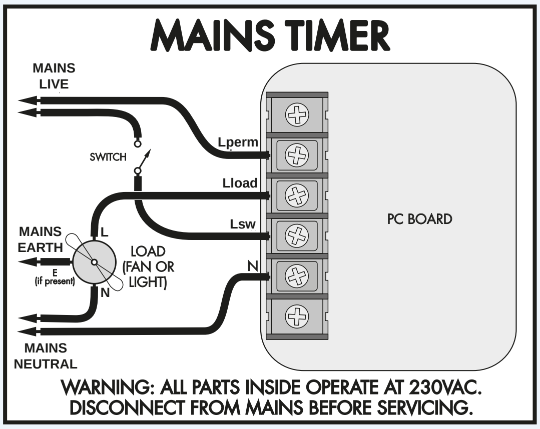


Fig.5: front panel label for the *Mains Timer*. Print this out, laminate it and glue it to the lid of the junction box (eg, using silicone sealant) for future reference.

In some cases, you may wish to use a single switch to control both a light and a fan – see Fig.1(c) for wiring details. Now, both the light and the fan will come on when the switch is turned on, but when it is turned off, the light will go off immediately while the fan will continue to run for the programmed period before turning off.

If the fan has an existing earth connection, this should be left intact. Fans with a metal housing will tend to have an earth wire, while those with a plastic housing may not. If the earth wire has to be cut, it can be re-joined using a double-screw connector.

Once everything is hooked up, check that all the terminal barrier screws are tight and there are no stray strands of copper from any of the wires that might short to something else. You can then clip the terminal barrier covering in place, fit the junction box cover, turn the power circuit back on and check that everything is working as expected.

Fans with 3-pin plugs

Many existing ceiling fans and all new fans these days come fitted with a lead complete with 3-pin mains plug. This simply plugs into an adjacent mains socket in the roof space.

In that case, a better idea may be to ditch the junction box and install the *Mains Timer* PCB in an IP65 sealed box. This can then be fitted with a socket, so that the fan can be plugged into it.

Short delay

Finally, note that in operation, you may notice a short delay between flicking the switch and the load coming on. This is usually only a couple of hundred milliseconds and is due to the power supply capacitors charging to the relay's operating voltage. It's short enough that it should not present a problem, especially when used with fans, which take some time to spin up anyway.

Table 3: Capacitor Codes

Value	µF Value	IEC Code	EIA Code
330nF	0.33µF	330n	334
220nF	0.22µF	220n	224
100nF	0.1µF	100n	104
22nF	.022µF	22n	223
1nF	.001µF	1n	102

Table 2: Resistor Colour Codes

❏	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❏	1	10MΩ	brown black blue brown	brown black black green brown
❏	2	3.3MΩ	orange orange green brown	orange orange black yellow brown
❏	2	1MΩ	brown black green brown	brown black black yellow brown
❏	1	100kΩ	brown black yellow brown	brown black black orange brown
❏	1	22kΩ	red red orange brown	red red black red brown
❏	1	10kΩ	brown black orange brown	brown black black red brown
❏	1	470Ω	yellow violet brown brown	yellow violet black black brown
❏	1	0Ω	single black stripe	single black stripe

Recycle It!

BY JULIAN EDGAR

Cheap Power!

Build this two-amp variable voltage power supply for around a fiver!

ANYONE who does anything with hobby electronics needs an adjustable voltage, bench power supply. And most of us could do with more than one. Whether that's for quickly supplying the right voltage to a prebuilt module, testing individual components, or providing an easy power source as one step along the way to a completed project, an adjustable power supply will never be without uses.

So, with that in mind, here's one you can build yourself for around £5 in about half an hour!

But how is that possible? You'll need to have an old unused laptop power supply lying around the place (for example, the type in Photo 2); a bought-in prebuilt module and a few components (the latter you probably already have); and to visit the supermarket to buy a box. And that's it…

Photo 2: An ex-laptop power supply is used. These have high current output for their size, typical output voltage of about 20V and are available free in large numbers if you look around. You may well have one tucked away yourself

The parts

The main building block of this design is a pre-built eBay module, as show in Photo 3. Available from a number of suppliers (just search under 'Digital display LM2596 Voltage Regulator DC-DC Buck Converter Module') the module will take any input voltage from 4V to 40V and turn it into a variable output from 1.25 to 37V. (If you decrease the voltage going into the module, the max output voltage also decreases.)

The module costs from about £5, delivered to your UK letterbox. That's just stunningly cheap – especially as it includes the on-board 3-digit LED voltmeter!

The maximum peak current that the module can handle is 3A; it can handle 2A for longer periods and 1A continuously. If you'd like the continuous power-handling figure raised, fit a heatsink to the IC. Note that the module has short-circuit and over-temperature shutdown built in.

In addition to this module, you'll need an old ex-laptop power supply – these are readily available in currents of about 3A and voltages up to about 20V. Any example that has anything like these specs written on it will be fine – and because they're often thrown away when a laptop is discarded, they're not hard to find.

I added an external pot to allow the voltage to be easily altered (a 20kΩ unit) and a small toggle switch to allow the output to be turned on an off (often useful when you are testing a circuit and want to quickly disconnect power to make a change).

I also used a couple of output power terminals – old speaker terminals salvaged from a discarded speaker.

So that the LED voltmeter could be seen through the box, I mounted the pot, switch and module inside a red translucent food storage box purchased from a bargain store for around a pound.

Building it

The first step is to ensure that the laptop power supply is working correctly. Cut off the low voltage DC plug and bare the wires. If there are more than

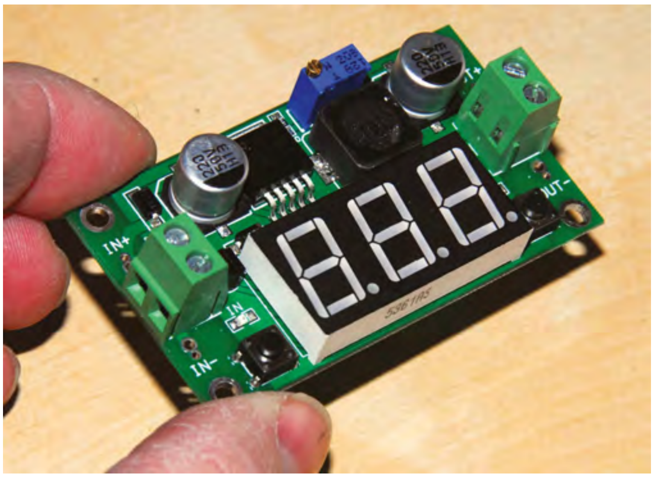


Photo 3: The heart of the power supply is this prebuilt module available incredibly cheaply on eBay. It is available from various sellers and will accept an input voltage up to 40V, giving a variable output from 1.25 to 37V. Note the blue pot at the top, which will be removed (see photo 4)

two wires, the two thicker wires will be the power supply. Connect your multimeter to these wires, turn on mains power, and check that you have the specified voltage (eg, 21V) on the output. Also at this stage, confirm which wire is positive and which is negative.

Disconnect mains power (and observing the correct polarity) connect the laptop power supply to the 'IN' terminals of the module. Plug back into mains power and check that when you rotate the on-board pot, the output voltage varies. By pressing the on-board buttons, you can turn the voltmeter on and off, and change the reading from input voltage to output voltage.

The trickiest part of the project is wiring-in the external pot. Because the printed circuit board is double-sided, it is best if you carefully use a pair of pliers to crush the on-board pot until its pieces can be removed, revealing the solder pads to which it is connected, see Photo 4.

Carefully solder extension wires to these pads and then connect them to the external 20kΩ pot, using the same wiring pin-outs on the new pot as were used on the old, as shown in Photo 5.

Reconnect mains power and check that you can vary the module output voltage by rotating the external pot.

I chose to mount a switch in the output circuit. That is, when mains power is applied to the power supply, the LED display is always illuminated – so acting also as a 'power on' indicator. The switch just turns the output on and off.

Next, the box, a typical suitable model is shown in Photo 6. Before assemby, I set the module pushbuttons to

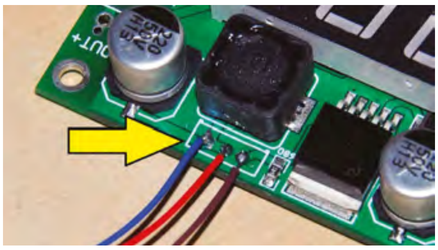


Photo 5: Here are the new leads that run to the remote-mount pot. Solder them on carefully!

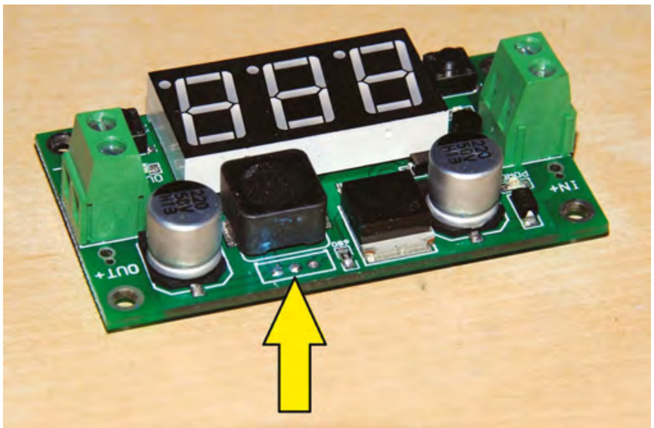


Photo 4: To allow external adjustment of the voltage, the on-board pot is removed (arrow) and a remote-mount pot replaces it. It is better to crush and then remove the pieces of the original pot from above – de-soldering on these double-sided boards can cause problems

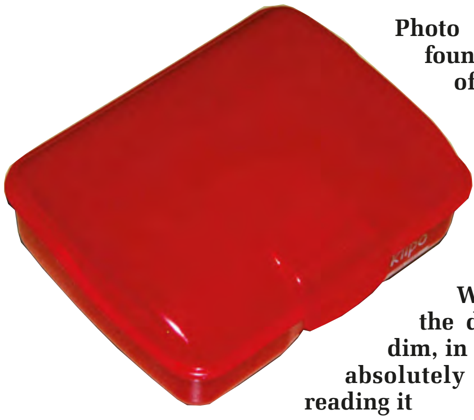


Photo 6: This box was found on the shelves of a supermarket. It is translucent, so the LED display can be mounted inside without the need for a special window. While in the photos the display may look dim, in real life there are absolutely no problems in reading it

switch the LED voltmeter on, and to configure it to show output voltage.

The module was mounted using stand-offs formed by screws and multiple nuts, inserted from the front. See Photo 7 for the project's 'innards'.

With the wiring completed, I used double-sided tape to stick the translucent box to the ex-laptop power supply, positioning the two 'blocks' so that the display and controls sat angled upwards. Photo 8 shows our completed bench power supply ready for action!

Photo 7 (right): The wiring is very straightforward. The output of the laptop power supply connects to the 'IN' terminals on the module. The output of the module connects to two ex-speaker terminals via an on/off switch. The new 20kΩ pot connects to the spots where the original on-board pot sat!

In use

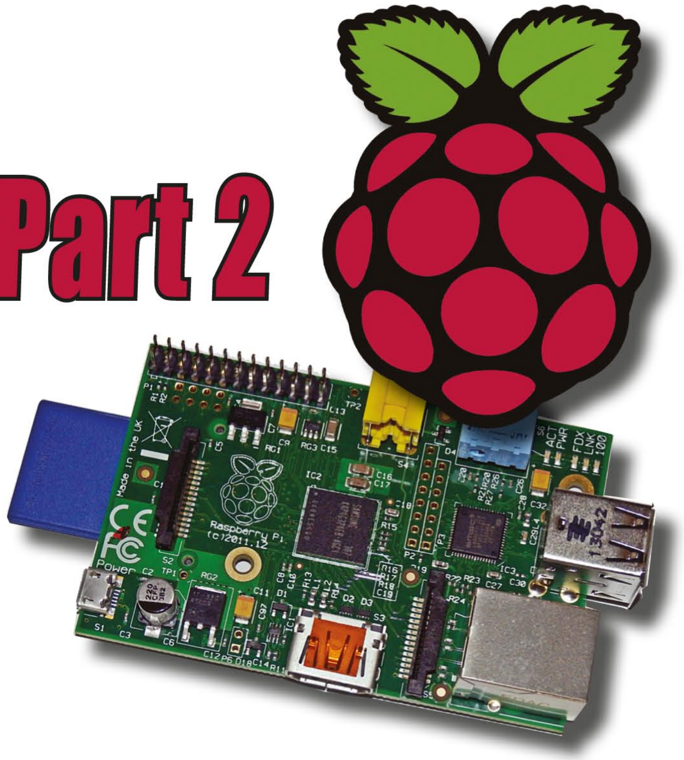
In use, the power supply works very well. The regulation is excellent and the supply will also cope with short-term short circuits. I didn't measure ripple, but if you are concerned, you could easily add some capacitors to the output.

There is one disadvantage though. You can't set the output voltage in very small increments – because the original on-board pot was a 10-turn unit and we're using a one-turn pot, the fine resolution of the original control isn't retained. That said, on the prototype and using a 3.42A, 19V laptop power supply, you can set the output at about 0.2V intervals from 1.1V to 18V.

This is a great project – cheap, very useful, rugged and (for beginners in electronics) safe to make.

Photo 8: This small power supply features adjustable output voltage from about 1V to 18V, a short-term output of up to 3A, over-current and temperature protection, and an LED display. And it's very cheap to make

Teach-In 2014 Raspberry Pi – Part 2



by Mike and Richard Tooley

Welcome to *Teach-In 2014* with Raspberry Pi. This exciting new series has been designed for electronics enthusiasts wanting to get to grips with the immensely popular Raspberry Pi, as well as computer buffs eager to explore hardware and interfacing. So, whether you are considering what to do with your Pi, or maybe have an idea for a project but don't know how to turn it into reality, our new *Teach-In* series will provide you with a one-stop source of ideas and practical information.

The Raspberry Pi offers you a remarkably effective platform for developing a huge variety of projects; from operating a few lights to remotely controlling a robotic vehicle through the Internet. *Teach-In 2014* is based around a series of practical exercises with plenty of information for you to customise each project to meet your own requirements.

The Raspberry Pi is no mean performer; it can offer you very similar performance to that which you might expect from a larger and much more expensive computer system, so don't be fooled by the relatively small price tag. By shopping around you can build a very effective computer system based on a Raspberry Pi for less than £100. However, if you are looking for something more modest and just want to take advantage of the Raspberry Pi as a single-board computer for a particular control application then you can be up and running for a very reasonable outlay.

This series will teach you about:

- **Programming** – introducing you to the powerful Python programming language and allowing you to develop your programming skills
- **Hardware** – learning about the components and circuits that are used to interface microcomputers to the real world
- **Computers** – letting you get to grips with computer hardware and software and helping you understand how they work together
- **Communications** – showing you how to connect your Raspberry Pi to a network and control a remote device using Wi-Fi and the Internet.

So, what's coming up? Regular features of *Teach-In 2014* with Raspberry Pi will include:

- **Pi Project** – the main topic for each part will be a project that explores a particular use or application of the Raspberry Pi in the real word. Projects will include shopping for your Pi, set up, environmental monitoring, data logging, automation and remote control.
- **Pi Class** – each of our Pi Projects will be linked to one or more specific learning aims. Examples will include methods of representing and handling data, serial versus parallel data transmission and architecture of a microprocessor system.
- **Python Quickstart** – a short feature devoted to specific programming topics, such as data types and structures, processing user input, creating graphical dialogues and buttons and importing Python modules. We will help you get up and running with Python in the shortest time!
- **Pi World** – this is where we take a look at a wide range of Raspberry Pi accessories, including breadboards, prototype cards, bus extenders and Wi-Fi adapters. We will also help you build your Raspberry Pi bookshelf with a selection of recommended books and other publications.
- **Home baking –** suggested follow-up and extension activities such as 'check this out', a simple quiz, things to try and websites to visit.
- **Special features –** an occasional 'special feature'. For example, how to laser cut your own mounting plate – with additional downloadable resources such as templates and diagrams.

What will I need?

To get the best out of our series you will, of course, need access to a Raspberry Pi. If you don't already have one, don't worry – we will be explaining what you need and why you need it (we will also be showing you how you can emulate a Raspberry Pi using a Windows PC).

This month

This month, *Teach-In 2014* is all about connecting the Raspberry Pi to the real world. Our *Pi Class* will take you on a brief tour of the graphical user interface (GUI) and the applications that are bundled with the Raspberry Pi's operating system. *Pi Project* will explain how the Raspberry Pi's general purpose input/output (GPIO) interface works and provides you with four simple I/O projects, together with the necessary Python code to make them work. Our feature for programmers, *Python Quickstart*, will provide you with an introduction to comparisons and loops. Last, but by no means least, *Home Baking* will explain how you can update your operating system and download more software applications from the Internet.

Pi Class

A brief tour of the Raspbian GUI

We hope that in the month since Part 1 of *Teach-In 2014* came out you've had a chance to get your own Raspberry Pi up and running and have already taken some time to play with the operating system. In this edition of *Pi Class* we're going to take you on a short guided tour of the Raspbian environment and the software that comes pre-installed as part of the

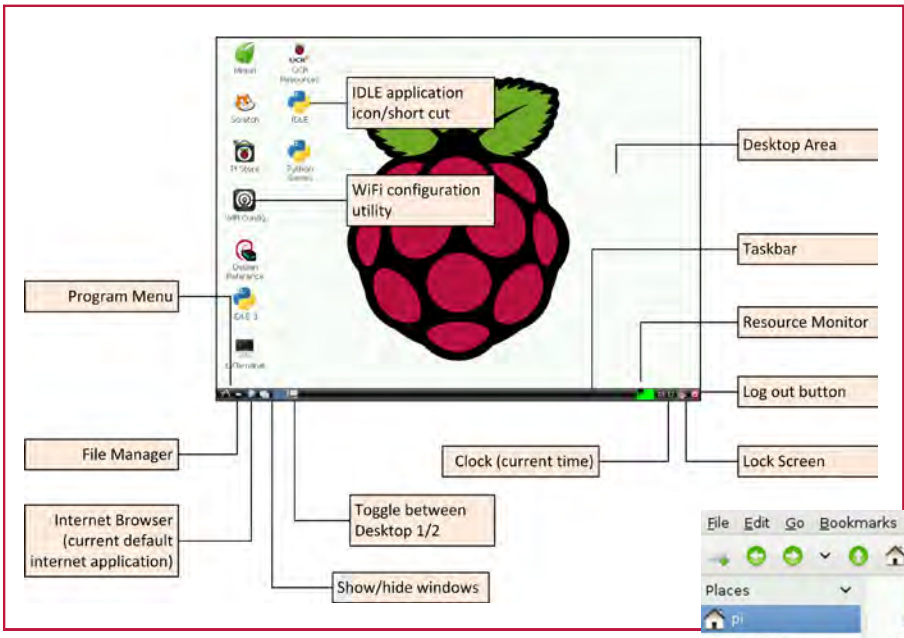


Fig.2.1. The Rasbian desktop

standard image. Later on, in *Home Baking* we'll also guide you through the process of updating your operating system and software, as well as finding, installing and managing your programs.

The Raspbian desktop is a streamlined Windows-like environment and you should find yourself at home with ease. Older Linux operating systems tended to be quite basic and lacked some of the usability features that we've become used to, such as 'drag and drop', 'copy and paste' and context menus (right-click). However, the Raspbian environment is fast and easy to use, with many of these features implemented. Gone are the days of needing a PhD in computer science to use a Linux-based computer.

Just as with a PC, you'll find a desktop area containing shortcuts to applications and files. A familiar taskbar runs across the bottom of the screen and contains the program menu (The 'Start' menu equivalent) and on the far left some quick launch icons (see Fig.2.2 for their functions). As with many other operating systems, when a window is opened a corresponding tab will appear in the taskbar to allow you to switch between and minimise/maximise windows. Raspbian gives you two desktop areas to work with (Desktop 1 and Desktop 2). This can be really useful; for example, if multi-tasking with several open windows you can leave them open on both desktops and flick between desktops rather than having to minimise and maximise windows continually. However, do bear in mind that the processor on the *Raspberry Pi* is quite modest, so having too many programs running concurrently will affect the performance adversely. In fact, you can monitor the CPU usage visually on the taskbar.

The program menu is divided into several categories. We'll check out each category in turn below and point out some useful programs as we go.

Accessories

Debian Reference – this provides help with using the Debian operating system. A simple viewer (see Fig.2.3) allows you to navigate pages, click through to linked articles or perform a search. Unlike some 'online' help systems this does not require Internet connection.

File Manager

The equivalent of Windows Explorer on Raspbian is *File Manager*. It shares many of the same features as its PC cousin (Fig.2.4). Drag and drop, multiple-selection methods (marquee, Shift-click, Ctrl-click) and context menu actions are all supported. On the left-hand panel you can access the home file area (a bit like 'My Documents' on a PC) as well as the desktop and program menu items should you wish to make any amendments. Removable media such as USB memory sticks will appear here (hot plug-and-play is supported, but always remember to eject the device for safe removal). To search, simply start typing your search term and a box will appear on the bottom right of the *File Manager* window.

Fig.2.4. The File Manager window

Calculator

This is of course Raspbian's obligatory calculator application, with *Leaf Pad* as the standard plain text editor. *Image Viewer* is the default program for handling graphics files. It provides facilities for viewing, rotating and slideshows. File Manager will display known graphics files as thumbnail icons.

Terminal

LXTerminal (shortcut also from the desktop) – this opens a command line window ready for command-based operations. You'll find that you'll be using this quite often. Root Terminal is essentially LXTerminal launched with root privileges. As its name suggests, Xarchiver handles compressed files in a multitude of formats.

Education

Scratch and *Squeak* are two programming systems designed primarily for the education sector. Developed and supported by the Massachusetts Institute

Fig.2.2. Program menu showing the accessories

Fig.2.3. The Debian Reference front page

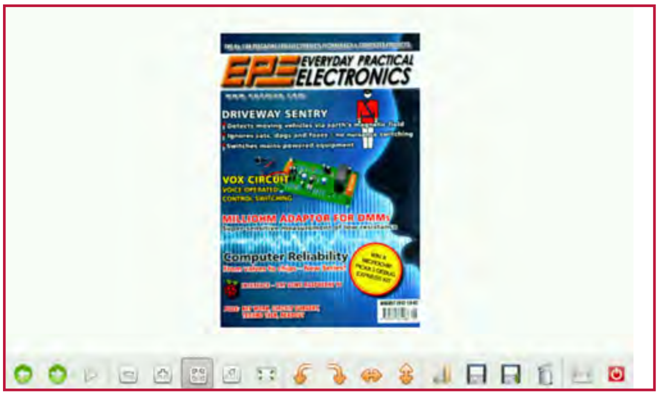


Fig.2.5. The Image Viewer window

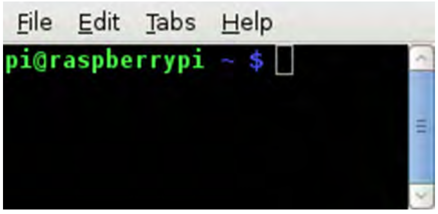


Fig.2.6. The LXTerminal window

Fig.2.8. Reading an issue of EPE *using Xpdf*

Fig.2.9. Using Midori to visit the EPE *website*

of Technology (MIT), Scratch provides a simple graphical 'tile-based' programming method, making it easy and fun for beginners to produce stories, animations and games. The Scratch website **http://scratch.mit.edu** contains a quantity of useful resources and examples. Programs can also be uploaded and shared directly from the program to the Scratch website. Squeak is the programming language/system that is used by Scratch behind the scenes (Fig.2.7).

Graphics

Xpdf is a simple lightweight PDF viewer (Fig.2.8). This utility is ideal for reading a wide variety of documents in the universal 'portable document format'.

Internet

Raspbian comes bundled with three Internet browsers; *Dillo*, *Midori* and *Netsurf*. All three are simple but relatively capable browsers, although some pages may not render as they should, particularly those produced using the latest standards. Your browser choice is really a personal preference and with any low-powered system there's always a trade-off between features and hardware demand. We have found *Midori* (Fig.2.9) to be the more capable in terms of displaying a modern website, although it is not the most lightweight of the three.

Programming

The Programming category also includes the Python programming environment IDLE, in addition to duplicate shortcuts for Scratch and Squeak described above. The *Python Quickstart* section of our *Teach-In 2014* series explores the Python environment and basic programming techniques.

System Tools

Task Manager (see Fig.2.11) allows you to monitor running applications/processes and their system resources usage. This can be useful for terminating unresponsive programs or freeing up memory/CPU time by closing unrequired services.

Preferences

Various system preferences can be setup here, such as the aesthetics of the interface and input methods in *Customise Look and Feel*. You'll notice no reference to adding/removing software here; we'll be looking at how to do this in our *Home Baking* section.

As with any new computer system, take time to work out where everything is and how it works – when you get accustomed to using Raspbian you'll be making good use of your Pi.

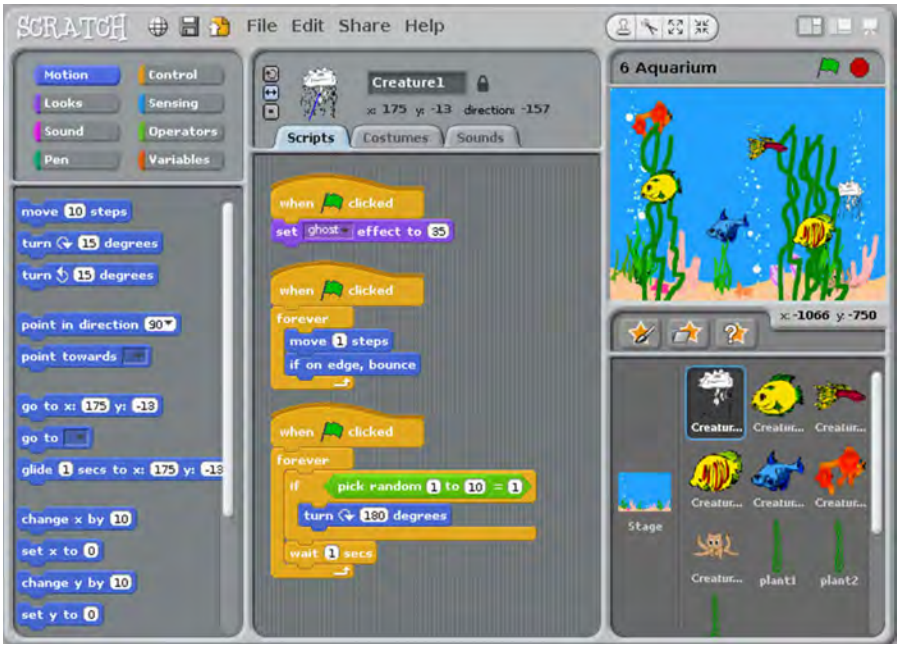


Fig.2.7. A virtual aquarium program being authored in Scratch

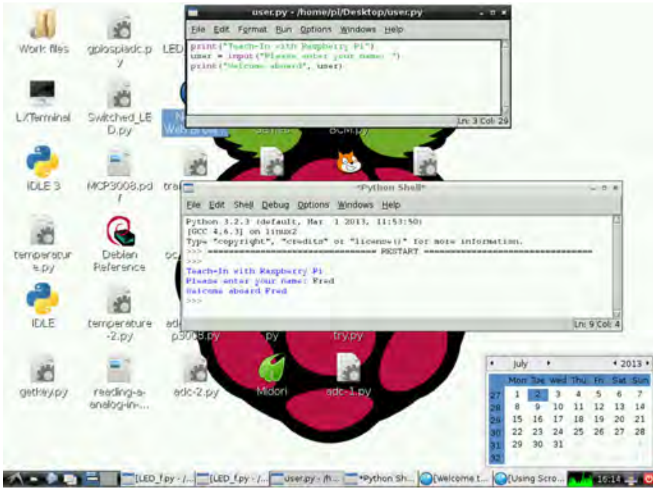


Fig.2.10. Program source code being authored in IDLE

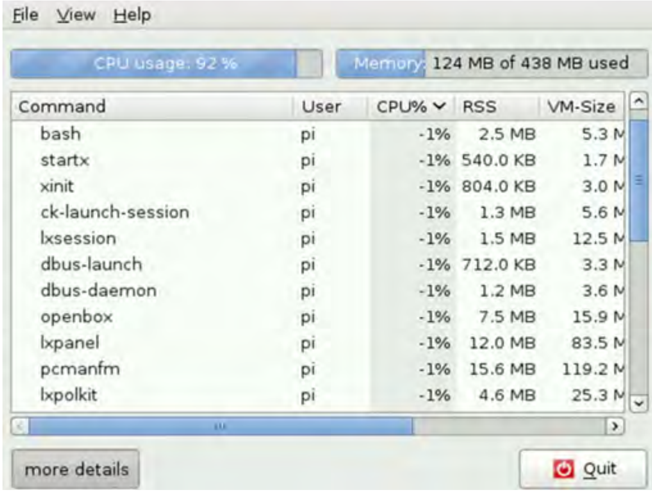


Fig.2.11. Raspbian's Task Manager

Emulating the Raspberry Pi in Windows

If you don't yet have a Raspberry Pi but would like to get a feel for using the system, you might like to know that you can emulate a Raspberry Pi on a Windows-based computer system. To do this you will need to download the qemu emulator from the Source Forge website by going to: **www.sourceforge.net/projects/rpiqemuwindows** and then selecting the zipped file, **qemu.zip**.

Having made a copy of the zipped file on your own computer you will need to extract the file to a suitable directory before unzipping it. After unzipping the file you need to click on 'run' to start the software. You might also find it convenient to create a shortcut on your desktop.

When you run the emulator for the first time you will be presented with a configuration screen to set various options using the arrow keys to move up and down and the enter or return key to select the options that you require. The tab key (above the caps lock key) will get you down to the two options at the bottom of the configuration screen. You will then be able to set the required options and finish.

After a short time a blank window will appear with the words raspberrypi login:. At the bottom of the screen you will need to type pi and hit enter. Next you will be asked for the password; at the prompt you should type raspberry followed once again by return or enter. This will bring you to the Debian command line. If you wish to set a new password you can type sudo passwd root followed by your choice of password. Note that you will need to do this twice in order to confirm your new choice. You should now be presented with a command line prompt – however, to change to a more friendly graphical environment you should enter the command startx.

It is important to note that, unless you have a fast PC, the emulator will often be significantly slower than a real Raspberry Pi. It will, however, allow you to experience the Raspberry Pi operating system and graphical user interface that we all know and love. Finally, if you need to release the emulator's 'mouse grab' so that you can regain control under Windows, you should hold down both the Ctrl and Alt keys momentarily.

Pi Project

Last month, *Pi Class* mentioned that to fulfil any useful function, a microprocessor system needs to have links with the outside world, and that these connections are provided by means of one or more programmable VLSI devices. Input/output (I/O) devices fall into two general categories; *parallel* (where one byte at a time is transferred along eight wires), or serial (where one bit is transferred after another along a single wire). This month, we will be delving a little deeper into this subject by looking at what constitutes an I/O port and how it needs to be configured under software control. We start with a look at the signals that are present on the Pi's GPIO connector.

Electrical characteristics of the GPIO

At this point, and before attempting to connect anything to the GPIO port, it is essential to be aware that the chip that drives the GPIO port can be very easily damaged by misconnection or the application of voltages outside the manufacturer's specified range. In particular, the voltage applied to the signal pins must never exceed +3.3V or fall below 0V. An inadvertent connection to the +5V rail must be avoided at all cost.

The digital signals present on the GPIO connector are normally quoted as:

- Low (or logic 0) represented by voltages 'near 0V'
- High (or logic 1) represented by voltages 'near +3.3V'

This definition can be a little problematic because both low and high states are actually represented by a range of voltages. However, what is more important is that any voltage outside the acceptable range (for example, a voltage level of +1.5V) is not misconstrued as representing either a low or high state. In practice, this means that the range of voltage between about +0.8V and +2.0V is indeterminate in terms of the logic state that it represents and thus needs to be avoided.

The acceptable range of signal voltage for the GPIO port is shown in Table 1. Thus, for example, an input voltage of +0.4V would be interpreted as a low (or logic 0) while an output voltage of +3.0V would be equivalent to a high (or logic 1) state.

Table 1: Safe I/O voltage ranges at the GPIO port

Characteristic	Typical
Input low voltage, V_{IL}	0V to +0.8V
Input high voltage, V_{IH}	+2.2V to +3.3V
Output low voltage, V_{OL}	0V to +0.6V
Output high voltage, V_{OH}	+2.4V to +3.3V

Output source current

The current sourced by the GPIO is derived from the Pi's +3.3V regulator (see Fig.1.8 of last month's *Teach-In 2014*). The 3.3V regulator is rated for a maximum continuous current drain of 50mA, and therefore the total current supplied by the GPIO signal pins must not be allowed to exceed this value. So, for example, it would be possible to source 8mA to each of five LEDs (total 40mA), but if eight devices were to be driven, then the current to be supplied to each individual LED would need to be reduced to no more than 6mA. This limitation of the 3.3V supply needs to be kept in mind when designing an interface board. Alternatively, it can often be advisable to use an external +3.3V power supply and use the Raspberry Pi's increased sink current capability (see next section).

Output sink current
The current that can be sunk by the GPIO is appreciably greater than that which can be sourced. Each of the Raspberry Pi's GPIO lines is capable of sinking a current of up to 16mA. Furthermore, provided that the 16mA maximum is observed, the total current limitation no longer applies.

Capacitive loads
So far we have assumed that the GPIO lines operate with purely resistive loads (eg, a series combination of a resistor and an LED). However, when driving a capacitive load there is a need to ensure that the transient current supplied to the capacitor does not exceed the source or sink current limitations mentioned earlier. This can be achieved by means of some additional series resistance to limit the capacitor's charging current. For example, a series resistance of 220Ω will limit the transient current to +3.3V/220Ω or about 15mA, regardless of the amount of capacitance present. Note that the additional resistance will tend to act as a low-pass filter and so this will impose a limit on the speed of operation, depending on the value of shunt (parallel) capacitance present in the load.

GPIO configuration
Note that many of the GPIO pins can be reconfigured to provide alternate functions, such as a simple serial interface for external devices compatible with the SPI or I2C interface standards. Following initialisation, the GPIO pins are placed in their default state and the GPIO channels become immediately available on the GPIO header (P1) for use as general purpose input or output lines.

Depending on the particular application that you are dealing with, the GPIO pins are extremely versatile and can be configured in a variety of different ways. We will be explaining how this is achieved in later instalments of *Teach-In 2014*, but for now we will simply be dealing with the default configuration that loads when the Raspberry Pi is initialised at boot time. Due to the versatility and sophistication of the Broadcom chip the GPIO port configuration is complex and so, at least for this part of *Teach-In 2014*, we will just restrict our investigation to the subset of GPIO signals, shown in Fig.2.12.

The GPIO library
The GPIO library module provides easy access to the features of the GPIO port from within your Python code. Before the library module can be used it needs to be imported using a statement of the form:

```
import RPi.GPIO as GPIO
```

The name of the file that we are going to import is `RPi.GPIO` and the '`as GPIO`' means that we can simply refer to the port as '`GPIO`' from that point onwards.

Note that if you don't have sufficient privileges the library import will fail and a run-time error will be generated. To overcome this problem you need to execute your Python script as a 'superuser', but you can set this privilege level by simply using `sudo` before the script name. For example, if your script has the name '`control.py`' you would execute it using the command:

```
sudo control.py
```

Next, we need to deal with another potential cause of confusion. When programming the GPIO port it is possible to refer to the signals in two different ways. We can either use the GPIO signal name or the name given by the manufacturers of the BCM chip. Fortunately, there is a solution to this problem since the GPIO library can be configured to use either of these two conventions.

The Python statement, `GPIO.setmode(GPIO.BOARD)`, sets the use of the Pi's board numbers, while `GPIO.setmode(GPIO.BCM)` sets the use of the Broadcom signal numbering.

To configure individual GPIO signals as inputs or outputs you can use the `GPIO.setup` command. For example `GPIO.setup(11, GPIO.IN)` sets GPIO channel 11 as an input based on the numbering system that you previously specified using the `GPIO.setmode` command. If this sounds a little complicated, here's a fragment of Python code that sets GPIO channel 17 as an input and GPIO channel 18 as an output using the BCM pin numbering convention:

```
import RPi.GPIO as GPIO
# use the BCM pin numbering
convention
GPIO.setmode(GPIO.BCM)
# setup channel 17 as an input
and 18 as an output
```

Understanding the Raspberry Pi's status LEDs

The Raspberry Pi provides a number of LEDs that provide you with information on the current status of the system. The LEDs are grouped together in one corner of the PCB and they flash periodically during normal operation of the system. The Model A version of the Raspberry Pi has two LED indicators, while the Model B has five (see Fig.2.14). The functions of the LEDs for Model B boards are shown in the table below:

Revision 1 labelling	Revision 2 labelling	Component reference	LED colour	Meaning
OK	ACT	D5	Green	SD card access
PWR	PWR	D6	Red	3.3V power good
FDX	FDX	D7	Green	Full-duplex LAN connected
LINK	LNK	D8	Green	Link/activity on the LAN
10M	100	D9	Yellow	100Mbit LAN connected

Table 2: Relationship between header pin numbers and the general purpose sub-set of BCM GPIO channels

GPIO header (P1) pin number	BCM channel number (Rev.0 boards)	BCM channel number (Rev.1 boards)
7	GPIO04	GPIO04
11	GPIO17	GPIO17
12	GPIO18	GPIO18
13	GPIO21	GPIO27
15	GPIO22	GPIO22
16	GPIO23	GPIO23
18	GPIO24	GPIO24
22	GPIO25	GPIO25

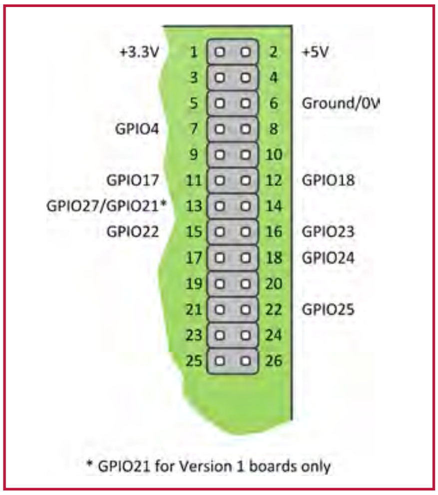


Fig.2.12. Subset of general purpose GPIO signals and their pin connections on the GPIO header (P1)

```
GPIO.setup(17, GPIO.IN)
GPIO.setup(18, GPIO.OUT)
```

Now here's some code that would have exactly the same effect, but using the Raspberry Pi board numbering. This code uses pin-11 of the GPIO header as an input and pin-12 as an output:

```
import RPi.GPIO as GPIO
# use the BCM pin numbering
convention
GPIO.setmode(GPIO.BOARD)
# set up the pin-11 as an input
and pin-12 as an output
GPIO.setup(11, GPIO.IN)
GPIO.setup(12, GPIO.OUT)
```

The relationship between the header pin-numbers for Rev.0 and Rev.1 boards and their corresponding general purpose BCM GPIO channels is shown in Table 2. Which method of configuring the GPIO via the `setmode` command you use is largely a matter of personal choice. There are advantages and disadvantages either way, but the BCM channel numbering is likely to be more future-proof in the possible scenario where the header pin numbers change in a future revision (note that there has been a change in some of

IDC connectors

The GPIO port lines on the Raspberry Pi are brought out to a 26-way header. This comprises two rows of 13 pins spaced 0.1" apart. The header is designed to be used with an insulation displacement (IDC) connector which uses a 26-way flat ribbon cable (see Fig.2.13). This greatly simplifies circuit construction and helps keep the wiring between the Raspberry Pi and any external boards neat and tidy.

The contact between the female cable socket and the conductors within the ribbon cable is made by 'displacing' (ie, piercing and pushing aside) the insulation so that an effective electrical connection is made between a tiny pair of jaws and the respective stranded copper wires inside the insulation provided by the ribbon cable.

Note that the pin numbering used by the Raspberry Pi foundation for the Pi's GPIO connector is a little unconventional, the even numbered pins are located along the board edge and this suggests that the ribbon cable should exit the header towards the centre of the printed circuit board rather than more neatly away from the board edge. Also note that on a conventional IDC connector, pin-1 is often marked with a triangular symbol and the corresponding conductor on the ribbon cable is marked with a red stripe (see Fig.2.13).

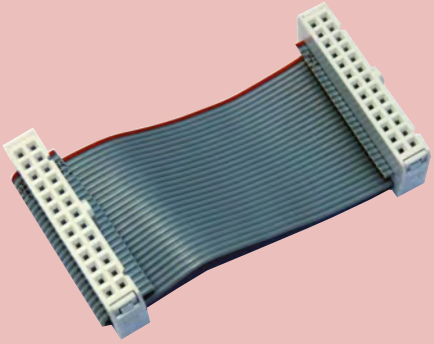


Fig.2.13. 26-way ribbon cable fitted with IDC connectors – note red stripe that indicates pin-1

Which version?

Since some of the GPIO connector's pin functions have changed between versions it is important to know which version you have. Of particular interest when dealing with the default chip configuration is that the signal carried on pin-13 of the GPIO connector was changed from GPIO21 in Version 1 of the board to GPIO27 in Version 2. Some other pin functions also changed between these two versions, but we will explain these when we start to use the Raspberry Pi in some of its other configuration settings. Fortunately, it seems unlikely that the GPIO connector will change in any subsequent versions of the Raspberry Pi, but it could be well worth checking if you do have a newer board version.

You can check your board version quite easily. A quick visual inspection of the board close to the LED status indicators will reveal several differences between Version 1 and Version 2, as shown in Fig.2.14. Note how the Version 1 board uses two 'zero ohm' resistors to replace the polyfuses used on earlier versions, and that these have been completely removed on the Version 2 board in order to make space for a mounting hole in the printed circuit board. The status LEDs have identical functions on the two boards, but are labelled slightly differently.

You can also check your board version by examining the CPU data stored in the system. To do this, use the `cat` command entered directly from the command prompt:

```
cat /proc/cpuinfo
```

This will display the board's revision number. A revision number of 0002 or 0003 will be displayed for a Version 1 board. Higher numbers correspond to Version 2, or later. As well as information on the processor, a typical response to the command might include the following lines:

```
Hardware      :  BCM2708
Revision      :  0003
```

This indicates that you are dealing with a Version 1 board. Note that if the revision number is preceded by 1000 then this will indicate that the processor has been over-clocked by raising its core-voltage – so, for example, the following indicates a Version 2 board that has been over-clocked (the over-clocked status is preserved in an internal write-once memory):

```
Hardware      :  BCM2708
Revision      :  10000004
```

The table on page 43 will help you to further identify a board and its manufacturer by means of its revision number. Note that the Model B Revision 2.0 board incorporates a number of changes (eg, removal of the poly-silicon fuses in series with the +5V power for USB devices), access to the 8-pin P5 header (non-populated) to provide additional GPIO pins, the addition of a 2-pin header (P6, non-populated) for a RESET button, and changes to some of the GPIO pin numbering (eg, pin-13 now becomes GPIO27 instead of GPIO21).

Fig.2.14. Differences between Version 1 (left) and Version 2 (right) boards can be easily detected by examining the status LEDs. Note also that the Version 2 (and later) boards are fitted with two mounting hole (missing from Version 1)

the pin functions between the Rev.0 and Rev.1 Raspberry Pi boards).

Reading and writing to the GPIO
Having configured the GPIO and having defined the pins/channels to be used for input and output it is very easy to read from and write to the port lines. As an example, after having configured the port for header pin-numbering (rather than BCM channels) the following fragment of code reads the state of pin-11 (with the result appearing as the input_value variable) before setting the output from pin-12 in the high state:

```
# input from pin 11
input_value  =  GPIO.
input(11)
# output to pin 12
GPIO.output(12, GPIO.HIGH)
```

Now here's the equivalent code based on the BCM channels:

```
# input from channel 17
input_value = GPIO.input(17)
# output to channel 18
GPIO.output(18, GPIO.HIGH)
```

Note that the state of a GPIO line can be described in different ways. `GPIO.LOW` can also be described as False or 0, while `GPIO.HIGH` can also be described as 1 or True. For example, all three of the following lines of code have exactly the same effect:

```
GPIO.output(18, GPIO.HIGH)
GPIO.output(18, GPIO.1)
GPIO.output(18, GPIO.True)
```

Cleaning up
At the end any program, and before the program makes an exit back to the operating system, it is good practice to clean up by setting the mode of all of the I/O channels to their default input state. This could help prevent damage if any of the I/O lines should become inadvertently short-circuited and can be very easily achieved by adding `GPIO.cleanup()` to the end of your Python code.

Finally the following lines of code will tell you the board revision and GPIO version of a particular Raspberry Pi:

```
# obtain the board's revision
status
GPIO.RPI_REVISION
# obtain the RPi.GPIO version
GPIO.VERSION
```

Simple GPIO interface projects
Having provided you with a brief introduction to the GPIO, it's time to move on and put this into context with some simple interfacing projects using switches, LEDs and transistors. All four of the following circuits can be assembled on a breadboard (available from several

How to identify your board version

Revision	Approximate release date	Model	PCB revision number	Memory fitted	Notes
Beta	Q1 2012	B	–	256MB	The original 'Beta' board
0002	Q1 2012	B	1.0	256MB	First Model B
0003	Q3 2012	B	1.0	256MB	Polysilicon fuses and D14 removed
0004	Q3 2012	B	2.0	256MB	Manufactured by Sony
0005	Q4 2012	B	2.0	256MB	Manufactured by Qisda
0006	Q4 2012	B	2.0	256MB	Manufactured by Egoman
0007	Q1 2013	A	2.0	256MB	Manufactured by Egoman
0008	Q1 2013	A	2.0	256MB	Manufactured by Sony
0009	Q1 2013	A	2.0	256MB	Manufactured by Qisda
000d	Q4 2012	B	2.0	512MB	Manufactured by Egoman
000e	Q4 2012	B	2.0	512MB	Manufactured by Sony
000f	Q4 2012	B	2.0	512MB	Manufactured by Qisda

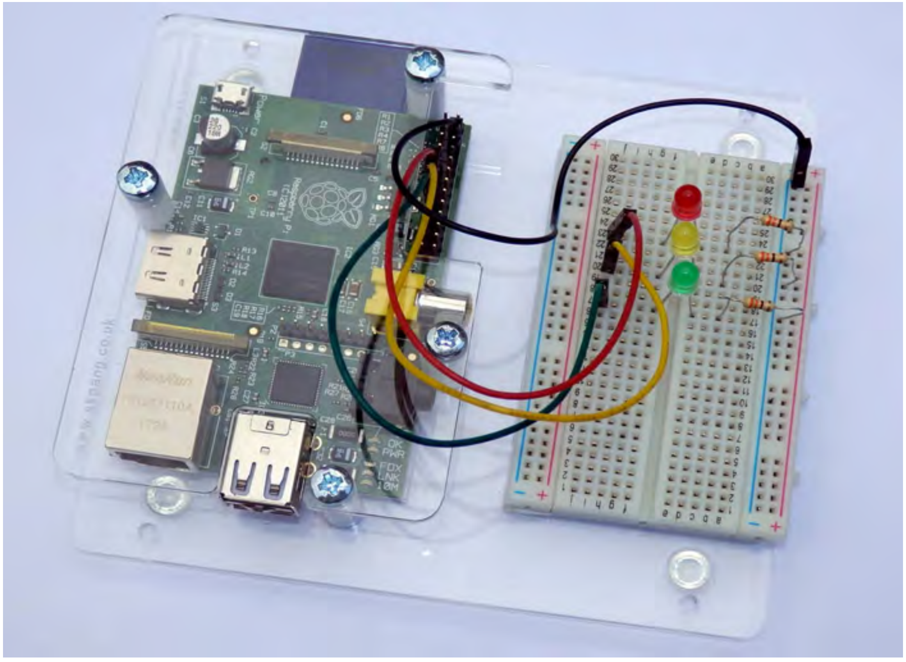
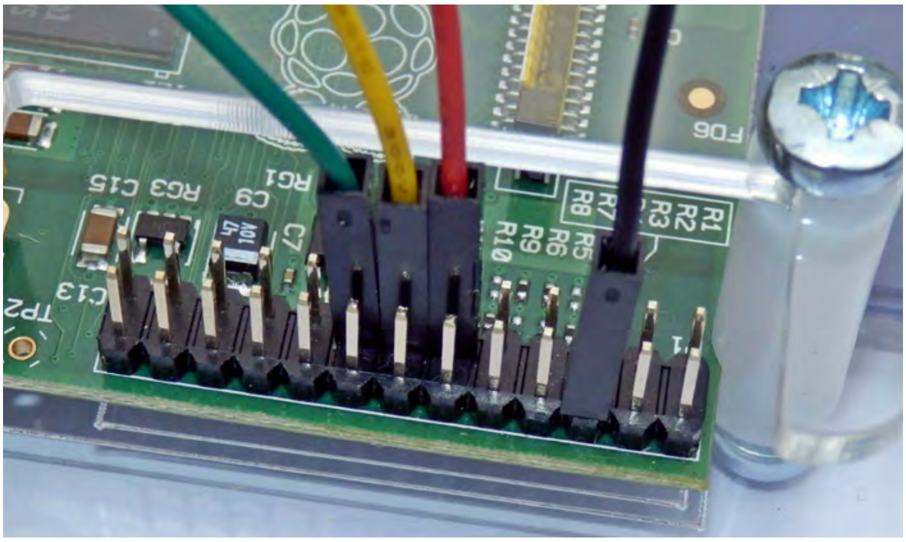


Fig.2.15. Simple interfacing projects and experiments can be based on a small breadboard placed adjacent to your Raspberry Pi

Fig.2.16. Use of coloured jumper wires to link the GPIO connector to the breadboard



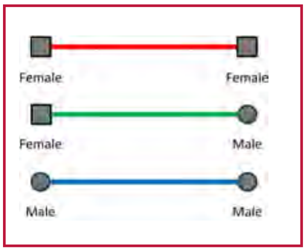


Fig.2.17. Convention used in Teach-In 2014 to indicate the gender of breadboard jumper wires

suppliers) positioned alongside your Raspberry Pi, as shown in Fig.2.15. Connections from the Pi to the breadboard can be made with the use of coloured jumper wires, see Fig.2.16. Note that we have adopted the convention shown in Fig.2.17 in order to identify the gender (ie, male-male, male-female, female-female) of the jumper wires. Packs of coloured jumpers of various lengths are also available from many Pi suppliers at reasonable cost.

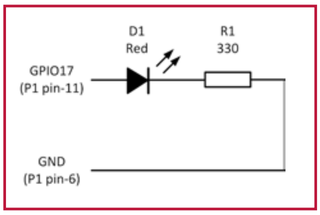


Fig.2.18. Flashing LED interface circuit

Flashing a single LED

For our first taste of using the Raspberry Pi's GPIO we will use just one of the GPIO port lines (GPIO4 on pin-7 of the GPIO connector) configured as an output to flash an LED using the arrangement shown in Fig.2.18 and Fig.2.19. The fixed resistor limits the current that we will supply to the LED to around 5mA. This is well within the limitations of the GPIO port (see earlier) and should provide a reasonably bright output from the LED.

When you've finished the breadboard circuit (it shouldn't take too long), start your Raspberry Pi in the normal way and use `startx` to begin a session with the GUI. Next, start the Python shell program by clicking on the IDLE icon. When the shell program has been initialised you will be presented with the usual >>> prompt. Now enter the following Python code as one long string of text:

```
import RPi.GPIO as GPIO
import time
GPIO.setmode(GPIO.BOARD)
GPIO.setup(11, GPIO.OUT)

while True:
    GPIO.output(11, True)
    time.sleep(2)
    GPIO.output(11, False)
    time.sleep(2)
```

In order to exit the program (and return control to the user) you should briefly press the `Ctrl` and `C` keys at the same time.

Next, here's a program that does exactly the same thing but uses the BCM channel numbers rather than the GPIO pin outs:

```
import RPi.GPIO as GPIO
import time
GPIO.setmode(GPIO.BCM)
GPIO.setup(11, GPIO.OUT)

while True:
    GPIO.output(17, True)
    time.sleep(2)
    GPIO.output(17, False)
    time.sleep(2)
```

Once again, pressing the `Ctrl` and `C` keys at the same time will stop the program and allow you to regain control of the Pi.

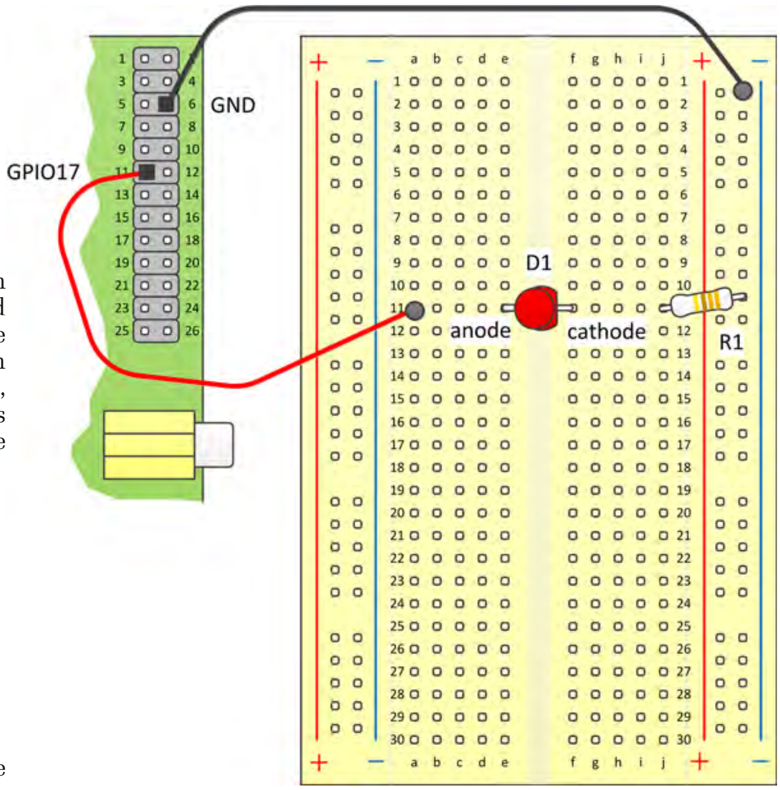


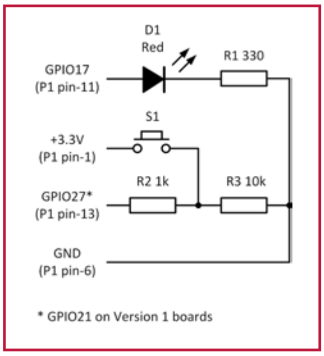
Fig.2.19. Flashing LED interface breadboard layout

Controlling an LED with a switch

Now for something just a little more complicated. Let's connect a switch as an input that can be used to operate the LED in the previous example. The circuit and revised breadboard wiring are shown in Fig.2.20 and Fig.2.21 respectively, *but do make sure that you power down the Raspberry Pi* before dismantling the previous circuit.

In this arrangement we will be using GPIO17 (pin-11 of the GPIO connector) as an output and GPIO27 (pin-13 of the GPIO connector) as an input (note that if you are using a Version 1 board the signal at pin-13 will actually be GPIO21 – as discussed earlier.). Also note the use of a 10kΩ pull-down resistor, R2, and a 1kΩ input current-limiting resistor, R3. This

Fig.2.20. Switched LED circuit



latter component ensures that the input current can never exceed 3.3mA under any circumstances. The switch, S1, can be any miniature push-button with a 'push to make' action.

Once again, start your Raspberry Pi in the normal way and use `startx` to begin a session with the GUI, then start the Python shell program by clicking on the IDLE icon. When the shell program has been initialised you will be presented with the usual >>> prompt. Now enter the following Python code as one long string of text:

```
import RPi.GPIO as GPIO
import time

# Configure GPIO
GPIO.setmode(GPIO.BOARD)
GPIO.setup(11, GPIO.OUT)  # LED as output
GPIO.setup(13, GPIO.IN)   # Switch as input

while True:
    # Read switch status
```

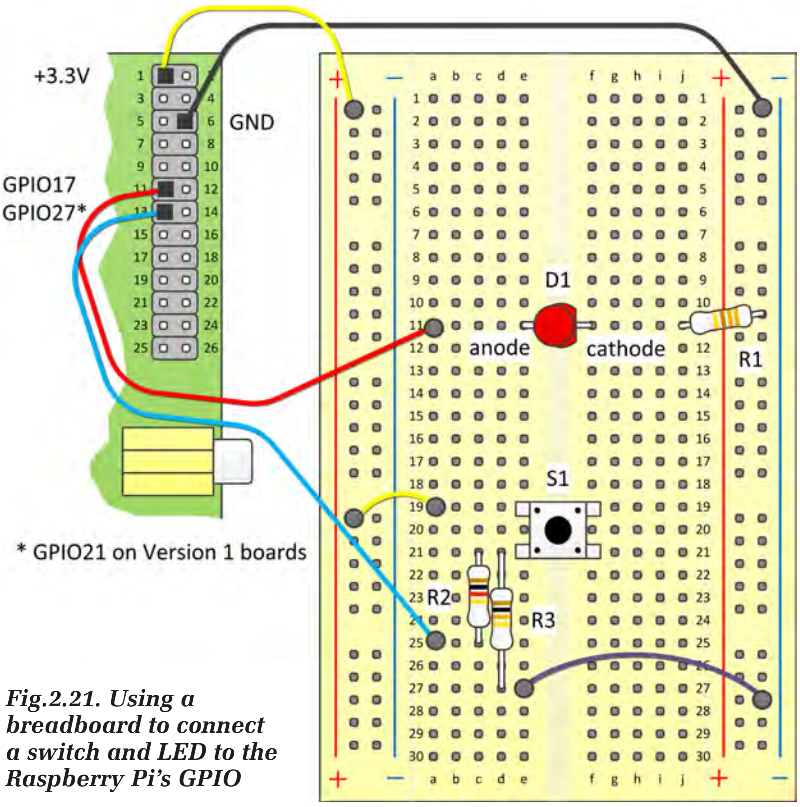


Fig.2.21. Using a breadboard to connect a switch and LED to the Raspberry Pi's GPIO

```
switch_state = GPIO.input(13)
if switch_state:
    # Switch contacts closed
    GPIO.output(11, True)
else:
    # Switch contacts closed
    GPIO.output(11, False)
```

Once again, you will need to briefly press the `Ctrl` and `C` keys at the same time to exit.

Raspberry Pi traffic lights

Our third example takes the form of a simple traffic lights display. The circuit and breadboard wiring is shown in Fig.2.22 and Fig.2.23 respectively. As before, make sure that you power down the Raspberry Pi before making any connections to the board.

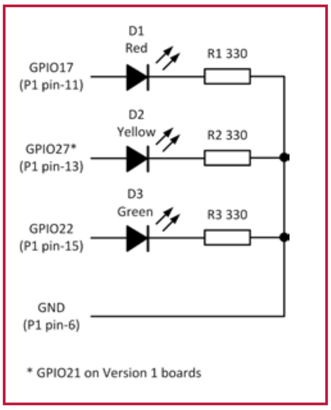


Fig.2.22. Traffic lights interface circuit

```
import RPi.GPIO as GPIO
import time

# Configure GPIO
GPIO.setmode(GPIO.BOARD)
GPIO.setup(11, GPIO.OUT)  # Red LED
GPIO.setup(13, GPIO.OUT)  # Amber LED
GPIO.setup(15, GPIO.OUT)  # Green LED

while True:
    # Red ON; Green and Amber OFF
    GPIO.output(11, True)
    GPIO.output(13, False)
    GPIO.output(15, False)
    time.sleep(10) # Wait 10 seconds
    # Red and Amber ON; Green OFF
    GPIO.output(11, True)
    GPIO.output(13, True)
    GPIO.output(15, False)
    time.sleep(5)   # Wait 5 seconds
    # Green ON; Red and Amber OFF
    GPIO.output(11, False)
    GPIO.output(13, False)
    GPIO.output(15, True)
    time.sleep(10)  # Wait 10 seconds
    # Amber ON; Red and Green OFF
    GPIO.output(11, False)
    GPIO.output(13, True)
    GPIO.output(15, False)
    time.sleep(5)   # Wait 5 seconds
```

Raspberry Pi count-down timer

Our fourth example takes the form of a count-down timer. The circuit and breadboard wiring is shown in Fig.2.24 and Fig.2.25 respectively. In this circuit we have used an NPN transistor (TR1) to provide sufficient current to drive a small audible transducer (BZ1). This component should be rated for operation from a nominal 5V supply and, because of this, we will use the +5V GPIO connection (pin-2 of P1 as shown earlier in Fig.2.12). As always, make sure that you power down the Raspberry Pi before making any connections to the board and take extra care as you will be using the +5V supply this time.

```
import RPi.GPIO as GPIO
import time

# Configure GPIO
GPIO.setmode(GPIO.BOARD)
GPIO.setup(11, GPIO.OUT)
while True:
    # Reset the alarm signal
    GPIO.output(11, False)
   delay = raw_input('Enter delay in seconds: ')
    confirm = raw_input('Press Enter to start
timing ....')
    print('*** Timing started - please wait!
***')
```

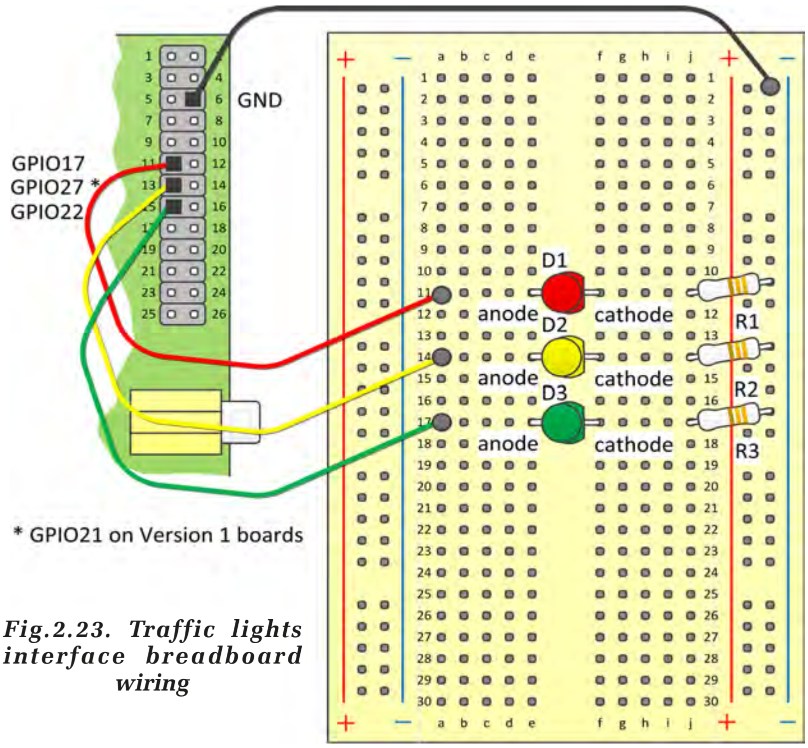


Fig.2.23. Traffic lights interface breadboard wiring

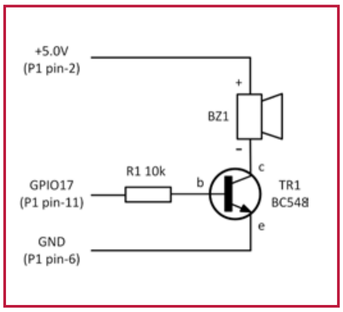


Fig.2.24. Count-down timer interface circuit

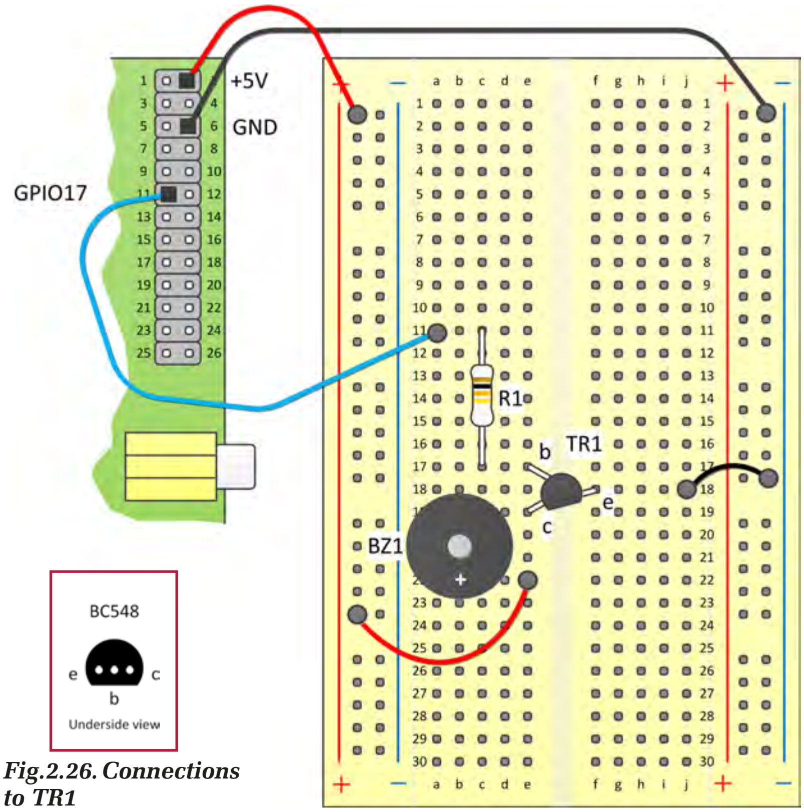


Fig.2.26. Connections to TR1

Fig.2.25. Count-down timer breadboard wiring

```
    # Start the delay
    time.sleep(float(delay))
    # Delay ended so sound the alarm signal
    GPIO.output(11, True)
    confirm = raw_input('Alarm sounding - press
Enter to cancel ....')
    print('*** Alarm cancelled! ***')
```

Note that if you are using a later version of Python you may need to change the three instances of `raw_input()` in the previous program to `input()`. This change is required in order to overcome one of the more significant changes that occurred when version 2.x of Python became version 3.x. When running from a terminal (rather than from within IDLE) `input()` will usually generate a parsing error because it is uncertain as to what type of variable it is dealing with. When using `raw_input` all entered values are assumed to be string variables.

More projects

The four interfacing projects that we've just described can all be very easily extended and modified. For example, the traffic-lights can be easily turned into a two-way set of lights by simply adding three more LEDs (one red, one amber and one green) together with three more resistors and extending the code accordingly. A good starting point would be sketch out a table showing the state of all six of the lights as they move through a complete cycle before attempting to modify the code. You will need to use three more GPIO lines (remember that you will need to configure them as outputs) and assign each of these to a corresponding LED on the second set of lights. Why not send in your ideas to *EPE* so that we can publish the best of them?

Python Quickstart

Last month, we looked at how to input a numeric value to use as a variable within a Python program and we finished with a program to print the date. This month, we shall be looking at how to implement a block of repeated code (known as a *loop*). Many simple programs involve repeatedly executing a series of commands and so loops can save a great deal of typing. Python offers us two types of loop construct, the `for` loop and the `while` loop. We shall briefly look at each of them.

For loops

One of easiest ways of repeating a block of program statements is with the aid of a for loop, as the following example shows:

```
# Example of a simple for loop
for x in range(1, 5):
    print (x)
```

As you might expect, this simply prints a list of numbers, as shown below:

```
0
1
2
3
4
```

Note that in this example the variable `x` takes values from 1 to 5, but the last value is not printed because Python considers it to be outside the range). Now for another example of using a `for` loop. This time we will count the number of items in a list:

```
# Loop to print a numbered list sensors
in a fire alarm system
sensor_list = ['kitchen', 'hall',
'stairs', 'landing']
index = 1
print('Sensor list:')
for location in sensor_list:
    print(index, location)
    index += 1
```

Note that `index +=1` is a neater way of saying `index = index + 1`. Following execution of the module the following information is displayed:

```
Sensor list:
1 kitchen
2 hall
3 stairs
4 landing
```

Wait loops

Here is an example of a `wait` loop that provides the same result as the simple `for` loop that we met earlier:

```
# Example of a simple wait loop
count = 0
while count < 5:
    print (count)
    count +=1
```

Note that each time round the loop the `count` variable is incremented and that the `while` loop is executed as long as the value of `count` is less than 5. When count reaches 5, program execution moves on to the next statement following the `while` construct.

Next, here's an example of a `wait` loop in the form of a password-checking module. Note that the password is unencrypted in the source code and so this routine cannot be considered to be very secure.

```
# Wait loop to check a password
before continuing
# First we need a dummy value
before entering the loop
password = "dummy_password"
# Wait for the correct password
to be entered
while password != "phantom":
      password = input("Enter
password: ")
# Now we can carry on with the
rest of the program
print ("Welcome - please select
an option: ")
```

In order to exit the password module without having to enter a password you can simply use the `Ctrl-C` combination, which will abandon program execution and return you to the command line. Here is some typical output from the module:

```
Enter password: ghost
Enter password: canary
Enter password: phantom
Welcome - please select an
option:
```

Hopefully you have spotted that, in the password routine we need to go back round the loop whenever the user enters a word that is *not* the password. We did this with the aid of a *comparison operator* – in this case we have used `!=` meaning 'not equal'.

Python provides us with several other comparison operators, as shown in the table below:

Table 3: Comparison operators

Comparison operator	Meaning
==	equal
!=	not equal
<	less than
>	greater than
<=	less than or equal
>=	greater than or equal

Finally, note that the examples that we've just described (and those given throughout this *Teach-In* series have been written using Python 3.3. Some minor modification may be needed if you are using an earlier version of Python.

Home Baking

In this month's edition of *Pi Class* we looked at the software that comes with the current standard build of Raspbian. However, what if you want to install some new software, and how do you keep your software up to date? We'll be answering these questions in this month's *Home Baking.*

Raspbian uses a really clever system for ensuring that applications, libraries and system files are kept up to date. The system called is the *Advanced Package Tool* or `apt` for short. Put very simply, a great big database of all of the versions of all of the available program packages (both operating system and additional applications) is held centrally on the web. Your Pi can then download the latest version of this database and use it to compare the versions of the items that it has installed. If it finds that a newer version is available it will then download and install the latest version straight from the web. You can also search the database to find packages to install. It's a really simple but ingenious concept; let's show you how it's done:

The first thing to do before using `apt` is to ensure that you have Internet connection. Now we can update our local cached version of the packages database; start a new terminal session by launching LXTerminal and enter the command:

```
sudo apt-get update
```

This command doesn't actually action any updates, it merely updates the package database itself before you use it for updating later. Always remember to do this before the following steps.

Updating your software

To update our operating system and installed packages there are two commands that are commonly used, although there is a key difference between the two as we'll explain below.

```
sudo apt-get upgrade
```

This will compare current packages to the database and download and install newer versions if they exist in order to update them. It does not remove any items or make any other changes.

```
sudo apt-get dist-upgrade
```

This command does a little more than the latter. Not only will it look for newer versions of the current packages, but it will also cleverly handle the dependencies (the other packages or libraries that packages may rely on to run) on your system. For example, when packages are updated, their dependencies may change. `dist-upgrade` will look for and remove any items that are no longer required by any packages or if dependent items are not found, it will try and download and install them. It basically updates, de-clutters and checks your system files/packages. It's obviously more involved than the standard upgrade and consequently will take longer. This is probably the best command to use regularly to keep you system up to date and working efficiently.

Finding and installing new software:

There are literally thousands of free programs available for you to install on your Raspberry Pi. The process of locating and installing an application is shown below in our example where we are going to find and install a simple card game based on the classic Windows game 'Hearts', which many of our readers will remember. Make sure that you've updated your `apt` database cache first, as described earier. This contains a listing of all of the packages available that we can then search using the following command:

```
apt-cache search hearts
```

This will return any packages that match our search term of 'hearts'. You can obviously use any term to try and locate the type of software that you require. The search results will then be shown on screen as shown in Fig.2.28 (it can take a few moments for it to search the whole database). Each line shows the package name and a short description. The software that we are going to install in this case is called 'gnome-hearts'. To action the install enter:

```
sudo apt-get install gnome-
hearts
```

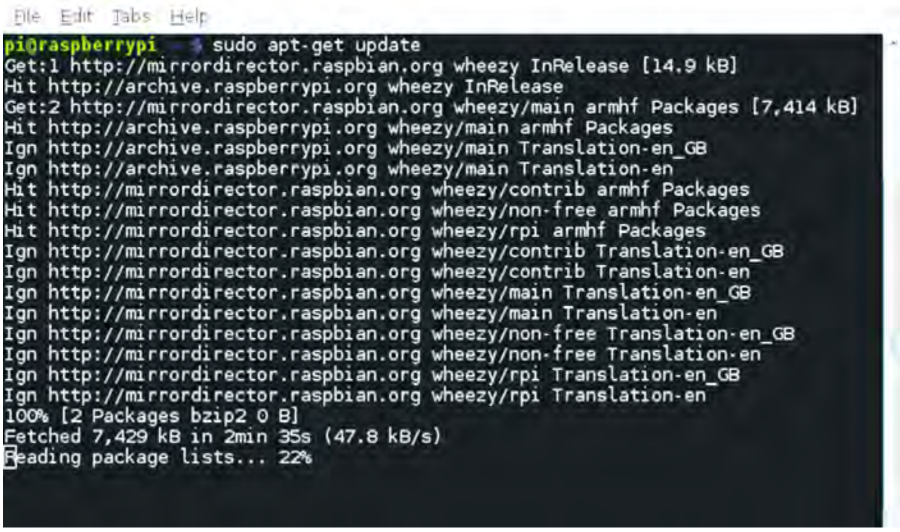


Fig.2.27. Downloading the latest package database using apt-get update

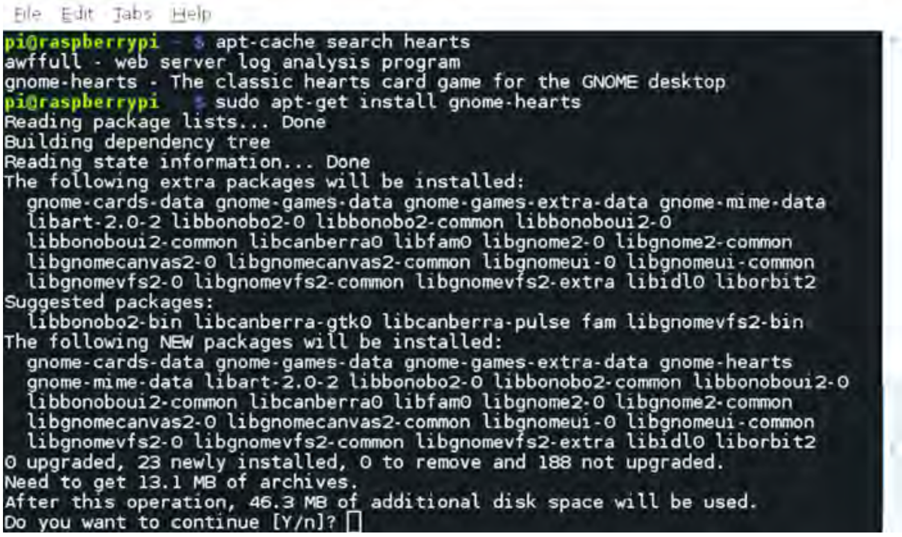


Fig.2.28. Search results for 'hearts'

Fig.2.29. Gnome-hearts in play

You will be asked to confirm the install before it downloads and installs the package and any required dependencies. Once installed, we can run the program using the command:

```
gnome-hearts
```

Tip: there are various websites that provide a catalogue of the packages available via `apt-get` with full descriptions so you can decide on what to install.

Uninstalling software

`apt` can also easily uninstall a piece of software. For example, to remove the Gnome Hearts game that we installed earlier use the command:

```
sudo apt-get remove gnome-hearts
```

Note that this will only remove the main package and not any dependent libraries that may no longer be required. To remove the main package or any otherwise orphaned libraries you can use the alternative command:

```
sudo apt-get autoremove gnome-hearts
```

It is also possible to remove orphaned libraries (those no longer used by any applications) by running the command:

```
sudo apt-get autoremove
```

You can find out more about the `apt` command at:
http://wiki.debian.com/Apt

In next month's Teach-In with Raspberry Pi

Next month's *Teach-In 2014* will delve further into the practical aspects of connecting the Raspberry Pi to the real world and we will be constructing a simple 8-channel high-current output driver that you can use to interface relays, actuators and motors. *Perfect Python* will show you how to define your own functions and make effective use them in your code. Finally, in *Pi World* we will have some suggestions for further reading.

READOUT

Matt Pulzer addresses some of the general points readers have raised. Have you anything interesting to say?

Drop us a line!

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All letters quoted here have previously been replied to directly

Email: editorial@wimborne.co.uk

☆ LETTER OF THE MONTH ☆

Fibre broadband troubleshooting

Dear editor
You might in interested to hear about my experience with having fibre broadband installed.

I previously used ADSL with two wired telephones. The upgrade to fibre went fine. However, there occurred a problem with DSL dropping whenever a telephone handset was either picked up or replaced. To cut a very long story short, it transpired that the powered phones I use were causing line interference ('rain') which was affecting the fibre broadband signal.

Unpowered phones work properly. The cure for the problem caused by the powered phones was to re-install the old ADSL telephone filters. With them back in place, everything then worked well.

According to BT you shouldn't need to install these filters with fibre, as the fibre data socket has a filter installed. However, practical experience indicates that with powered phones they may still be needed with fibre broadband.

John Taylor, by email

Matt Pulzer replies:

Thanks John, a useful tip for anyone about to upgrade to fibre broadband from ADSL.

Green member

Dear editor
I read with interest John Pugh's article about an electronic version of *EPE*. I mirror John's history, apart from the PIC aspects, but am trying to get to grips with Raspberry Pi, mainly because schools use it a lot.

I've been a 'Green Member' of *Elektor* since the electronic version of their magazine was launched, and receive the downloads weekly and monthly. My personal feelings are that there is a problem with what to do with old magazines, but reading and 'using' a paper magazine, especially during the construction of a project has no equal, where else can you flick the solder residue?

I will not be subscribing to *Elektor's* electronic version after my current subscription expires. My preferred compromise would be to purchase a CD-ROM of the 12 editions for archiving, and then perhaps retain just specific editions. The cost of producing paper magazines has to be weighed against the 'creation' of the electronic version, which according to one publisher: 'there is little difference between the two'.

So what to do? Keep up the good work, paper or otherwise.

Mike Baker, by email

Matt Pulzer replies:

Thank you Mike
I suspect there is no single solution that would keep everyone happy, but we will certainly continue with paper – as you say it really has no equal!

I hope you are enjoying our Raspberry Pi Teach-In series.

Give PICs a chance!

Dear editor
I am building the *Micro Pic Scope* from April 2000. I know this is an old project, but due to an accident that left me handicapped, I am revisiting an old hobby – electronics – and decided to give 'PICs a chance'. I am a beginner, but I've have managed to complete a few other PIC-based projects.

Unfortunately, with this project I made the mistake of making the PCB, getting all components and then doing the PIC burning last (since I was happy in the knowledge that I had the source code (or ASM) for the project, which I downloaded from your website). The problem is I get all kinds of error messages and I can't build the hex.file.

Are there any tricks to compiling the ASM, are you able to supply the hex.file?

Can you help? I would appreciate staying with the original PIC, a 16F876A.

Dan Bendeke, by email

Matt Pulzer replies:

Hi Dan
I am sorry to hear about your accident, but pleased that you have chosen to revisit electronics. I do hope it proves to be rewarding.

A project from April 2000 is really going back some. Alan Winstanley looks after our legacy software for projects, and he may be able to help. I do recommend you ask on EPE*'s lively forum,* Chat Zone*:* **www.chatzones.co.uk/cgi-bin/discus/discus.cgi**

We have many active and enthusiastic contributors to CZ who often go out of their way to help fellow builders, and there may be someone who has built this project and has the code you need.

I wish I could be more helpful, but for such an old project I am limited in the help I can offer.

Best of luck to you and I wish you success in hunting down the code

Just as we went to press we have had a positive follow up from Dan:

Just wanted to let you know I worked it out. Apparently you can't use MPASMWIN from Microchip (which I thought was standard).

EPE has a toolkit, TK3, which allows you to do the compilation. I downloaded this toolkit from your FTP site and the problem was solved.

Capacitor accuracy

Dear editor
I've just built the *Low Capacitance Adapter* for DMMs (*EPE*, January 2013 p.30) using the Jaycar kit. Here's a hint for other builders.

First, I set the calibration oscillator frequency on the 'scope (bought from an *EPE* advertiser!). However, I couldn't null the zero-capacitance value with VC1. You can't know whether to add or subtract the offset from the true reading.

This was a surprising case of inadequate stray capacitance. To the rescue was a ham radio trick, two short pieces of solid-core insulated wire were added, one soldered to each unknown-capacitor terminal, then twisted together to bring the null adjustment into range (this is sometimes called a ‘gimmick’ capacitor). Once nulled, hand capacitance across the terminals is just enough to show a reading on the meter.

Calibration is now within the stated tolerance of a selection of silver mica capacitors.

Godfrey Manning G4GLM, Edgware

Matt Pulzer replies:

Nice trick Godfrey, and I’m pleased to hear you achieved ‘silver mica capacitor accuracy’

Historic PSU

Dear editor

I’m looking for information on the project *MOSFET Variable Bench Power Supply*, by Mark Stuart, published in the April 1994 issue of *EPE*. Component CSR1 has no number. Is it CSR or SCR? Is there any additional info available on this project. After all these years I still want to make one.

Aubrey Jaftha, via email

Matt Pulzer replies:

Unfortunately my collection of EPE *only goes back to 1995 so I cannot advise you immediately. I have asked Wimborne if they can send me a copy of the relevant article, but it might take some finding.*

Given that it is a power supply project, I would imagine that ‘CSR’ is a misprint for ‘SCR’ – ie, a silicon-controlled rectifier, aka a thyristor. It might be part of a ‘crowbar’ protection circuit on the output.

In the meantime, I would like to suggest three things:

1) If this is definitely the project for you, for whatever reason, then ask around on our forum, Chat Zone*:* **www.chatzones.co.uk**

We have many long-standing readers, and one or two of them may be able to offer specific guidance on this particular project.

2) Please do not start the project until you are certain all parts are available. After nearly 20 years it is more than possible that a crucial part may be obsolete and/or no longer for sale.

3) If you simply want to make a power supply, then do feel free to give me some idea of the specification you are after and I may be able to suggest a more up-to-date project. For example, last year we ran a dual-tracking PSU with LCD display and the following specification:

Output voltage ±0-19V or +0-38V
Output current Up to 1.6A
Load regulation 0.1% (0-1A) 0.1% (0-500mA)
Line regulation (230V ±10%) 0.2%
Noise (0-1A) <525µV peak-to-peak
Ripple (0-1A) <1mV RMS, <1.7mV peak-to-peak
Display options: + Voltage, – Voltage, + Current, – Current, Total Voltage, Current Limit
Voltage reading accuracy typically <1%
Current reading accuracy typically <2.5% ±10mA

Also, in May this year, we had a nice project – Cheap, High-Current Bench Supplies *– that recycles a PC PSU*

Pinout

Dear editor,

I recently ordered a copy of a breadboard project for the *Bat Detector* (*EPE*, March 2009, p.48). During the process of putting this together I was unable to match one of the component’s pin design with the component layout. I wondered if you or one of the technical staff could help me resolve this issue.

I bought a BC108 NPN transistor and according to the data sheet the emitter and collector pins are reversed compared to the arrangement seen in Fig 6.2. Maybe I have the wrong component, but any help sorting this out would be much appreciated.

Barry Timms, by email

Matt Pulzer replies:

Thanks for your email. I agree it is not the clearest diagram – in fact, it is wrong and you are correct.

All is not lost though – inset TR1 with the emitter and collector as shown in Fig.6.2, but with the transistor tab pointing ‘NW’ as opposed to ‘SW’ and connect the base between the collector and emitter, leaving a connection point for R1.

Sorry for the confusion – and very well spotted!

Practically Speaking

Robert Penfold looks at the Techniques of Actually Doing it!

PCB soldering basics

BUILDING the circuit board is probably a fairly routine matter for those with plenty of experience at electronic project construction. They know from past experience how to deal with any problems that may occur, and perhaps more importantly, how to avoid most problems in the first place. Modern electronics involves the use of components that come in a vast assortment of shapes and sizes, and there will almost certainly be the occasional awkward component to deal with. The 'mega' projects that were much in evidence some years ago are now relatively scarce, but there might be the occasional project that requires a bit more attention due to the large number of components involved. Apart from the occasional 'outsize' project, building the circuit board is probably the easy bit as far as most 'old hands' are concerned.

The situation is rather the opposite for complete beginners, who will be taking a step into the unknown, and will probably approach the task with a certain amount of trepidation. Some DIY tasks can be a bit off-putting due to the sheer scale involved, and in a sense this can be the case when building a modern circuit board. It is more a lack of size that is the problem though, and there are typically a few dozen tiny components to be fitted onto a printed circuit board about the size of one or two credit cards. It is a very different world to the one of normal DIY activities such as fitting shelves, putting together pack flat furniture or building a conservatory!

It would definitely be misleading to say that 'there is nothing to it', but as is the case with most creative hobbies, once you have mastered a few skills it becomes much easier to build circuit boards. You might struggle a bit at first, but there is every chance that your first few circuit boards will work perfectly first time, provided you go about the job in a painstaking fashion. As with practically any creative task, rushing in without any real preparation or forethought more or less guarantees that there will be problems.

Board decision

A printed circuit board consists of a piece of thin board made from an insulating material. In its most basic form there are copper pads and tracks on one side of the board, with a small hole drilled through the board at the centre of each pad. Components are mounted on the plain (non-copper) side of the board with their leads or pins fitted through the appropriate holes. The leads are trimmed using a pair of miniature wire cutters, and then the pins and leads are soldered to the copper pads. The copper tracks provide the connections between the components.

There are variations on this basic scheme of things, such as double-sided boards that have tracks on both sides of the board and connections taken through the board from one side to the other. There are also surface-mount boards that do not have holes for component leads and pins. Instead, special surface-mount components are used, and these are soldered direct to the pads on the copper side of the board. There are also double-sided surface-mount boards.

Stripboard is a further variation and this is basically just a conventional single-sided board that has a matrix of small holes with copper strips running along rows of holes on one side of the board. Unlike a custom printed circuit board, stripboard can be used to construct practically any circuit. Initially it is best to choose projects that use custom single or double-sided board of the conventional variety. Until you have gained some experience at constructing circuit boards it is definitely a good idea to avoid surface-mount boards and the difficulties associated with them.

Right first time

You should not underestimate the importance of getting it right first time when building a circuit board. It is possible to correct mistakes, but even with the simplest of errors this runs the risk of damaging some of the components or even the board itself. Before soldering any component in place make quite sure that it is the right component, it is in the correct position on the circuit board, and where appropriate, that it is fitted the right way round. If you are unsure about something, find the right answer before fitting the component, and do not take a guess-and-hope approach.

With a component that has two leads, such as a resistor or capacitor, correcting mistakes is relatively easy. Provided you do the job carefully, the risk of damaging something is quite low. The situation is very different with components that have a number of pins, such as integrated circuits. Where possible, multi-pin components such as integrated circuits should be fitted via holders rather than soldering them direct to the board. This eliminates the risk of them becoming overheated when they are fitted to the board, because they are simply plugged into place on the holder. It also means that there is no need to desolder numerous

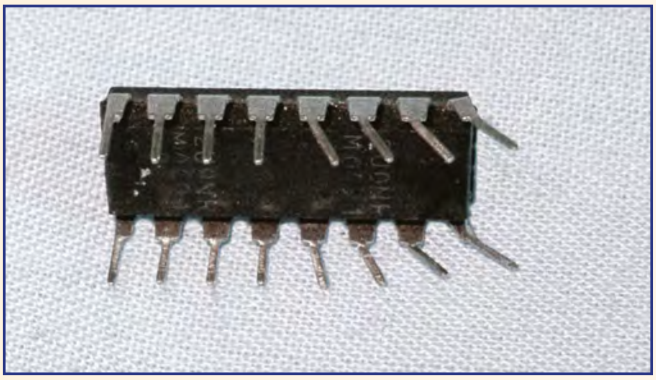


Fig.1. Wrenching an integrated circuit from its holder can easily bend some of the pins, as in this example. They can be bent back into position, but might break off in the process

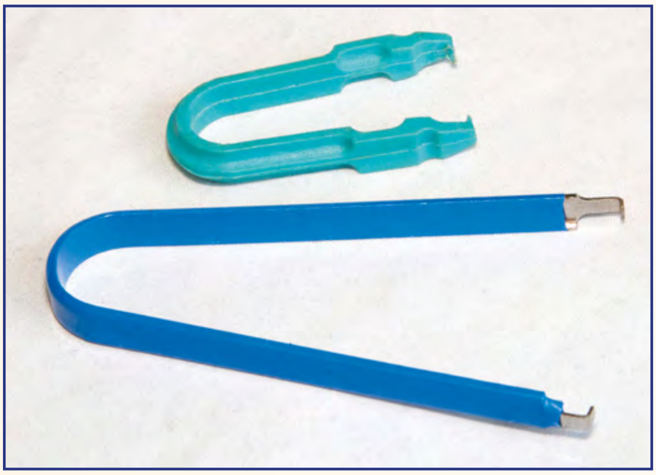


Fig.2. Special tweezers such as these make it easier to remove integrated circuits from their holders without damaging the pins. The job still has to be done carefully though

pins if the component is fitted the wrong way round. It just has to be unplugged and refitted correctly.

Removing an integrated circuit from its holder is actually a bit tricky, especially with the larger types. They tend to pull free at one end first, resulting in the pins at the other end becoming bent (Fig.1). Usually the pins can be carefully straightened, but with this type of thing there is always a risk of one or two pins breaking off. There are integrated circuit removal tools that eliminate, or greatly reduce, the likelihood of problems, such as the special tweezers shown in Fig.2. Alternatively, use the blade of a small screwdriver to prise one end of the device upwards by a millimetre or two, then do the same at the other end, and then repeat this process two or three times until the device comes away from its socket.

Avoiding problems

Many errors can be detected and corrected while building the board. Experienced project builders have been there before and know what to look out for, but matters are less clear for beginners. What errors should you look for while constructing circuit boards? Printed circuit boards have become more intricate over the years, with modern boards tending to have masses of tightly packed copper tracks and pads. In the case of stripboard, the nature of the product dictates that the tracks have to run very close to one another for their full lengths.

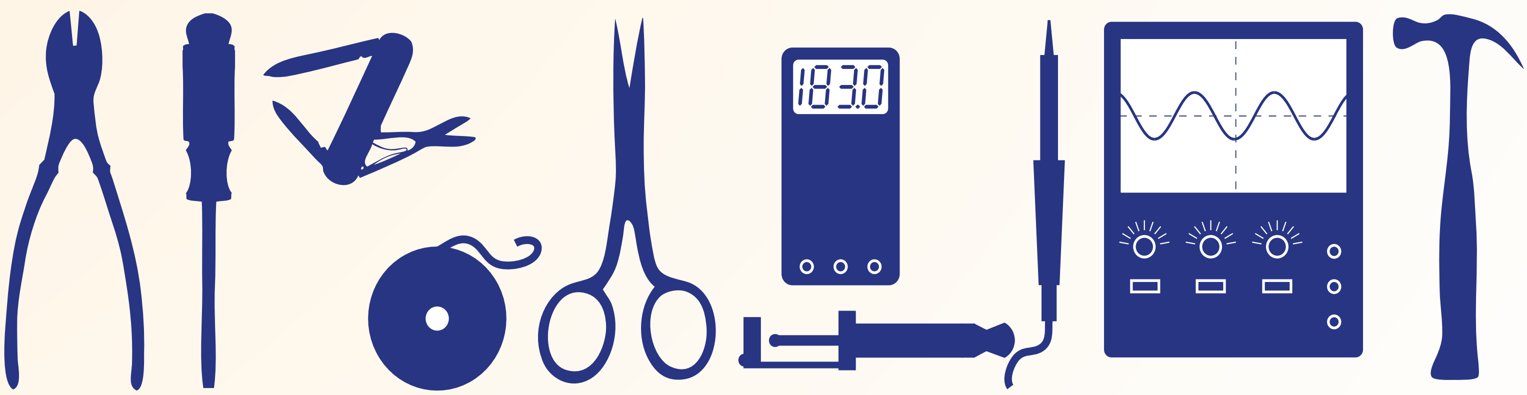
Probably the most common problem is short circuits caused by excess solder flowing between the tracks and pads. Custom printed circuits often have the non-copper part of the board covered with a solder resist that helps to avoid this problem. However, it is a potential problem with any board that has densely packed copper pads, which these days probably means every board you will use. Taking care not to feed an obviously excessive amount of solder into a joint will help to avoid problems. It is essential to use an iron having a suitably small diameter bit, which means one having a diameter of about 2.5mm or even less.

It is probably best to regard the occasional short circuit as inevitable, even when you have become skilled at soldering. Fortunately, most solder blobs and trails will be spotted immediately provided you are observant and inspect each joint as soon as it is completed. When two pads are bridged with solder, any form of desoldering equipment should be able to easily remove the excess solder. In most cases there is no need for any desoldering equipment, and the excess solder can simply be wiped away using the bit of the soldering iron. The solder removed from the joint will probably be oxidised, and it should be removed from the bit so that it cannot give problems with the next joint. The bit can be cleaned using a moist sponge or one of the cleaning blocks produced for this purpose.

Running dry

So-called 'dry' joints used to be a common problem, but are less so these days. A dry joint is produced when insufficient solder is applied to the joint, or (more usually) the solder fails to flow properly and it does not cover the lead and pad correctly. This is usually the result of dirt or corrosion on one of the surfaces, or a lack of flux in the solder. Improvements in components and solders have rendered dry joints something of a rarity, but they can still occur. If there is any obvious contamination on the lead or copper pad it should be scraped away with the blade of a penknife before trying to solder the joint.

Dry joints are usually quite easy to spot because they tend to have something other than the usual mountain like shape. Also, the solder might have a dull and crazed finish instead of the usual smooth and shiny type. A variety of duff and dubious joints are shown in Fig.3, including the one in the bottom right-hand corner where the solder has flown nicely over the copper track but has refused to have anything to do with the component lead. The three joints in the top row have the opposite problem, with the solder flowing over the leads but not spreading out over the copper track very well.



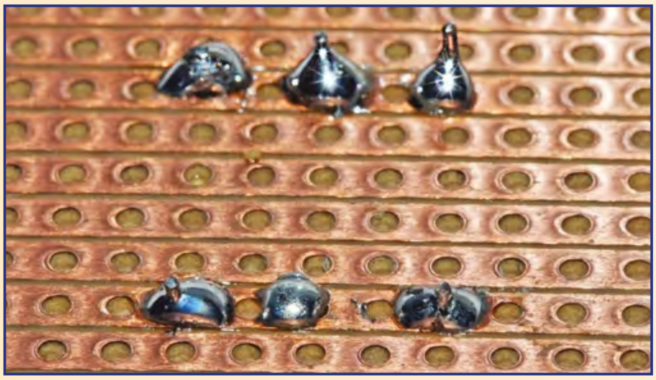


Fig.3. The middle joint in the front row is typical of one where the leadout wire has been cut too short, or is otherwise not protruding far enough through the board. The solder has not flowed over the lead in the bottom right-hand joint

Fig.4. These soldered joints are better, but there is a lack of solder on the joint circled in red. It is making an electrical connection but will be physically weak

The soldered joints in Fig.4 are better, but the one circled in red has an obvious paucity of solder. It is actually making a good electrical connection, but will lack physical strength. When a joint appears to be at all iffy, remove all the solder, clean the two surfaces, and try again. Always check that you have not made the ultimate form of dry joint. This is the type where you overlook it and do not make the connection at all!

Gaping error

Perfectly sound soldered joints can be let down by the common mistake of leaving a gap between the body of the component and the circuit board. It is very important to ensure that the components are fitted tight against the board, as in Fig.5(a). If a gap is left between the component and the board as in Fig.5(b) or it is fitted at an angle as in Fig.5(c), any pressure on the component tends to break the pads away from the board. Modern circuit boards usually have tiny pads and very fine tracks, which makes them vulnerable to this kind of damage. The board could easily be damaged even before you get it finished.

Be especially careful to avoid the gap problem when dealing with vertical mounting components, which mainly means electrolytic capacitors and some inductors. Vertical mounting components tend to get pushed and knocked slightly while the board is being constructed and installed in the case. Unless fitted tight against the board they tend to keel over sideways, which looks a bit untidy, and could easily result in damage to the pads and tracks.

It is important to learn the art of making quick and effective soldered joints. Spending too long on each joint could produce a weak joint, which will not actually matter too much if it also results in the component being damaged by overheating! It is often obvious if you take too long to complete a soldered connection, with the component becoming discoloured, and possibly showing other signs of damage.

Things will be much easier if you become proficient at soldering before starting on your first project. It is a good idea to practice with a piece of stripboard and some cheap components such as resistors. Soldering irons and kits are often supplied complete with a useful instruction leaflet. There is also the extremely helpful and well-regarded soldering guide on the *EPE* website, which should be considered essential reading.

Frame up

Soldering components onto a circuit board is easy if you happen to have three hands! One hand is needed for the soldering iron, another is needed to feed the solder into the joint, and a third hand is needed to hold the board and components in place. Most constructors soon develop their own way of dealing with this problem.

Something like a large chunk of 'Plasticine' or Bostik 'Blu Tack' can be used to hold a few components in place, and to temporarily fix the board to the worktop with the copper side facing upwards. With the board and the components held firmly in place, both hands are free to deal with the solder and the iron.

A better solution is to use a printed circuit construction frame. These differ slightly from one maker to another, but they all have a clamp for the board and a large piece of soft foam material beneath this. The board, fitted with all or some of the components, is mounted with the copper side facing upwards, and the components pressed down into the piece of foam material, which presses them in place against the board. Construction frames do not usually work well with a mixture of small and large components, and it is best to deal with the small components first, and then progress to the larger ones that protrude further above the board. The main problem with printed circuit construction frames is their cost, which is simply too high for most electronics hobbyists.

Checking

Checking the board as you go along and correcting errors that are found should produce a good working circuit board, but it is still important to thoroughly check the finished board. Clean the underside of the board and check it for accidental short circuits or dodgy looking joints. This should be done with the aid of a magnifying glass or a loupe. Check that everything is in the right place on the top side of the board, and, where appropriate, fitted the right way round. The board is then ready to be fitted in the case and tested.

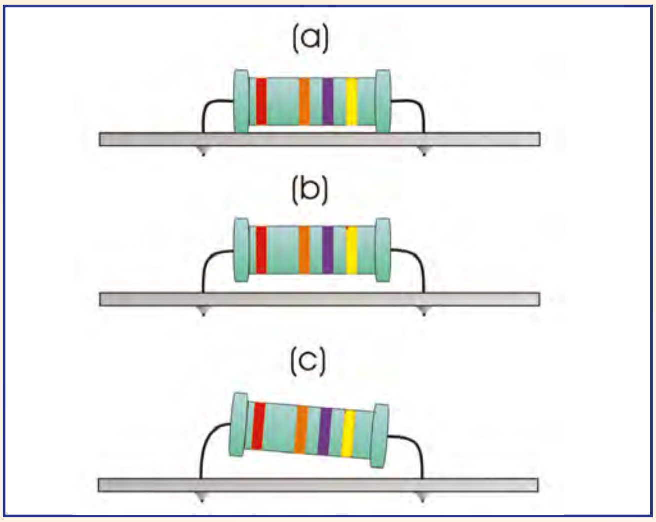


Fig.5. Components should be mounted right against the board, as in (a), and not with a gap as in (b) and (c). Leaving a gap risks damage to the copper pads and tracks on the underside of the board

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Mastering rotary encoders – Part 2

IN the past few months there have been a couple of threads on the *EPE Chat Zone* relating to rotary encoders. Last month, ***Lincoln*** asked about a budget (65p from Alps) three-terminal rotary encoder to advance or retard counters in a PIC circuit. In his circuit, one of the encoder outputs interrupts the program and the interrupt then reads the other pin to see if the encoder has been turned forwards or backwards, which in turn raises an appropriate flag. He found that the counting was not always working the way he wanted; he tried software debouncing and adding capacitors, but felt that these solutions were not ideal. Lincoln also asked about the advantages of more expensive rotary encoders and if he needed to raise the clock speed of his PIC.

A little later ***atferrari*** asked if Schmitt triggers are required between an encoder and a microcontroller such as a PIC.

Last month, we looked mainly at the encoders themselves; this month, we look in more detail at the quadrature signals produced by incremental encoders; and next month, we will look at dealing with problems such as switch bounce and noise.

To recap briefly, rotary encoders convert rotational or angular mechanical position or movement into an electronic signal, usually a digital code or sequence. Rotary encoders have a wide range of uses. Initially they were mainly found in industrial settings such as robotics. Low cost rotary encoders are now frequently found in the user interfaces of electronic equipment. The cheapest of these cost less than one pound.

Absolute and incremental

There are two types of rotary encoder – absolute and incremental. Absolute encoders output a specific digital code for a specific rotational position. Incremental encoders produce signals which indicate the direction and amount of movement, their outputs cannot be interpreted directly as a specific position – you can only measure relative movement. Last month, we looked at the basic principles of both types; this month, we will focus on incremental encoders

Incremental encoders contain two sensors or switches which operate (turn on and off) as the encoder moves. They are set up so that they generate a quadrature signal, that is, two waveforms offset by a 90-degree phase shift. The relative position of the sensors/switches means that it is impossible for both of them to change at the same time. These signals can be used to control a hardware or software counter to obtain a binary representation of relative movement.

Fig.1 shows the quadrature signals (QA and QB) obtained for continuous clockwise/forward and anticlockwise/backwards movement. For convenience, we typically draw quadrature signals with nice even spacing, as shown in Fig.1, but in reality the time between changes on the signals will vary as the speed of movement of the encoder changes. Even spacing of changes to the input signals cannot be assumed, but as long as maximum speeds are not exceeded this does not matter – it is the sequence of changes on the two inputs which is important, not the exact timing. This is illustrated by Fig.2, the same amount of movement as the clockwise/forward example in Fig.1, but with varying speed during the movement.

The specific timing of signals does become important when we consider problems such as noise and switch bounce. We will look at this in detail next month, but initially we will assume that the quadrature signals are ideal and relate only to encoder movement.

System structure

Fig.3 shows the typical building blocks and signal flow of an incremental encoder-based position measurement

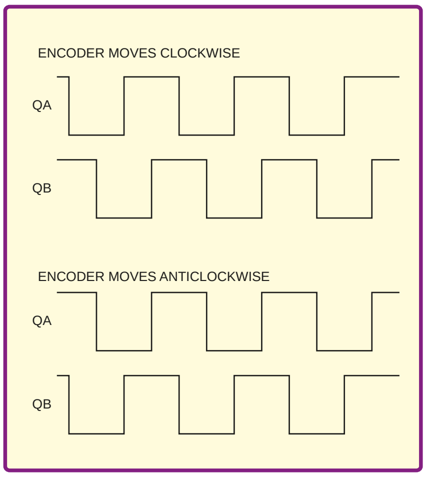

Fig.1. Quadrature signals from an incremental encoder for clockwise/forward and anticlockwise/reverse movement

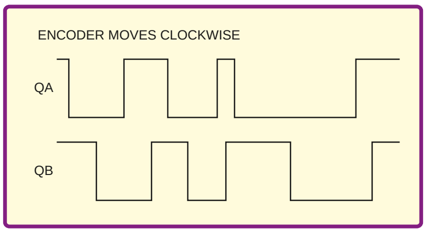

Fig.2. Real quadrature signals are not evenly spaced square waves, unless the speed of movement is constant. This is the same amount of movement as the clockwise example in Fig.1, but with varying speed

system. Strictly speaking the system measures relative position, or movement, rather than absolute position, but in typical user interface application this does not matter because the changes produced by any movement are fed back to the user by a display, or simply by the overall system's reaction to the adjustment made by the control. Apart from the encoder itself, and any analogue signal conditioning, all functions can be implemented in either hardware or software. Using hardware may increase cost, but can reduce the potential burden on the microcontroller as hinted at by ***Lincoln***. There is no single correct way to partition the hardware and software – it depends on the individual system. This is something which is an import design decision in many electronic systems, not just those with rotary encoders.

The raw, unconditioned quadrature outputs of the incremental encoder (QAU and QBU in Fig.3) are processed by the signal conditioning block to remove switch bounce, noise and possibly other non-ideal qualities of the raw signal. The conditioned quadrature signal then passes to the quadrature decoder, which produces 'direction' and 'move' signals. These are used to control a counter which tracks the relative movement of the encoder. The 'move' signal tells the counter when to count and the direction signal indicates if it should count up or down. The counter output can be used to control some parameter in the overall system, for example the volume in an audio system.

Signal states

A key aspect of quadrature signals is that if the two signals have a particular value then there are only two possible values which can occur next as the

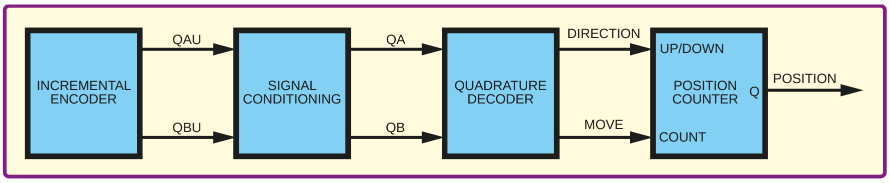

Fig.3. Building blocks and signal flow in an incremental encoder

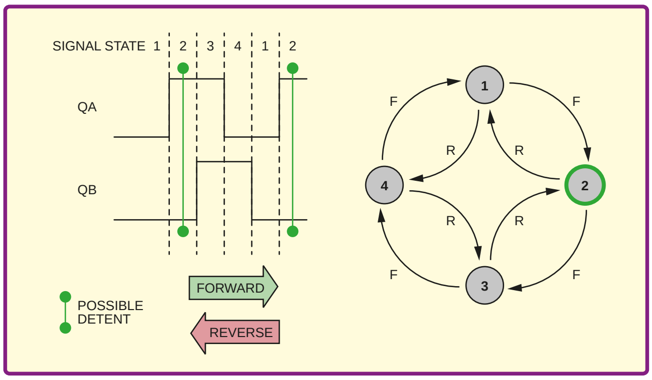

Fig.4. Quadrature signal states and the possible changes between them for forward/clockwise (F) and reverse/anticlockwise (R) movement of the encoder. There is a possible detent on the encoder corresponding with signal state 2 (for example)

encoder moves. These two values correspond with forward and reverse movement. We can label four possible combined values (or states) of the two quadrature signals 1,2,3 and 4, as shown in Fig.4, such that forward motion will produce the sequence 1,2,3,4,1,... and reverse motion 1,4,3,2,1,....

If the signal is in state 1 the next possible states are 2 (forwards) and 4 (reverse), similarly for state 2 the possible next states are 3 and 1, and so on. This can be depicted in a diagram (also shown in Fig.4) in which the signal states are represented as circles, with arrows to show the possible changes between the states.

As mentioned by ***Lincoln***, and discussed last month, many incremental encoders intended for user controls sometimes have detents which cause the control to snap into particular mechanical positions. Typically, the detents correspond to just one of the 4 possible signal states from the encoder, as is also illustrated in Fig.4. This means that the minimum movement the user can apply (assuming the detents function correctly) will take the encoder output signal through a complete cycle of 4 states; starting at, and returning to the detent state. In the case of the example in Fig.4, for a minimum forward movement, the signal states would be 2,3,4,1,2 and for reverse movement 2,1,4,3,2. Larger movements will produce several such cycles consecutively. It should be noted, however, that not all encoders have detents and they are not appropriate in all applications.

Counting options

There is more than one way to count movement from a quadrature signal, which results in three different levels of position resolution (×1, ×2, and ×4 counting). These are described below and illustrated in Fig.5, which highlights which input changes depicted on the diagram in Fig.4 cause the position counter to change value. Which of these applies depends on the logic implemented by the quadrature decoder. Some commercial quadrature decoders have a fixed way of counting; others allow the user to select between different counting modes. Fig.4 and Fig.5 provide a reasonable depiction of how a quadrature decoder and counter should behave, but may not be wholly adequate. We will return to this later.

×1 counting

One count per complete state cycle, for example, synchronised with the positive edges (0 to 1 changes) on QA. This example would count up for encoder state change 1→2 going forward, and down for encoder state change 4→3 during reverse movement (as shown in Fig.5a). Alternatively, ×1 counting could use negative edges on QA or one of the edges on QB.

×2 counting

Two counts per complete state cycle, for example, synchronised with all changes on QA. This example would count up for encoder state changes 1→2 going forward and 3→4, and down for encoder state changes 2→1 and 4→3 during reverse movement (as shown in Fig.5b). Alternatively, ×2 counting could use all changes on QB.

×4 counting

Four counts per complete state cycle. Counts on every change on both inputs (see Fig.5c).

Fig.6 shows an example quadrature waveform for simple forward movement, with the corresponding count output for the three different count resolutions. The numbers produced by different counting modes may result in different interpretations of the same physical movement. For user controls, the relationship between movement and its effect (hence the feel of the control) will depend how the software maps the position count to the controlled parameter. Higher resolution counting could be scaled down in software, but a low-resolution quadrature decoding cannot be increased later. The ×1 counting produces one count per detent (for detents located as in Fig.4, if present) and is therefore probably most appropriate for encoders of this type.

Fig.7 shows an example quadrature waveform for a change of direction, with the count output for the three different count resolutions. In this example the count starts at 0 and the amount of reverse movement is larger than the forward movement. In such a situation a typical position counter will 'underflow', resulting in the maximum count value. The example in Fig.7 shows a count down from 0 to 255, the maximum for an 8-bit unsigned binary number, but this could also be interpreted as a value of –1.

Bit count and overflow

The situation shown in Fig.7 raises some issues which need to be considered when designing or using a position counter. First, how many bits should/does the counter have, or what counting range does it have? Second, what should happen when the counter underflows or overflows? If the counting is implemented in software then there is probably greater potential for flexibility in the response to each event from the quadrature decoding.

Incremental encoders aimed at user controls typically produce a small number of pulses per revolution (eg, 12 or 24 pulses on both QA and QB per revolution). This may not match the number of different values you want to be able to set with the control; however, the number of revolutions is typically unlimited so, in theory, any number of values could be accommodated (if the user is happy to the spin the control

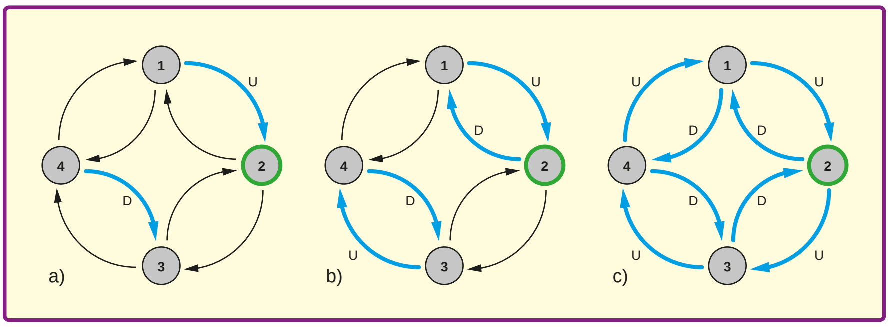

Fig.5. Quadrature signal changes for position counting in various modes: a) ×1 QA counting, b) ×2 QA counting, c) ×4 counting. U – count up, D – count down. There may be a detent on the encoder for state 2. In some situations Fig.5a may lead to erroneous counting

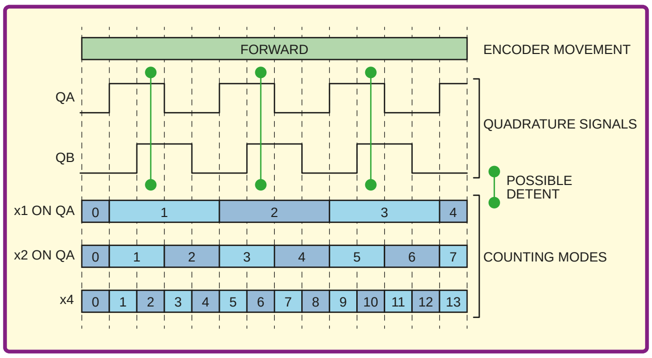

Fig.6. Forward movement with various counting modes

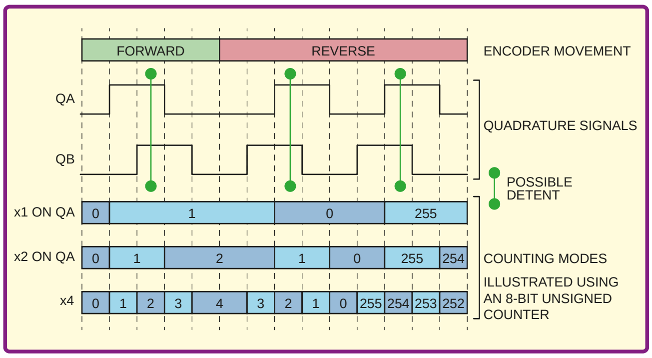

Fig.7. Direction change example with various counting modes

for a long time). Typically, the software will limit the value to be set at a defined maximum and minimum, allowing the user to carry on moving the control in the same direction with no effect on the value until the direction is changed.

Detents

Fig.8 shows another example, which illustrates a potential pitfall for designers of incremental position measurement systems. The signals shown occur when one of the sensors/switches (QA in this case) changes continuously while the other sensor/switch remains static. This will happen if a user deliberately moves a control backwards and forwards a very small amount. It could also occur inadvertently if an encoder came to rest exactly over the trigger point of one of the sensors/switches and movement due to background mechanical vibration was sufficient to repeatedly turn the sensor on and off.

Detents aim to prevent this happening, by mechanically enforcing a minimum movement through all four encoder states, as we discussed earlier, and ensuring that the resting place snaps to a position away from a switching point. Note that the signals in Fig.8 at no point cross the previously indicated possible detent point. Although we are not discussing switch bounce in full detail yet, it is worth mentioning that a signal from a bouncing switch may be logically equivalent to that in Fig.8. Thus the problem we are about to describe may be prevented by detents for perfect switching, but could still occur due to bouncing switches or noise if not adequately dealt with by the signal conditioning.

A correctly designed position system will respond properly to the situation shown in Fig.8. For ×2 on QA and ×4 counting this simply means counting up and down by one on each successive input change, thus following the 'vibration' pattern. For ×2 counting based on QB no counting would occur because there are no changes on QB in this example. Both an 'oscillating' count and no change are correct responses and simply reflect different resolutions.

For ×1 counting on QA, based on Fig.5a, we have a problem. The signal goes through the sequence 1,2,1,2,1,2,… and each 1→2 transition produces an up count. Thus a small backward and forwards movement of the encoder produces a continuous up count, which is incorrect. It is possible that some of Lincoln's problems were due to this, but we cannot be certain.

The problem is due to the fact that the encoder really has 8 states, not four as shown in Fig.5. Each signal state (which we labelled 1,2,3,4) in can be arrived at by forward or backwards movement. If we include a 'memory' of the direction of arrival we have 8 states, as shown in Fig.9. Here, for example, state 1F means currently QA=0, QB=0 and previously QA=0, QB=1, that is QA=0, QB=0 was arrived at by forward movement.

Using Fig.9 the signal in Fig.8 follows the sequence 1F,2R,1R,2R,1R,2R,… assuming we started in 1F. Only the 1F→2R transition produces an up count, so the counter response is correct. Fig.9 is simplified by omission of several of the transitions, but hopefully it should not be too hard to work the others out if you are interested. There are 16 valid transitions in total.

There are a couple of common ways of implementing quadrature decoders based on the ideas discussed in this article. One approach is to sample the encoder signal and store the current and previous values. This gives four stored bits, which can be decoded by a combinational logic circuit or software function to find the eight transitions shown in Fig.4. The other eight combinations (four bits gives 16 combinations) includes four where there was no movement (current=previous) and four invalid transitions which should never occur if the encoder and signal conditioning are OK. An up or down count is made when an appropriate transition is detected, depending on the counting mode required; however, the problem described above with 'vibration' signals may occur in a simple implementation.

State machines

Readers familiar with state machines will have noticed that Fig.4 and Fig.9 look like state machine diagrams. These figures were used here to describe what the encoder signals do as the encoder moves, but a state machine defined by a similar diagram will be able to exactly track what the encoder is doing and consequently provide the correct signals to the counter (for any required counting mode). Using the full version of Fig.9 as the basis of the state machine means the decoder would handle the vibration condition. Additional states can be used for reset (implies direction currently unknown) and for detection of invalid transitions, which suggests a faulty encoder, overwhelming noise or inadequate debouncing. Next month we will look at switch bounce and noise problems.

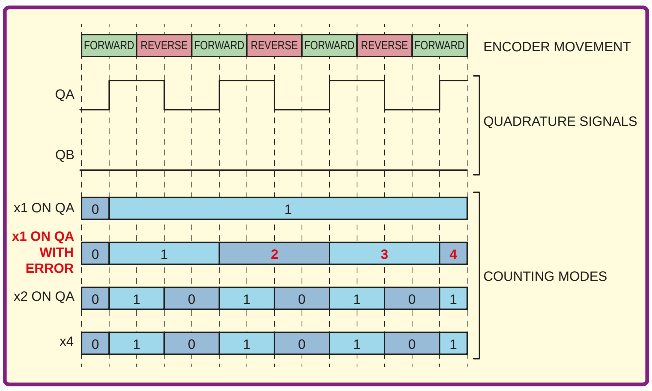

Fig.8. Possible 'vibration' movement with various counting modes

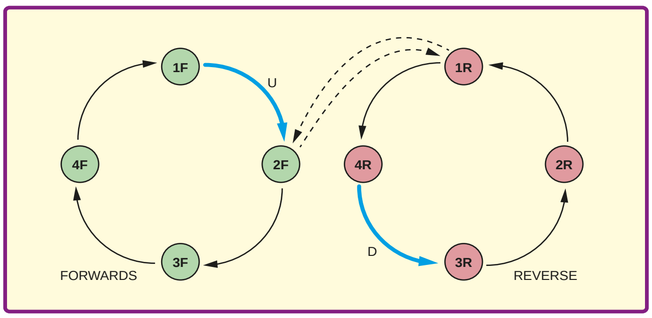

Fig.9. Simplified diagram of quadrature signal changes taking current direction into account. Not all possible changes (state transitions) shown. Dotted arrows indicate direction changes important in the quadrature waveform (Fig.8). Transitions for ×1 counting on QA highlighted (U – count up, D – count down)

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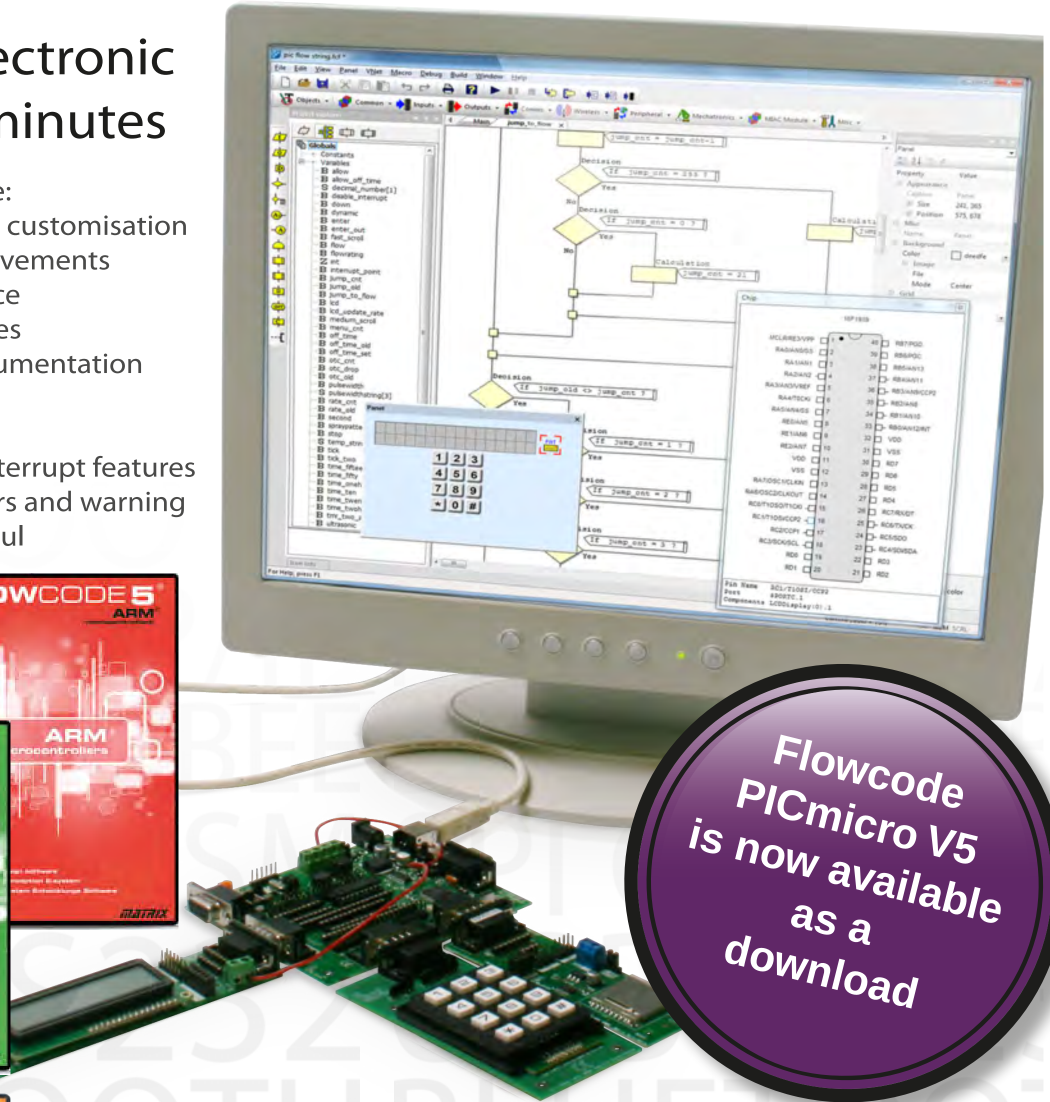

Flowcode PICmicro V5 is now available as a download

The FlowKit can be connected to hardware systems to provide a real time debug facility where it is possible to step through the Flowcode program on the PC and step through the program in the hardware at the same time. The FlowKit can be connected to your own hardware to provide In-Circuit Debug to your finished designs.

PRICES **Prices for each of the items above are:**

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(UK and EU customers add VAT to 'plus VAT' prices)

	Flowcode 5 PICMICRO/AVR/DSPIC/PIC24 & ARM Download only
Hobbyist/Student	**£58.80 inc. VAT**
Professional (Schools/HE/FE/Industry)	**£199.00 plus VAT**
Flowkit	**£64.90 plus VAT**

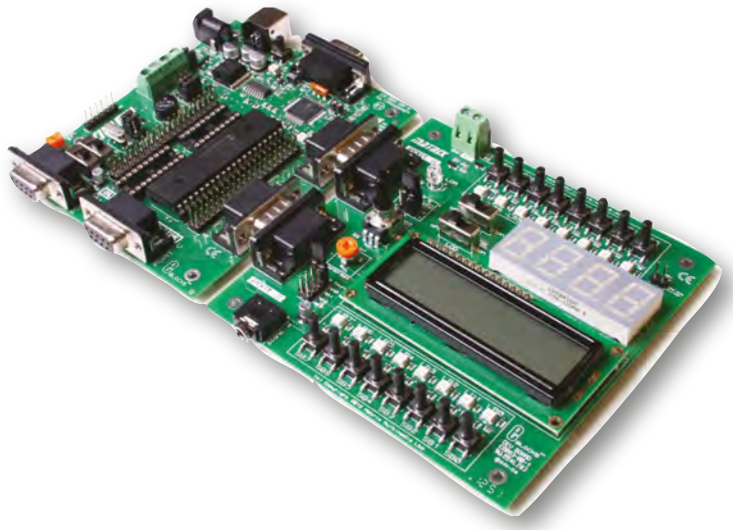
Please note: **Due to popular demand, Flowcode PICmicro, AVR, DSPIC, PIC24 & ARM V5 are now available as a download. Please include your email address and a username (of your choice) on your order. A unique download code will then be emailed to you. If you require the CDROM as a back-up then please add an extra £14 to the above price.**

PICmicro TUTORIALS AND PROGRAMMING

HARDWARE

PICmicro Multiprogrammer Board and Development Board

Suitable for use with the three software packages listed below



This flexible PICmicro microcontroller programmer board and combination board allows students and professional engineers to learn how to program PICmicro microcontrollers as well as program a range of 8, 18, 28 and 40 pin devices from the 12, 16 and 18 series PICmicro ranges. For experienced programmers all programming software is included in the PPP utility that comes with the multiprogrammer board. For those who want to learn, choose one or all of the packages below to use with the hardware.

- Makes it easier to develop PICmicro projects
- Supports low cost Flash-programmable PICmicro devices
- Fully featured integrated displays – 16 individual LEDs, quad 7-segment display and alphanumeric LCD display
- Supports PICmicro microcontrollers with A/D converters
- Fully protected expansion bus for project work
- USB programmable
- Compatible with the E-blocks range of accessories

£167 including VAT and postage, supplied with USB cable and programming software

SOFTWARE

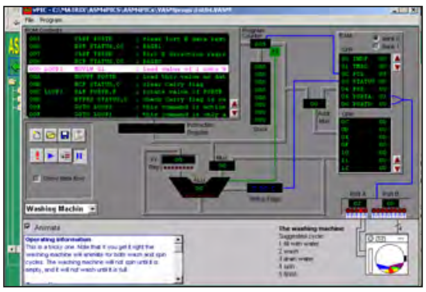
ASSEMBLY FOR PICmicro V4

(Formerly PICtutor)

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

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

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

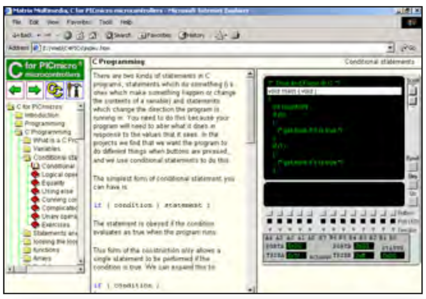


‘C’ FOR 16 Series PICmicro Version 4

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

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

● Complete course in C as well as C programming for PICmicro microcontrollers ● Highly interactive course ● Virtual C PICmicro improves understanding ● Includes a C compiler for a wide range of PICmicro devices ● Includes full Integrated Development Environment ● Includes MPLAB software ● Compatible with most PICmicro programmers ● Includes a compiler for all the PICmicro devices.



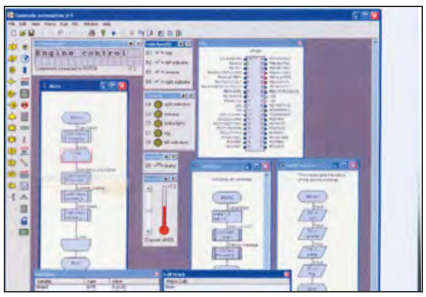
Minimum system requirements for these items: Pentium PC running, 2000, ME, XP; CD-ROM drive; 64MB RAM; 10MB hard disk space.
Flowcode will run on XP or later operating systems

FLOWCODE FOR PICmicro V5 (see opposite page)

Flowcode is a very high level language programming system based on flowcharts. Flowcode allows you to design and simulate complex systems in a matter of minutes. A powerful language that uses macros to facilitate the control of devices like 7-segment displays, motor controllers and LCDs. The use of macros allows you to control these devices without getting bogged down in understanding the programming. When used in conjunction with the Version 3 development board this provides a seamless solution that allows you to program chips in minutes.

- Requires no programming experience
- Allows complex PICmicro applications to be designed quickly
- Uses international standard flow chart symbols
- Full on-screen simulation allows debugging and speeds up the development process.
- Facilitates learning via a full suite of demonstration tutorials
- Produces ASM code for a range of 18, 28 and 40-pin devices
- 16-bit arithmetic strings and string manipulation
- Pulse width modulation
- I2C.

Features include panel creator, in circuit debug, virtual networks, C code customisation, floating point and new components. The Hobbyist/Student version is limited to 4K of code (8K on 18F devices)



PRICES

Prices for each of the CD-ROMs above are:

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Hobbyist/Student	£58.80	inc VAT
Professional (Schools/HE/FE/Industry)	£150	plus VAT
Professional 10 user (Network Licence)	£499	plus VAT
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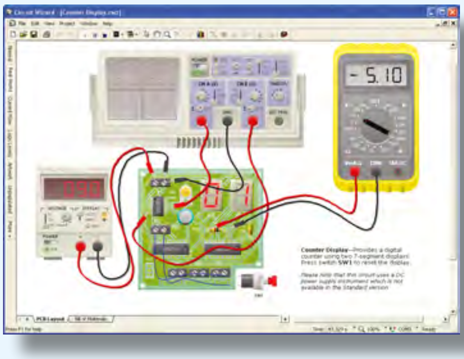
Flowcode Professional (Schools/HE/FE/Industry)	£199	plus VAT
Flowcode 10 user (Network Licence)	£599	plus VAT
Flowcode Site Licence	£999	plus VAT

CIRCUIT WIZARD

Circuit Wizard is a revolutionary software system that combines circuit design, PCB design, simulation and CAD/CAM manufacture in one complete package.
Two versions are available, Standard or Professional.

By integrating the entire design process, Circuit Wizard provides you with all the tools necessary to produce an electronics project from start to finish – even including on-screen testing of the PCB prior to construction!

✱ Circuit diagram design with component library (500 components Standard, 1500 components Professional) ✱ Virtual instruments (4 Standard, 7 professional) ✱ On-screen animation ✱ Interactive circuit diagram simulation ✱ True analogue/digital simulation ✱ Simulation of component destruction ✱ PCB Layout ✱ Interactive PCB layout simulation ✱ Automatic PCB routing ✱ Gerber export ✱ Multi-level zoom (25% to 1000%) ✱ Multiple undo and redo ✱ Copy and paste to other software ✱ Multiple document support



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

Standard **£61.25** inc. VAT Professional **£91.90** inc. VAT

Minimum system requirements for these CD-ROMs: Pentium PC, CD-ROM drive, 32MB RAM, 10MB hard disk space. Windows 2000/ME/XP, mouse, sound card, web browser.

GCSE ELECTRONICS

Suitable for any student who is serious about studying and who wants to achieve the best grade possible. Each program's clear, patient and structured delivery will aid understanding of electronics and assist in developing a confident approach to answering GCSE questions. The CD-ROM will be invaluable to anyone studying electronics, not just GCSE students.

✱ Contains comprehensive teaching material to cover the National Curriculum syllabus ✱ Regular exercises reinforce the teaching points ✱ Retains student interest with high quality animation and graphics ✱ Stimulates learning through interactive exercises ✱ Provides sample examination ques-tions with model solutions ✱ Authored by practising teachers ✱ Covers all UK examination board syllabuses ✱ Caters for all levels of ability ✱ Useful for self-tuition and revision

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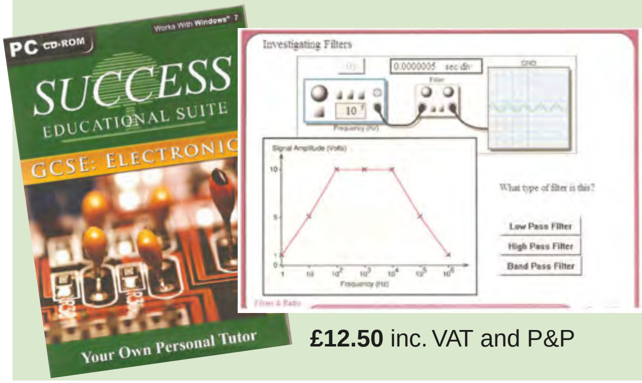

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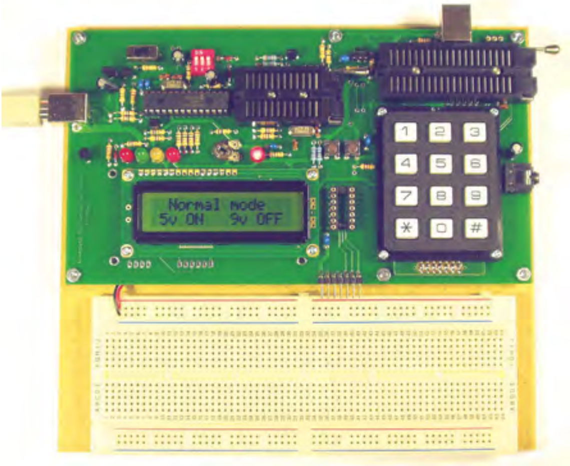
PIC Training Course



P931 Course £148

There is a common belief that programming a computer is beyond the capability of normal people but if approached in the correct way computer programming is a good deal easier than learning to speak. Imagine trying to teach English grammar to a child before allowing him or her to speak!. Yet that is how most books approach a technical subject. We start by setting a simple objective for the microcontroller. We write the instructions to do this using the simplest possible code in the natural language of the microcontroller. We load these instructions into the microcontroller, start it running and watch the results. It sounds easy and it is easy because, like teaching a child to speak for the first time, we choose very simple phrases. A second common belief is that the natural language of microcontrollers (assembly language) is extremely complex. In reality the problem is no different to using the English language. All complex phrases can be expressed in very simple terms without any loss of meaning.

Our PIC training course consists of our PIC programmer, a 320 page book teaching the fundamentals of PIC programming, a 306 page book introducing the C language, and a suite of programmes to run on a PC. Two ZIF sockets allow most 8, 18, 28 and 40 pin PICs to be programmed. The programming is performed at 5 volts then verified at 5 volts and 2 volts or 3 volts.

P931 PIC Training & Development Course comprising.....
USB powered 16F and 18F PIC programmer module
+ Book Experimenting with PIC Microcontrollers
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+ PIC assembler and C compiler software on CD
+ PIC16F1827, PIC16F1936 & PIC18F2321 test PICs
+ USB cable. £148.00
(Postage & insurance UK £10, Europe £20, Rest of world £30)

Serial Coms Extension £31

This third stage of our PIC training course starts with simple experiments using 18F PICs. We use the PIC to flash LEDs and to write text to the LCD. Then we begin our study of PC programming by using Visual C# to create simple self contained PC programmes. When we have a basic understanding of PC programming we experiment with simple PC to PIC serial communication. We use the PC to control how the PIC lights the LEDs then send text messages both ways. We use Visual C# to experiment with using the PC to display sinewaves from simple mathematics. Then we expand our PC and PIC programmes gradually until a full digital storage oscilloscope is created. For all these experiments we use the programmer as our test bed. When we need the serial link to the PC we flip the red switches to put the control PIC into its USB to USART mode.

In the second part of *Experimenting with Serial Communications* 4th Edition we repeat some of the serial experiments but this time we use a PIC18F2450 with its own USB port which we connect directly to a USB port of your PC. We follow this with essential background study then work through a complete project to use a PIC to measure temperatures, send the raw data to the PC, and use the PC to calculate and display the temperature.

290 page book + PIC18F2450 test PIC +USB lead..... £31

P942 Course £173

This has the same books and features as the P931 course. The P942 programmer/development module can be powered from a separate PSU (programming verified at 5.5 volts, 5 volts and 2 or 3 volts) or powered from USB (programming verified at 5 volts and 2 volts or 3 volts). The P942 can programme 3.3 volt as well as 5 volt 16F and 18F PICs, and has an RS232 port as well as the USB port for experimental use. See website for details.

Ordering Information

Our P931 & P942 programmers connect directly to any USB port on your PC. All software referred to operates correctly within Windows XP, NT, 2000, Vista, 7, and Windows 8 etc. telephone for a chat to help make your choice then go to our website to place your order (Google Checkout or PayPal), or send cheque/PO, or request bank details for direct transfer. All prices include VAT if applicable

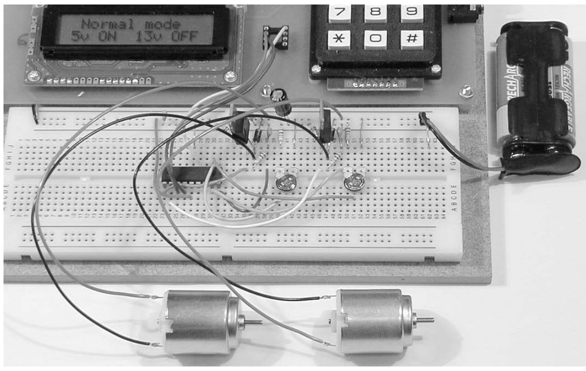
Experimenting with PIC Microcontrollers

This book introduces PIC programming by jumping straight in with four easy experiments. The first is explained over seven pages assuming no starting knowledge of PICs. Then having gained some experience we study the basic principles of PIC programming, learn about the 8 bit timer, how to drive the liquid crystal display, create a real time clock, experiment with the watchdog timer, sleep mode, beeps and music, including a rendition of Beethoven's *Fur Elise*. Then there are two projects to work through, using a PIC as a sinewave generator, and monitoring the power taken by domestic appliances. Then we adapt the experiments to use the PIC18F2321. In the space of 24 experiments, two projects and 56 exercises we work through from absolute beginner to experienced engineer level using the very latest PICs.

Experimenting with PIC Microcontrollers

The second book starts with an easy to understand explanation of how to write simple PIC programmes in C. Then we begin with four easy experiments to learn about loops. We use the 8/16 bit timers, write text and variables to the LCD, use the keypad, produce a siren sound, a freezer thaw warning device, measure temperatures, drive white LEDs, control motors, switch mains voltages, and experiment with serial communication.

Web site:- www.brunningsoftware.co.uk



White LED and Motors

Our PIC training system uses a very practical approach. Towards the end of the PIC C book circuits need to be built on the plugboard. The 5 volt supply which is already wired to the plugboard has a current limit setting which ensures that even the most severe wiring errors will not be a fire hazard and are very unlikely to damage PICs or other ICs.

We use a PIC16F1827 as a freezer thaw monitor, as a step up switching regulator to drive 3 ultra bright white LEDs, and to control the speed of a DC motor with maximum torque still available. A kit of parts can be purchased (£31) to build the circuits using the white LEDs and the two motors. See our web site for details.

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NET WORK

by Alan Winstanley

Have a KitKat

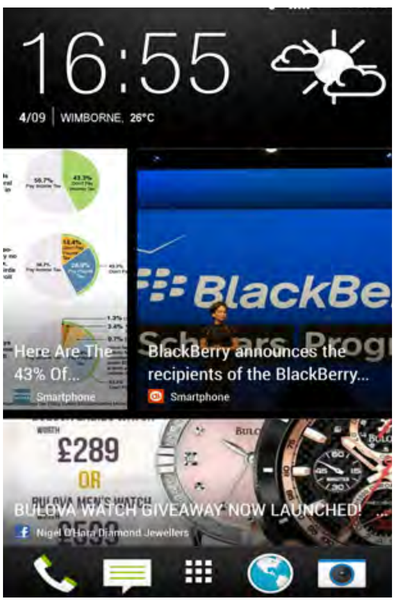
LAST month's *Net Work* adopted the theme of advancements being made in mobile phone and tablet technology, and the way in which so-called 'featurephones' are increasingly exploiting the latest applications (apps) to offer users a fully-connected network experience.

This month, I'll continue with this theme, mainly to highlight the likely trends in networking and to show what a modern smartphone or tablet can do for you. It's aimed especially at readers who may be considering an upgrade or perhaps adding some network-capable equipment onto their home computer system for the first time, or perhaps who are about to take the plunge and replace their old television with a Smart TV such as the Samsung model that I highlighted earlier this year. Now is a good time to explore network capabilities and hopefully I can offer readers some food for thought.

Making phone calls is genuinely a secondary consideration for many smartphone users who are more interested in using Facebook, Twitter and texting. I previously mentioned that I plumped for an HTC One smartphone, a high quality phone that uses the Android OS. Rival Android phones to consider include Samsung's Galaxy S3 or S4, or Sony's Experia and others, and don't overlook Android tablets as well. Presently, over two thirds of new mobile phones run Android. My own phone quickly updated itself to Android 4.2.2 (Jelly Bean) and a further increment to 4.3 is awaited. The next version of Android 4.4 has been branded KitKat (not Key Lime Pie as was anticipated), and chocolate bar makers Nestlé has joined in the fun with a brilliant spoof of Android, **www.kitkat.com**.

It remains to be seen whether current Android phones will receive an update to KitKat and whether KitKat will create problems with existing apps that run happily under Jelly Bean. Windows 8 is also making inroads into the mobile market, with some exceptional models being released by Nokia, who continue to claw back market share after a lengthy period in the doldrums. Just as Google, the name behind Android, acquired Motorola Mobility to gain access to its mobile phone hardware and patents, in September Microsoft announced the purchase of Nokia's mobile phone and smart device business in a $7.2 billion deal. Apple's iPhone remains omnipresent, but there is no doubt that Android and Windows offer some tempting choices.

I am embarrassed to admit that I could not figure out how to turn on my new HTC One! In fact the miniscule infra-red blaster window doubles as the power button. Nor was there any printed manual, and instead a PDF was stored on the phone. That's a Catch-22, as you have to charge up the phone and switch it on in order to find the manual that tells you how to switch it on – but even then the manual doesn't tell you where the power button is. Incidentally, the free Android app *ES File Explorer* would later prove invaluable – it's an equivalent to Windows Explorer, and it's thanks to this app that the HTC One Manual PDF was spotted nestling on the phone. ES File Explorer also lets you share, copy or email files and can be installed direct from Google Play Store.



HTC BlinkFeed delivers updates from the web to the home screen in tiles

Google answered my power-up problem and the phone was soon up and running. My next move was to apply a near-invisible screen protector made from 3M's excellent Vakuiti film that's die-cut for this model. I highly recommended them and they are available on eBay to fit most phones.

Android's own e-mail client and soft keyboard are fairly basic but effective, and configuring incoming (POP3) mailboxes was simple enough. A Gmail client is also included for seamless connection to your Gmail account. The solutions for outbound mail have changed in recent years though, and previously I recommended a dedicated SMTP service such as AuthSMTP (**www.authsmtp.com**) for the simple reason that the same SMTP settings can be used in any device whether a PC, laptop or phone, and regardless of location you can always send email successfully using your current connection. Unfortunately, I failed to configure AuthSMTP to run Android 4.2.2 on the HTC One. AuthSMTP claims that their service is compatible, but their website only alludes to Android 2.2 which I use on a tablet (which it is agreed does send mail successfully). For a while, I was stumped and could not send email.

The mailserver settings for most mobile carriers can be googled, but if you have an ISP of your own (eg, a broadband provider at home) then you can perhaps push your mobile phone mail through their SMTP server instead, which is what I did. This never used to be possible and it was counter-intuitive, because SMTP mail was previously 'tied' to the ISP that your particular device was connected to: change ISP and you had to change settings, hence the use of AuthSMTP instead. Happily, using the broadband provider's SMTP seems to work, but sending mail is still troublesome at times and Android's email client provides no error codes or helpful information when there's a problem.

I mentioned last month that, thanks to Wi-Fi, mobile data packages might offer more traffic than you might actually need; in the past I barely scratched the surface of my 1Gb per month tariff, as most traffic is handled through Wi-Fi instead of the phone carrier's data service. The HTC's Wi-Fi was soon configured and in no time a slew of updates was downloading automatically via my home network and the phone was soon ready to go.

Swipe and wipe

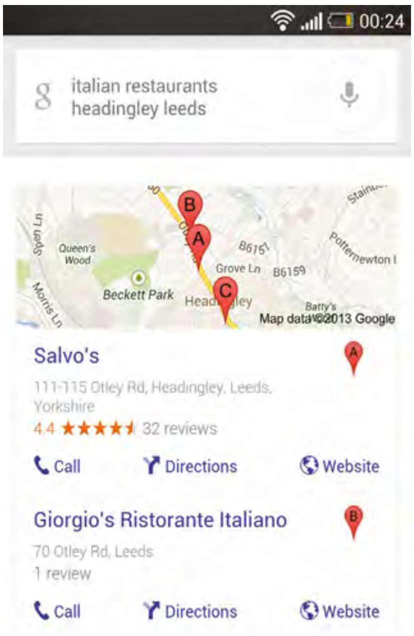
It is testimony to Android's usability that it was straightforward to find one's way around the operating system. A lot of on-screen swiping and sliding is needed, as well as stabbing the Settings and three-dotted Options icons, but modern touchscreens are incredibly responsive and after switching from one screen to another it wasn't long before the phone was configured to my liking. Check security options and configure a PIN while you're in settings. Transferring the contacts and picture IDs from my old Windows phone wirelessly using the Transfer Content feature went smoothly.

HTC's BlinkFeed home screen is a pleasure to use and it shows updates, news, Facebook posts and more in 'tiles' that give an at-a-glance update – click a tile to learn more. Android is supplied with a range of Google apps as one would expect, so a good place to start is at Google Play, from where free and paid-for apps can be downloaded (a Google account is needed). In tandem with this, the phone busily downloaded updates to various apps including Google's own services, Facebook, Twitter and others. Progress is shown in the notifications bar at the extreme top of the screen: swipe the bar downwards to learn more.

Google Search takes on a whole new dimension when helped by voice recognition, and the built-in Voice Search app does a remarkably good job of translating one's spoken word into a search phrase. Speech recognition previously needed a fast PC together with software such as *Dragon Naturally Speaking*, but now you can simply press the microphone icon on the touch keyboard and start talking away. Speak 'What is 28 degrees Celsius in Fahrenheit?' and Google Voice Search talks back with the answer (it's 82.4°F – time to put the fan on). Emails, Facebook, SMS and word processing can all be used this way, offering impressive levels of speech recognition instead of laborious touchscreen typing.

Google Search is increasingly fine-tuning its localisation, so that, for example, speaking "Italian restaurants Headingley Leeds" produced a flawless transcription with the spoken response that there were several such listings, along with a helpful Google Map. Furthermore, a Call icon puts each restaurant just a click away from getting your phone call to book a table (where I had a pizza, and my guest chose the hake.) Local businesses will want to ensure that they are No. 1 in Google to drum up valuable new trade from searches made by people who are searching using powerful smartphones. Google Maps or Street View will guide you there, and car navigation systems are also gradually entering the loop with route information being networked from a Google Map search directly to the car's dashboard. It's becoming a seamless, end-to-end experience.

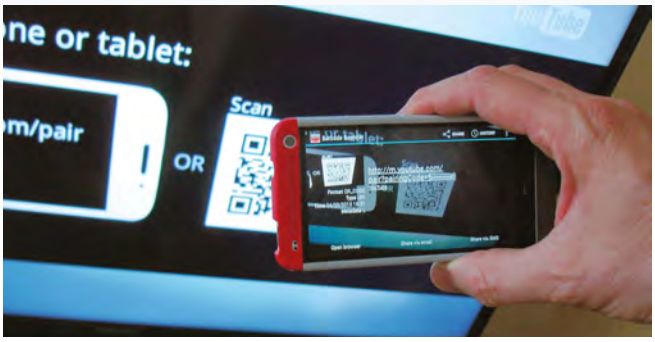
Of course, Apple iPhone plays tricks as well with Siri, but Google's Android shows the way (in more ways than one) that search and mobile technology are heading, combining together more closely than ever before, and trying to deliver accurate results effortlessly, monetised along the way with advertising revenue.



Voice Search accurately spelt place names and showed a Google Map with locations, phone numbers and reviews

What's on the YouTube?

Google owns many other properties of course, including YouTube. It's at this point that I started to dabble with my Smart TV, which is hooked onto my home network through a mains plug-in Wi-Fi access point repeater (see *Net Work*, December 2012). Regular readers might recall the nightmarish problems that setting up a Wi-Fi repeater caused the writer. In effect, my repeater is connected wirelessly to my router and it then broadcasts its own SSID that you can connect to. As it has an Ethernet port as well, I connected the Smart TV to that while using the repeater's Wi-Fi for a separate Humax PVR recorder, my mobile phone and cheap Android tablet.



Scanning a QR code on a TV screen to pair it with the phone's YouTube app (photo: Author)

The Samsung Smart TV brims with a choice of apps to provide big-screen entertainment as well as displaying Catch-up TV (BBC iPlayer etc.) streamed over the web. However, I found the TV's YouTube app to be disappointing and impractical: too much on-screen keyboarding controlled by a dumb IR controller is clumsy, and the app is cumbersome to use. As you would expect, the HTC One has a YouTube app as well, and since the TV and mobile phone both have Internet access, I decided to see how they could be networked together.

The TV's YouTube app will offer to 'pair' with networked devices such as a phone or tablet, but then what? A unique code number appears on-screen which is entered into a mobile device's web browser, or type the code into the device's YouTube app; better still, a QR code is generated on-screen to simplify the job. For this, a free barcode reader app (Barcode Scanner 4.4 from Zxing) was installed from Google Play which utilises the phone's camera. I could only marvel at its supermarket-checkout speed of recognition on every QR code or EAN barcode that I could find. Scanning newspaper car sales adverts containing QR codes produced instantaneous results.

Pairing the Samsung TV with the HTC One was accomplished by scanning the on-screen QR code, following some simple instructions and the two devices were soon connected. The net effect (no pun intended) is that instead of needing the mediocre TV YouTube app, the phone handset app is used to search YouTube instead: voice recognition lets you speak search phrases and the phone responds very rapidly with YouTube results. Instead of playing movies on the phone screen, choose the connected TV instead and simply add movies to a TV queue: they will play on the big-screen TV immediately and you can keep adding more movies in the background. This transformed our viewing and the family was soon enjoying one music video after another, followed by more YouTube content as the night drew on.

The icing on the cake was to configure HTC's TV app as a remote-control for the TV. This and the EPG (electronic program guide) were set up largely without a hitch, and although the EPG has only limited coverage at this time, I can choose programs and control all the basic functions of the TV using the phone. That infra-red button has a use after all!

Not all aspects of the new phone proved compatible with some existing gadgetry though, and next month I'll detail more apps, workarounds and benefits as I discover more that the smartphone has to offer. I will also look at what's in the pipeline in the emerging smartwatch market. These wrist-wearable devices link to a smartphone to provide a more convenient hands-free (almost) operation. You can e-mail the writer at **alan@epemag.demon.co.uk** or share your views with the editor at **editorial@wimborne.co.uk** for possible inclusion in *Readout*, and you could win a valuable prize!

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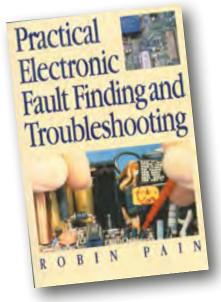

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All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 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)**.

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Next Month

Content may be subject to change

Class-D amplifier – Part 2

Following on from this month, we will describe the construction of the superb CLASSiC-D Amplifier, power supply options and its accompanying Loudspeaker Protector. We also describe how to test the completed modules and show the connection details for mono, stereo and bridged modes of operation.

Six test instruments in one tiny box

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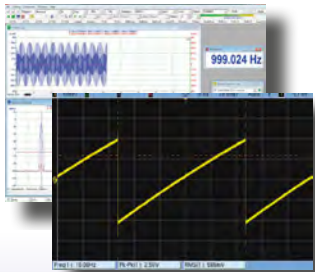
Virtins Technology – Multi-Instrument 3.2

To accompany our USB interface instrumentation project, we look at the PC software for using your PC as the engine for a suite of virtual audio test instruments. Here's a run-down on a powerful software package that will let you use it as a 2-channel audio scope combined with a powerful spectrum analyser, a 2-channel audio signal/function generator and a DMM which even includes a frequency counter!



Teach-In 2014: Raspberry Pi – Part 3

Next month's *Teach-In 2014* will delve further into the practical aspects of connecting the Raspberry Pi to the real world and show you how to construct a simple 8-channel high-current output driver that you can use to interface relays, actuators and motors. *Perfect Python* will show you how to define your own functions and make effective use of them in your code. Finally, in *Pi World* we will have some fantastic suggestions for further reading.

NOVEMBER '13 ISSUE ON SALE 3 OCTOBER 2013

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