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EVERYDAY

Vol.33 No.11

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PROJECTS ... THEORY ... NEWS ...
COMMENTS ... POPULAR FEATURES ...

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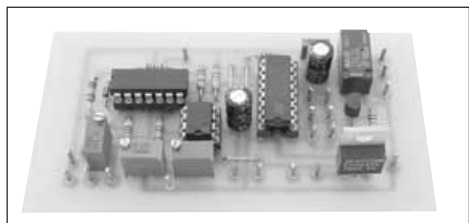
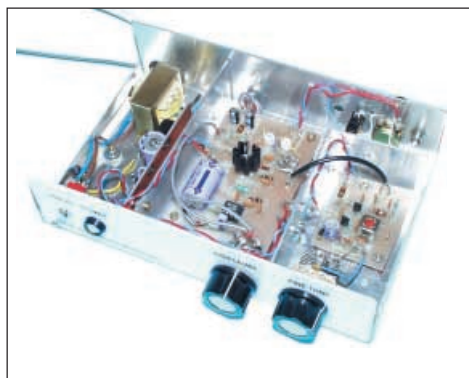
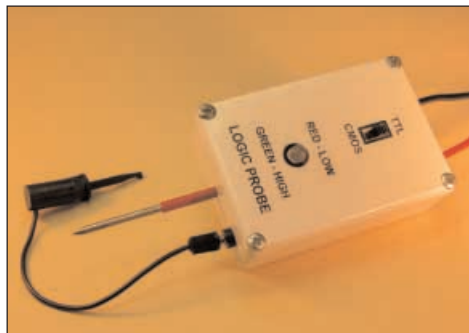
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Our December 2004 issue will be published on Thursday, 11 November 2004. See page 751 for details

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NEXT MONTH

VERSATILE PIC FLASHER MK2

The original Versatile PIC Flasher (Dec '02) Christmas Star generated random lighting effects on its various l.e.d.s, with switches providing a choice of different speeds and modulation depths.

This article describes four add-on sensor boards which can be used with the Flasher to control its flashing rate in response to sound, temperature, light and movement. For example, a proximity sensor sends the Star into its "shimmer" mode when someone passes by. You can also talk to the Star, and get a response – kids love shouting at it to "wake up"! It is a good "Christmas Time" design, which might even allow you to suitably light-up Santa!



SUPER VIBRATION SWITCH

This project simulates an old-fashioned vibration switch in which movement of a flexible lever makes contact with an electrical terminal. There are three significant differences, though. First, there is an indicator light, which shows that vibration has been detected. Second, the circuit's output is via a relay, allowing it to be plugged into other circuits having widely varying supply voltages.

The real difference, however, lies in its sensitivity. It may justifiably be described as being "super-sensitive". While the old-fashioned vibration switch is best suited to detecting noticeable motion, this design is capable of picking up very subtle vibrations indeed, depending on its adjustment setting. It will easily pick up a person walking across a wooden floor at virtually any distance (e.g. at the far side of a hall). The author's prototype was capable of picking up a pin striking a wooden floor at two metres distance. It reliably picked up a telephone receiver being put down in the next room!

LIGHT DETECTOR

This project makes use of an l.e.d. as a simple light sensor that generates a photovoltage that varies with light intensity. By comparing the photovoltage with a variable reference voltage, the circuit provides a digital output signal that changes state when the monitored light level crosses a preset threshold.

The detector also provides visual indication by illuminating the sensor l.e.d. when the light exceeds the preset level. In this way, the l.e.d. provides a dual function, acting as both the sensor and the indicator. An optional, optically-isolated output is also available.

WIND DIRECTION INDICATOR

Although designed originally for the use of yachtsmen, this simple wind direction indicator could equally well find use in an amateur weather monitoring station. The input device is a modified mechanical shaft encoder with 4-bit Gray-coded output. The circuit to which this is attached converts the code to a form suitable for driving 16 l.e.d.s arranged in a circle, from which the prevailing wind direction can be seen clearly.



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(LDC441) £4.95 / USB (LDC644) £2.95

NEW! USB 'All-Flash' PIC Programmer

USB PIC programmer for all 'Flash' devices. No external power supply making it truly portable. Supplied with box and Windows Software. ZIF Socket and USB Plug A-B lead not incl.

Kit Order Code: 3128KT – £34.95

Assembled Order Code: AS3128 – £44.95



Enhanced 'PICALL' ISP PIC Programmer

Will program virtually ALL 8 to 40 pin PICs plus certain ATMEL AVR, SCENIX SX and EEPROM 24C devices. Also supports In System Programming (ISP) for PIC and ATMEL AVRs. Free software. Blank chip auto detect for super fast bulk programming. Requires a 40-pin wide ZIF socket (not included)

Assembled Order Code: AS3144 – £54.95

ATMEL 89xxx Programmer

Uses serial port and any standard terminal comms program. 4 LEDs display the status. ZIF sockets not included. Supply: 16VDC.

Kit Order Code: 3123KT – £29.95

Assembled Order Code: AS3123 – £34.95



NEW! USB & Serial Port PIC Programmer

USB/Serial connection. Header cable for ICSP. Free Windows software. See web-site for PICs supported. ZIF Socket and USB Plug A-B lead extra. 18VDC.

Kit Order Code: 3149KT – £34.95

Assembled Order Code: AS3149 – £49.95

Introduction to PIC Programming

Go from a complete PIC beginner to burning your first PIC and writing your own code in no time! Includes a 49-page step-by-step Tutorial Manual, Programming Hardware (with LED bench testing section), Win 3.11-XP Programming Software (will Program, Read, Verify & Erase), and a rewritable PIC16F84A that you can use with different code (4 detailed examples provided for you to learn from). Connects to PC parallel port.

Kit Order Code: 3081KT – £14.95

Assembled Order Code: AS3081 – £24.95



ABC Maxi AVR Development Board

The ABC Maxi board has an open architecture design based on Atmel's AVR AT90S8535 RISC microcontroller and is ideal for developing new designs.

Features:

8Kb of In-System Programmable Flash

(1000 write/erase cycles) • 512 bytes

internal SRAM • 512 bytes EEPROM

• 8 analogue inputs (range 0-5V)

• 4 Opto-isolated Inputs (I/Os are

bi-directional with internal pull-up resistors)

• Output buffers can sink 20mA current

(direct i.e.d. drive) • 4 x 12A open drain

MOSFET outputs • RS485 network

connector • 2-16 LCD Connector

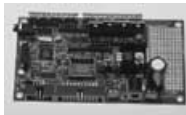
• 3-5mm Speaker Phone Jack

• Supply: 9-12VDC.

The ABC Maxi STARTER PACK includes one assembled Maxi Board, parallel and serial cables, and Windows software CD-ROM featuring an Assembler, BASIC compiler and in-system programmer.

Order Code ABCMAXISP – £79.95

The ABC Maxi boards only can also be purchased separately at £59.95 each.



Controllers & Loggers

Here are just a few of the controller and data acquisition and control units we have.

See website for full details. Suitable PSU for all units: Order Code PSU445 – £8.95

Rolling Code 4-Channel UHF Remote

State-of-the-Art. High security.

4 channels. Momentary or

latching relay output. Range

up to 40m. Up to 15 TXs can

be learned by one Rx (kit

includes one Tx but more

available separately).

4 indicator LEDs.

Rx: PCB 77x85mm, 12VDC/6mA (standby).

Two & Ten Channel versions also available.

Kit Order Code: 3180KIT – £41.95

Assembled Order Code: AS3180 – £49.95



Computer Temperature Data Logger

Serial port 4-channel temperature logger. °C or °F. Continuously logs up to 4 separate sensors located 200m+ from board. Wide range of free software applications for storing/using data. PCB just 38x38mm. Powered

by PC. Includes one DS1820 sensor and four header cables.

Kit Order Code: 3145KT – £19.95

Assembled Order Code: AS3145 – £26.95

Additional DS1820 Sensors – £3.95 each



NEW! DTMF Telephone Relay Switcher

Call your phone number using a DTMF phone from anywhere in the world and remotely turn on/off any of the 4 relays as desired. User settable

Security Password, Anti-Tamper, Rings to Answer, Auto Hang-up and Lockout.

Includes plastic case. 130 x 110 x 30mm.

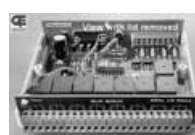
Power: 12VDC.

Kit Order Code: 3140KT – £39.95

Assembled Order Code: AS3140 – £49.95



Serial Port Isolated I/O Module



Computer controlled 8-channel relay board. 5A mains rated relay outputs and 4 opto-isolated digital inputs (for monitoring switch

states, etc). Useful in a variety of control and sensing applications. Programmed via serial port (use our new Windows interface, terminal emulator or batch files). Serial cable can be up to 35m long. Includes plastic case 130 x 100 x 30mm. Power: 12VDC/500mA.

Kit Order Code: 3108KT – £54.95

Assembled Order Code: AS3108 – £64.95

Infra-red RC 12-Channel Relay Board



Control 12 on-board relays with included infra-red remote control unit. Toggle or momentary. 15m+ range. 112 x 122mm.

Supply: 12VDC/0-5A.

Kit Order Code: 3142KT – £41.95

Assembled Order Code: AS3142 – £51.95

PC Data Acquisition & Control Unit

Monitor and log a mixture of analogue and digital inputs and control external devices via the analogue and digital

outputs. Monitor pressure, temperature, light intensity, weight, switch state, movement, relays, etc. with the appropriate sensors (not supplied). Data can be processed, stored and the results used to control devices such as motors, sirens, relays, servo motors (up to 11) and two stepper motors.



Features

• 11 Analogue Inputs – 0-5V, 10 bit (5mV/step)

• 16 Digital Inputs – 20V max. Protection 1K in

series, 5-1V Zener

• 1 Analogue Output – 0-2.5V or 0-10V. 8 bit (20mV/step)

• 8 Digital Outputs – Open collector, 500mA, 33V max

• Custom box (140 x 110 x 35mm) with printed front & rear panels

• Windows software utilities (3-1 to XP) and programming examples

• Supply: 12V DC (Order Code PSU203)

Kit Order Code: 3093KT – £69.95

Assembled Order Code: AS3093 – £99.95

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

Hot New Kits This Summer!

Here are a few of the most recent kits added to our range. See website or join our email Newsletter for all the latest news.

NEW! EPE Ultrasonic Wind Speed Meter



Solid-state design wind speed meter (anemometer) that uses ultrasonic techniques and has no moving parts and does not need

calibrating. It is intended for sports-type activities, such as track events, sailing, hang-gliding, kites and model aircraft flying, to name but a few. It can even be used to monitor conditions in your garden. The probe is pointed in the direction from which the wind is blowing and the speed is displayed on an LCD display.

Specifications

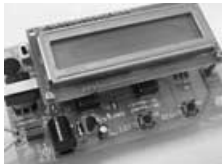
- Units of display: metres per second, feet per second, kilometres per hour and miles per hour
- Resolution: Nearest tenth of a metre
- Range: Zero to 50mph approx.

Based on the project published in Everyday Practical Electronics, Jan 2003. We have made a few minor design changes (see website for full details). Power: 9VDC (PP3 battery or Order Code PSU345).

Main PCB: 50 x 83mm.

Kit Order Code: 3168KT – £34.95

NEW! Audio DTMF Decoder and Display



Detects DTMF tones via an on-board electret microphone or direct from the phone lines through the onboard audio transformer. The

numbers are displayed on a 16-character, single line display as they are received. Up to 32 numbers can be displayed by scrolling the display left and right. There is also a serial output for sending the detected tones to a PC via the serial port. The unit will not detect numbers dialled using pulse dialling. Circuit is microcontroller based.

Supply: 9-12V DC (Order Code PSU345).

Main PCB: 55 x 95mm.

Kit Order Code: 3153KT – £17.95

Assembled Order Code: AS3153 – £29.95

NEW! EPE PIC Controlled LED Flasher



This versatile PIC-based LED or filament bulb flasher can be used to flash from 1 to 160

LEDs. The user arranges the LEDs in any pattern they wish. The kit comes with 8 superbright red LEDs and 8 green LEDs.

Based on the Versatile PIC Flasher by Steve Challinor, EPE Magazine Dec '02. See website for full details. Board Supply: 9-12V DC. LED supply: 9-45V DC (depending on number of LED used). PCB: 43 x 54mm.

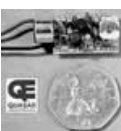
Kit Order Code: 3169KT – £10.95

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

FM Bugs & Transmitters

Our extensive range goes from discreet surveillance bugs to powerful FM broadcast transmitters. Here are a few examples. All can be received on a standard FM radio and have adjustable transmitting frequency.

MMTX' Micro-Miniature 9V FM Room Bug



Our best selling bug! Good performance. Just 25 x 15mm. Sold to detective agencies worldwide. Small enough to hide just about anywhere.

Operates at the 'less busy' top

end of the commercial FM waveband and also up into the more private Air band.

Range: 500m. Supply: PP3 battery.

Kit Order Code: 3051KT – £8.95

Assembled Order Code: AS3051 – £14.95

HPTX' High Power FM Room Bug

Our most powerful room bug.

Very Impressive

performance. Clear and stable output signal thanks to the extra circuitry employed.

Range: 1000m @ 9V. Supply: 6-12V DC (9V PP3 battery clip supplied). 70 x 15mm.

Kit Order Code: 3032KT – £9.95

Assembled Order Code: AS3032 – £17.95

MTTX' Miniature Telephone Transmitter



Attach anywhere along phone line.

Tune a radio into the signal and hear

exactly what both parties are saying.

Transmits only when phone is used. Clear, stable signal. Powered from phone line so completely maintenance free once installed. Requires no aerial wire – uses phone line as antenna. Suitable for any phone system worldwide. Range: 300m. 20 x 45mm.

Kit Order Code: 3016KT – £7.95

Assembled Order Code: AS3016 – £13.95

3 Watt FM Transmitter



Small, powerful FM transmitter. Audio preamp stage and three RF stages deliver 3 watts of RF power. Can be used with the electret

microphone supplied or any line level audio source (e.g. CD or tape OUT, mixer, sound card, etc). Aerial can be an open dipole or Ground Plane. Ideal project for the novice wishing to get started in the fascinating world of FM broadcasting. 45 x 145mm.

Kit Order Code: 1028KT – £22.95

Assembled Order Code: AS1028 – £34.95

25 Watt FM Transmitter

Four transistor based stages with a Philips BLY89 (or equivalent) in the final stage.

Delivers a mighty 25 Watts of RF power.

Accepts any line level audio source (input sensitivity is adjustable). Antenna can be an open dipole, ground plane, 5/8, J, or YAGI configuration. Supply 12-14V DC, 5A.

Supplied fully assembled and aligned – just connect the aerial, power and audio input. 70 x 220mm.

Order Code: 1031M – £124.95



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30, 130, 200 and 300-in-1 project labs also available – see website for details.



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With over 300 projects in our range we are the UK's number 1 electronic kit specialist. Here are a few other kits from our range.

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- 3106KT – 50W Mono Hi-fi Amplifier £19.95
- 3143KT – 10W Stereo Amplifier £9.95
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- 1019KT – Car Alarm System £11.95
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- 1080KT – Liquid Level Sensor £6.95
- 3003KT – LED Dice with Box £7.95
- 3006KT – LED Roulette Wheel £8.95
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- 3063KT – One Chip AM Radio £10.95
- 3102KT – 4-Ch Servo Motor Driver £15.95
- 3155KT – Stereo Tone Controls £8.95
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- 3049KT – Ultrasonic Detector £13.95
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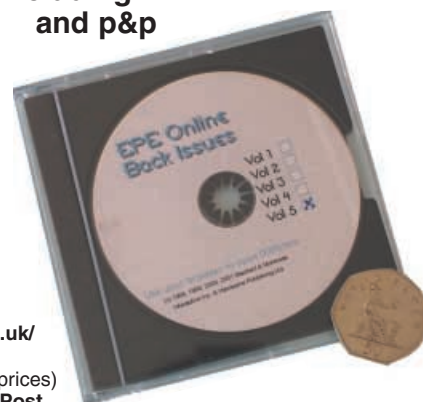
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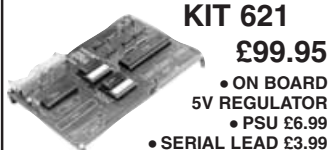
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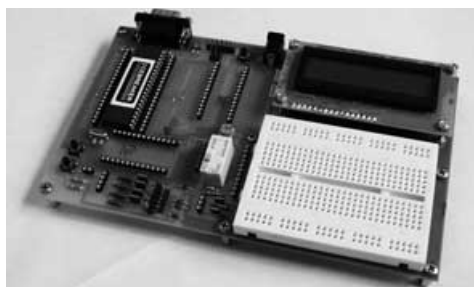
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Back In Time

This issue marks the 40th anniversary of the launch of *Practical Electronics* magazine and John has produced a short piece on the history of the magazine. Interestingly it is also 100 years since Fleming patented the valve (*tube* for our USA readers) so we have come a long way in that time. *PE* was one of the first magazines to use printed circuit boards, introduced stripboard to many hobbyists and later published projects employing integrated circuits. Nowadays few of our projects are without i.c.s. and many of them use chips with thousands of components on.


The sophistication of the electronics we use has changed dramatically over the years – who would have envisaged students programming microcontrollers for their projects – we introduced our readers to microcontrollers just over ten years ago now; or using a PC as part of a test equipment set-up, or asking about floating point maths for PIC microcontrollers?

The Future

Predicting the future is always fraught with pitfalls but I do wonder where we will be in another 40 years time – I doubt I will be around to see it and I do wonder if hobbyists will still be able to keep up with cutting edge technology.

At the present time it is still possible to restore and repair radio equipment from the 1920s through to the 1970s (as proved by our sister magazine *Radio Bygones* which, interestingly, has only been around for 15 years – still in “short trousers”!), but items made after that date are much more difficult to service due to the lack of availability of any specialist i.c.s used. Obviously as technology progresses more and more of it becomes “throw away” once it goes wrong. Although, hopefully, breakdowns become less frequent.

Maybe our hobby will actually become retro in the future.



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Thunderstorm Monitor

Thomas Scarborough

Lightning poses a significant risk to us all, it causes more deaths than do most other natural hazards, including hurricanes and tornadoes. This low-cost “early warning” monitor will indicate the possibility of a thunderstorm in advance of any thunder or lightning, greatly reducing the risk of injury.

THERE is at least one good reason why you should consider building a Thunderstorm Monitor. Scientific studies have shown that by the time you hear the most distant rumble of thunder, or see the most distant flash, it may already be too late. You are already within range of the next lightning strike. That is, as humans we are incapable, through our five senses, of receiving timely warning of a possible strike.

Two leading lightning researchers in Japan (N. Kitagawa and A. Sugita) recently stated, “It is concluded that there exists no safe time interval during which a human is free from direct strikes.”

In keeping with this, it has been shown that a thunderstorm’s danger zone covers a radius of at least sixteen kilometres (or 800 square kilometres’ area) beyond a given lightning strike. A classic example of this is the phrase “bolt from the blue” – that is, a lightning strike under clear skies, which often happens “within range” of a nearby thunderstorm. This phenomenon is so common that it has become an idiom of the English language.



At Risk

Lightning is not an insignificant risk to humans. It causes more deaths than do most other natural hazards, including hurricanes and tornadoes. The author knows several people who experienced near misses from lightning – including his wife, who was once missed by a mere four metres! She was sitting outside to admire the storm at the time.

The risk is particularly acute if you should be standing out in the open, or should find yourself on open waters when a thunderstorm approaches. Patrons of golf clubs, soccer clubs, and boating clubs are at particular risk – not to speak of the clubs themselves, which might be held liable for injury or death if they have no early-warning system or lightning safety policy in place.

Alas, you are not necessarily safer indoors. Another major cause of lightning strikes on humans is electrical equipment they happen to be handling at the time – a leading offender being the telephone. Moreover, when talking on the phone, you are less likely to hear that distant rumble, or to see a flash, and might quite unwittingly be speaking your “famous last words”. No less than one in four lightning injuries in the UK is caused through the telephone.

Having said this, direct strikes on humans are not the only hazard. Lightning poses a significant risk to livestock, forests, power transmission and distribution apparatus, buildings, electrical

equipment, and in particular computer equipment.

Conventional wisdom until recently held that computer systems should be shut down when lightning approached to within about three kilometres’ radius. This is now considered inadequate, with a minimum of ten kilometres being considered more realistic.

Principle of Operation

There are two broad approaches to lightning detection. The design presented here represents the less common of the two.

The most common approach is to detect electromagnetic pulses emitted by lightning flashes, and this is the method most often used by meteorological (met) offices. However, while it is very effective, it is still by no means a failsafe warning system – the reason being that it relies on the detection of *prior* lightning discharges. That is, if you should be extraordinarily unlucky, the first large discharge of a storm might be the one to strike *you*!

The alternative is to monitor atmospheric charge – or, related to this, *instability* of atmospheric charge. The present circuit takes the approach of detecting and reporting an unusually high charge on the atmosphere – or rather, an unusually high potential difference between the atmosphere and the earth.

At first the author sought to detect instability of atmospheric charge, which is typical of a building thunderstorm. This *instability* may in some cases be considerable.



But since lightning strikes average only one per square kilometre per annum in his home city Cape Town, he felt that he did not have sufficient "material" to turn out a dependable and repeatable circuit.

However, not much is lost by this, since it is not a given phenomenon that thunderstorm activity will cause significant unsteadiness of atmospheric charge – and conversely, ordinary cumulus clouds, and sometimes sudden and unexplained shifts in atmospheric charge may be reported by a circuit as instability – not to mention people walking past the antenna, or electromagnetic pulses (e.g. fluorescent lighting) in the vicinity.

What seemed to be the most dependable indicator of a looming thunderstorm was the *overall* level of atmospheric charge, which was thought to offer fair warning of potential lightning strikes. After all, without a significant potential difference between the atmosphere and the earth, there can be no lightning strike.

Usually this potential difference covers a large part of the sky, so that the Thunderstorm Monitor would report a raised charge many tens of kilometres away from the epicentre of any electrical activity. In theory, therefore, the circuit should have a range well beyond that of our five senses.

However, it needs to be borne in mind that sometimes a raised atmospheric charge may be localised, and the potential difference between the atmosphere and the earth can change very quickly (that is, within minutes) as a charged thunderhead races across the landscape.

Observations

The author found one common factor between most of the storms which he monitored. This was a greatly increased charge on the atmosphere, which easily exceeded the average daily maximum.

On an average day, at sea level, the average daily minimum charge will be roughly 100V per metre elevation, and the average daily maximum charge roughly 135V.

When there is thunderstorm activity nearby, atmospheric charge may rise to hundreds if not thousands of volts per metre elevation. The present circuit switches a relay (and any alarm attached to it) when an estimated 170V per metre elevation is detected – i.e. twice the average daily maximum variation. This avoids meaningless triggering on the one hand, yet is very responsive on the other.

In most cases, the Thunderstorm Monitor picked up the possibility of a thunderstorm well in advance of any thunder or lightning. However, in two cases, atmospheric charge remained unexpectedly low (about 125V per metre elevation), while lightning was seen over the Atlantic at a few kilometres' distance.

Whether these "phantom" thunderstorms would have represented any real danger is unknown, although it is thought unlikely. In one case, such lightning preceded a "real" thunderstorm which moved in about an hour later.

It would therefore seem that, just as there are dangerous situations where no danger is perceived, there may be lightning and thunder within several kilometres' distance which represents no immediate dan-

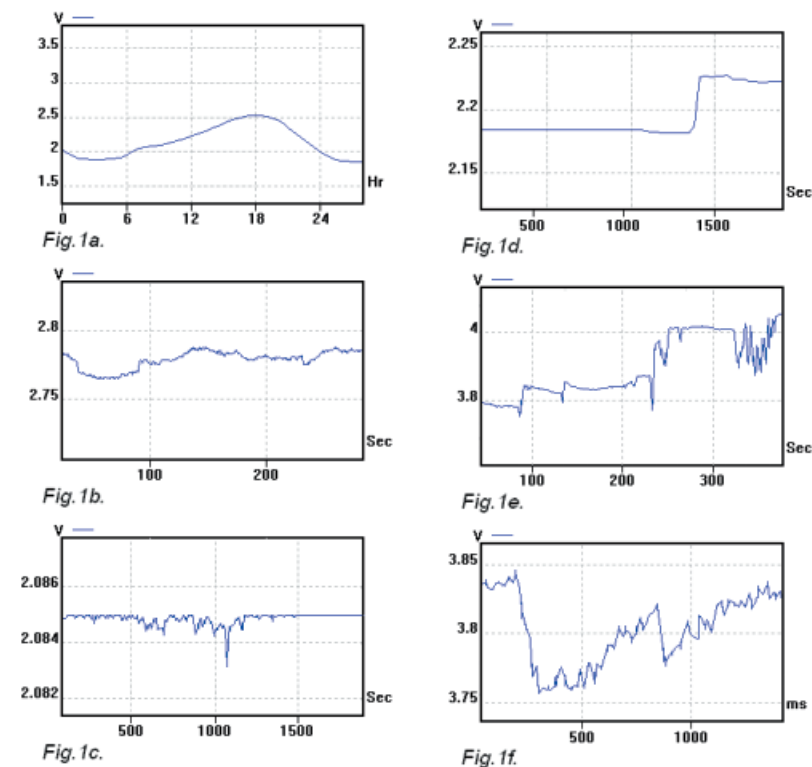


Fig.1. Different atmospheric activity graphs. Most days the atmospheric charge meanders slowly up and down (a); on cloudy days it's more "lumpy" (b); at times the readings become very lively without a storm, likely indicating electrical activity at a distance (c); occasionally, unexplained "quantum leaps" of charge occur (d). A breaking thunderstorm is shown in (e) and a high speed record of a thunderstorm directly overhead is shown at (f).

ger. It would seem a shame, for instance, to call off a wedding reception because of some rumbling in the sky, when the atmospheric charge in fact remains within the normal daily variation.

Activity Log

Atmospheric activity was monitored on and off for a year, by means of a computer logger attached to IC1 output pin 6 (solder pin C in Fig.4). In practice, this output voltage is "clamped" between 1.48V and 4.16V – nonetheless, the results are very informative. (In contrast, the final prototype described here offers a full scale deflection readout.)

Different vertical (atmospheric charge) and horizontal (time) axes are shown in the graphs of Fig.1a to Fig.1f. On most days, atmospheric charge meanders slowly and steadily up and down (Fig.1a). On cloudy days, the graph is more "lumpy", with cumulus clouds in particular raising the atmospheric charge (Fig.1b).

There are times when readings become very lively, even without a storm. Often such episodes are on a small scale, measuring less than 0.1V (Fig.1c), likely indicating electrical activity at a distance.

Occasionally, inexplicable "quantum leaps" of charge occur (Fig.1d). The jagged ascending patterns of Fig.1e show a thunderstorm breaking, and finally, Fig.1f is a high speed record of a thunderstorm directly overhead (note that recording this was not without risk to the author's logger and computer system).

During a thunderstorm, a negative charge builds up in the lower regions of the clouds in relation to the earth. When the electrical difference between a thundercloud and the ground overcomes the insulating properties of the surrounding air, a cloud-to-ground lightning strike occurs, with the cloud discharging to earth. Not all strikes are of this nature, however, with many lightning flashes occurring within the clouds themselves, and a few strikes (about 10%) discharging from earth-to-cloud.

When a cloud discharges to earth, atmospheric charge, within milliseconds, will dramatically drop, then rapidly return close to its original level. Not only does the charge drop beneath the cloud itself, but it may drop across the entire visible atmosphere.

During observations, it was noted that variations in atmospheric charge frequently *predicted* weather conditions – in particular, giving a good indication of likely flooding at the complex where the author works. This has him puzzled as to why weather stations seldom, if ever, incorporate measurements of atmospheric charge.

Block Diagram

The block schematic diagram for the Thunderstorm Monitor is shown in Fig.2. It begins with a 5V regulator (IC4), which is required to provide a suitable voltage for IC1 in particular, and to ensure stability for what is a very sensitive circuit.

The “engine room” of the circuit is represented by comparator IC1, which includes an antenna and an earth. Note that the circuit is ground referenced (the earth), since one is measuring the potential difference between the atmosphere and the ground.

Atmospheric charge monitors are often complex circuits – however, this does not have to be the case, as this circuit shows. Beyond IC1, all the rest of the circuit merely provides an “interface” to the user. A number of options exist for the interface, one of which is a three-stage bargraph (IC2b to IC2d), which is translated to a three-stage dot-mode “traffic light” i.e.d. display by means of decoder IC3 (an 8-way bilateral switch).

Therefore, when atmospheric charge is low (within daily averages), a Green i.e.d. illuminates. When it is raised, an Amber i.e.d. illuminates. When it is high, a Red i.e.d. illuminates. Further, when the red i.e.d. is on, a relay is triggered.

A relay was chosen here above, say, a pulsed alarm at the output, since one might wish to use the Thunderstorm Monitor in situations where a more powerful alarm would be required, or to switch other circuits.

Further options are provided to attach a VU meter, a 100µA meter, or a 200mV digital meter. In this case, IC2a is used as a buffer, to prevent the output of IC1 from being skewed through undue loading. These meters all provide full scale deflection (f.s.d.), as described below.

The moving coil meters in particular give a very useful visual impression of atmospheric instability. As a thunderstorm approaches, even at a distance, they may visibly begin to twitch. A high impedance multimeter or computer logger may also be attached either at the output of IC1 – in which case the output voltage is “clamped” as described above – or may be attached to the output of IC2a (see below).

Circuit Details

The author first encountered the present approach to lightning detection in an electronics publication of 1965. The core of this circuit is shown in all its magnificent detail in Fig.3.

This represents a simple potential divider, with the potential at the emitter varying with atmospheric charge. The original circuit added a meter at the output.

The germanium transistor, which is now obsolete, was evidently very carefully selected. However, unsatisfactory results were obtained with a modern-day equivalent and therefore, a j.f.e.t. op.amp. wired as a simple comparator, was tried and produced very good results.

With the prototype antenna being about 2.2m in height, the voltage at the tips of the antenna must be in the region of 220V to 300V. However, atmospheric current is so small (a mere 2 picoamps per square metre), and the input impedance of most test equipment so low (relatively speaking), that this voltage is practically unmeasurable. If, however, input impedance is raised sufficiently, a meaningful result can be obtained, although with much reduced voltage.

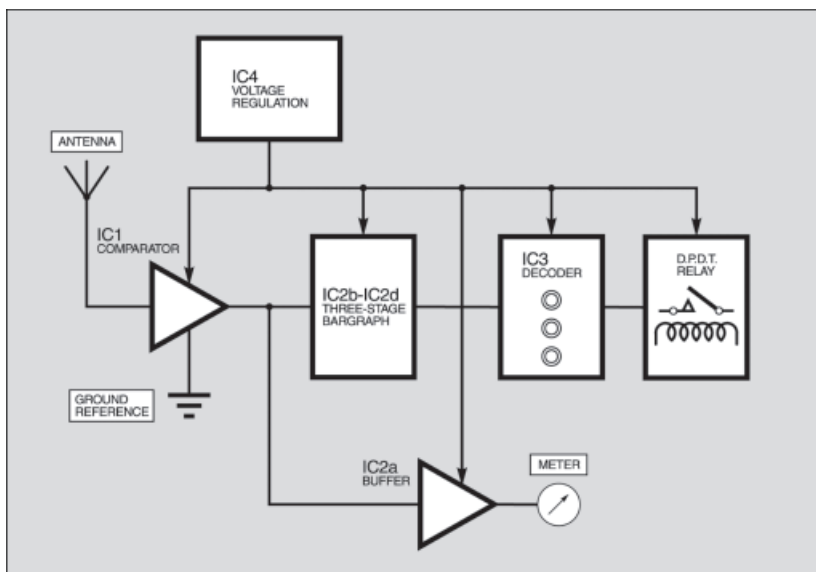


Fig. 2. Block diagram for the Thunderstorm Monitor.

The full circuit diagram for the Thunderstorm Monitor is shown in Fig. 4. The TL071CN j.f.e.t. op.amp. i.c. was chosen for IC1, chiefly for its high input impedance of around 1T, or 50pA. This reduces atmospheric charge at 2.2 metres' height to an estimated 1V at the non-inverting input (IC1 pin 3).

By way of comparison, if one were to use a 741 op.amp. instead, one would measure nothing at all, even though its open loop voltage gain is very similar to that of the TL071CN. All of the charge would be lost “down the tip” of the op.amp.’s hungry non-inverting input (about 700nA).

At the very height of a thunderstorm, the input voltage at IC1 pin 3 may rise quite high – potentially higher than the supply voltage of IC1 – and IC1 could be at risk. Yet such a situation should be rare.

If protection circuitry were added at the input, this would drain away precious picoamps, which this circuit cannot afford. In a worst case scenario, the Thunderstorm Monitor could trigger an alarm for a while – then blow out!

The TL071CN i.c.’s open loop voltage gain (106dB) is almost perfectly suited to measuring atmospheric charge – yet it is a little on the high side, which causes output voltage swings which are a little too wild. Therefore, a small amount of feedback is

applied in the form of resistor R1 to reduce the gain.

User Interface

Virtually all of the rest of the circuit represents standard electronics. Operational amplifiers IC1b to IC1d form a simple three-stage bargraph circuit (see *Teach-In 2004*, *EPE* April 2004), whose outputs read binary 100, 110, or 111. These binary numbers are decoded to decimal through IC3, an 8-way bilateral switch, giving the “traffic light” display mentioned earlier. An additional stage (binary 000) would be available through IC3 pin 13. Ballast resistor R7 is inserted before the common terminal (pin 3) of the bilateral switch.

The three op.amps IC1b to IC1d are used in preference over a standard bargraph i.c., since their resistor chain R3 to R6 may be adjusted to order. As shown, the green i.e.d. D3 begins to illuminate when IC1’s output rises to around 1.9V (or a little more), the amber i.e.d. D4 when it rises to around 2.9V, and the red i.e.d. D5 when it rises to around 3.5V. There is just a little overlap between the i.e.d. colours displayed.

The binary 111 output (decimal 7), at IC3 pin 4, is further used to switch a relay (RLA) via transistor TR1. In order to overcome any relay judder as amber switches to red, capacitor C1 is inserted at IC3 pin 4. The specified d.p.c.o. sub-miniature relay is rated at 2A, with a maximum switched voltage of 220V d.c. or 250V a.c. per set of contacts (two sets of contacts are twinned on the printed circuit board, thus raising the rating to 4A). Other 5V relays may be pressed into service here provided a protection diode is included against back-e.m.f., and, of course, the contact ratings are able to handle the requirements of any additional alarm device being used.

Monitoring Meter

If a logger or multimeter is used to monitor atmospherised ric charge, it is recommended that a switch be ito temporarily disconnect relay RLA, since the activation of the relay may unduly influence results.

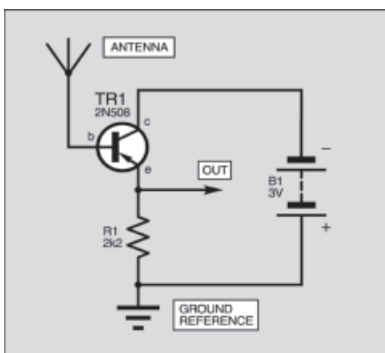


Fig.3. Early detector circuit using a germanium transistor.

THUNDERSTORM MONITOR

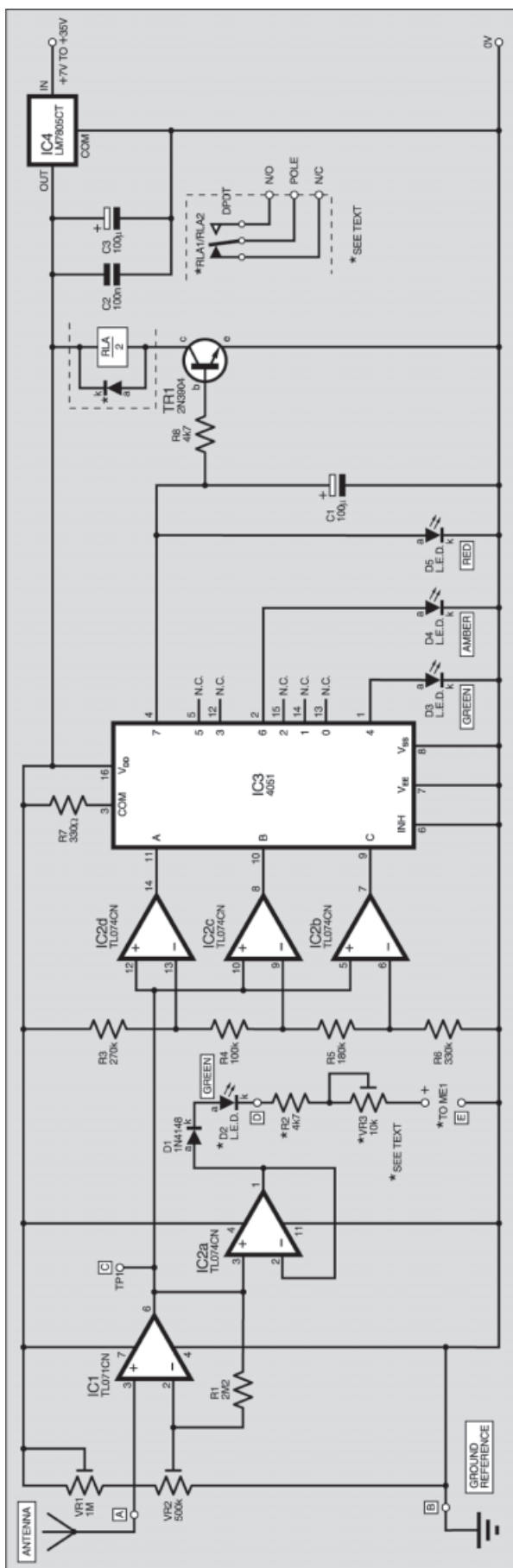
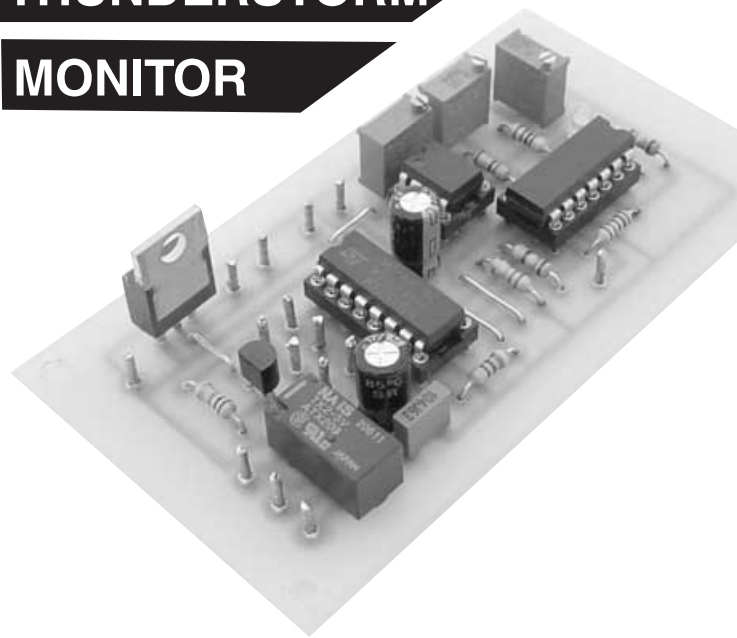


Fig.4. Complete circuit diagram for the Thunderstorm Monitor.

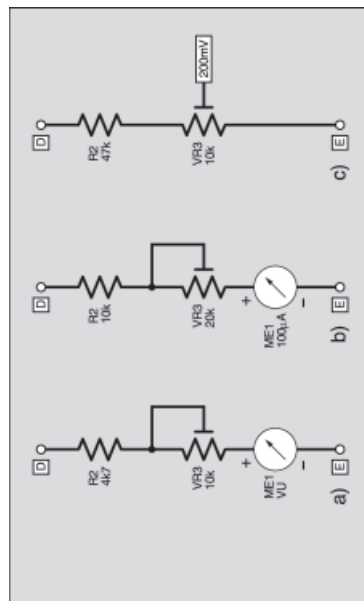


Fig. 5. Adding a VU meter (a), a 100A μ meter (b) or a 200mA digital voltmeter/multimeter.

If desired, an integral moving coil meter may be added to the Thunderstorm Monitor. This has been incorporated in the prototype model, and provided for in the circuit diagram. As already mentioned, the output voltage of IC1 is "clamped" between 1.48V and 4.16V, while ideally a meter would have full scale deflection (f.s.d.).

With this in mind, op.amp IC2a serves as a buffer, which prevents the current drain of the meter from skewing the output voltage of IC1. Diodes D1 and D2 serve to drop virtually all of the "dead zone" below 1.9V. Resistor R2 and preset VR3 then adjust the current through the meter. The meter may be a standard VU meter (Fig.5a)

or a 100 μ A d.c. moving coil meter (Fig.5b). Note that the value of R2 is 4k7

and the value of VR3 10k for a VU meter, and the value of R2 is 10k

and the value of VR3 20k for a 100 μ A meter.

If R2 is replaced with a 47k resistor, and if the short link wire beside preset VR3 is removed from the p.c.b. (see Fig.7), then with the VR3 wiper being taken to a 200mV digital voltmeter, one could obtain a digital read-out (Fig.5c). This same arrangement could also feed a multimeter or computer logger set to its 200mV scale.

Finally, a common 7805 +5V voltage regulator (IC4) is used. This will accept a supply voltage between 7V and 35Vd.c. The Thunderstorm Monitor's power consumption (without an integral meter) is typically 15mA, therefore a quality plug-pack power supply would be recommended for long-term use.

Construction – Circuit Board

The Thunderstorm Monitor circuit is built up on a printed circuit board (p.c.b.) measuring 97mm × 54mm. This board is available from the *EPE PCB Service*, code 470. The p.c.b. topside component layout and full-size underside copper foil master are shown in Fig.6. The author's prototype worked satisfactorily in an ABS plastic case, although a metal case, connected to 0V on the p.c.b., would help stabilise performance in electrically "noisy" situations.

By way of preparation, take preset VR1, and adjust it about half way – that is, to about 500k. Preset VR1 serves merely to match temperature coefficients, and once it has been soldered into place, is not touched again. A 470k resistor could serve just as well here, but could cause a little drift if not temperature matched with preset VR2.

In its simplest form, only R1, VR1 and VR2, C2 and C3, IC1 and IC4, as well as i.c. sockets and the various link wires and solder pins need to be soldered into place. This would be sufficient to monitor atmospheric charge with a high impedance multimeter or computer logger attached to solder pin C (TP1).

The "next step up" would be to add an integral meter (ME1) or a 200mV voltmeter, for which R2, VR3, D1, D2, and IC2 (and the required 14-pin i.c. socket) would need to be inserted on the p.c.b. However, a meter, unless taken e.g. from old hi-fi equipment, may cost significantly, and this whole section of the circuit may therefore be omitted. The author used an old VU meter (250µA) with backlight, taken from a junked hi-fi system.

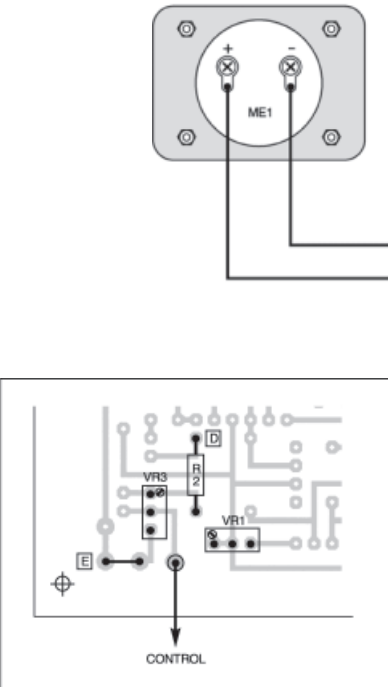
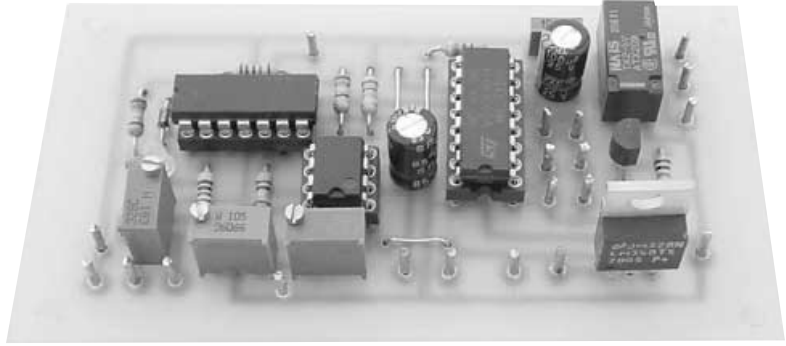


Fig.7. Modification to the p.c.b. wiring so that a 200mV digital voltmeter can be used. This same arrangement could also feed a multimeter or computer logger set to its 200mV scale.



Layout of components on the completed circuit board.

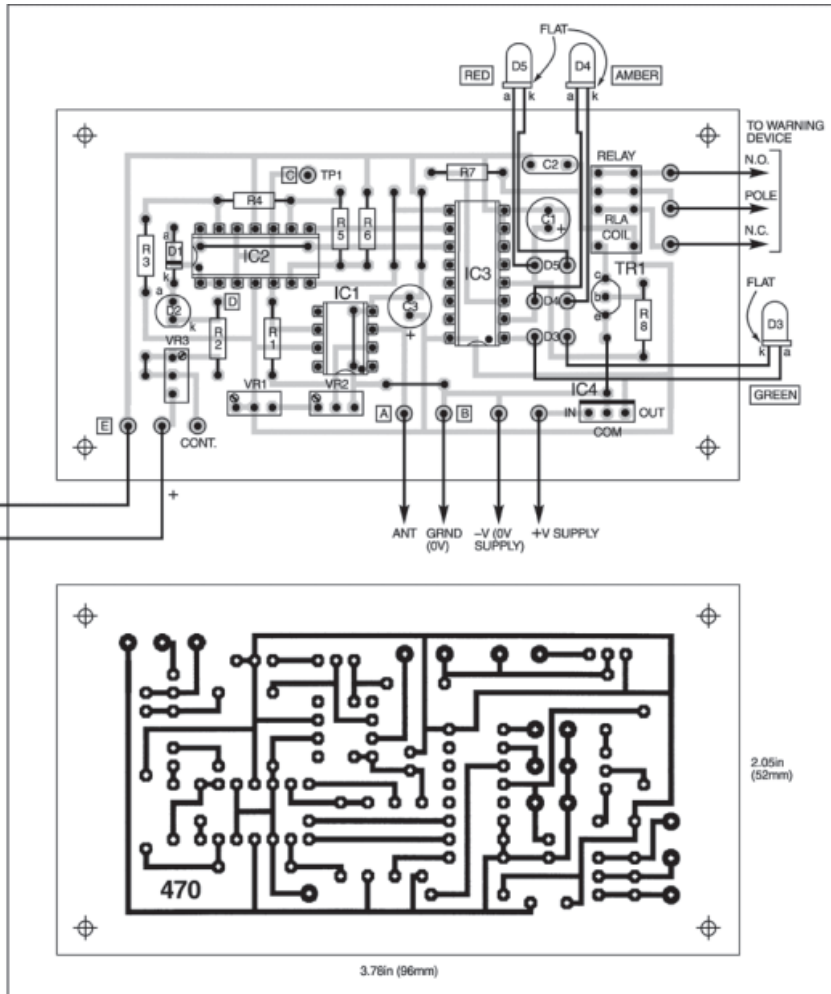
Depending on the option selected, take note of the component values shown in Fig.5a to Fig.5c. If a voltmeter is used, then the link wire next to preset VR3 needs to be omitted (see Fig.5), and an additional link wire inserted between VR3 and solder pin E as shown. The meter's control wire is taken to the solder pin marked CONT.

Thirdly, a much cheaper "traffic light" readout and relay may be added (relay RLA may be omitted if it is not required, along with R8 and TR1). Solder the relay into place, and the remaining 16-pin d.i.l.

socket (for IC3), the resistors, capacitors, i.e.d.s, and transistor TR1.

The author found it easiest first to mount the necessary off-board components on the case with trailing wires, then to take these wires to the respective solder pins on the p.c.b. The 0V terminals of the off-board components may be commoned before taking a single wire to the p.c.b.

The antenna is attached to solder pin A on the p.c.b., and the ground wire (the screen) to solder pin B. These connections must be very secure.



COMPONENTS

Approx. Cost
Guidance Only

£12

excl. case, meter & power supply.

Resistors

R1	2M2
R2	4k7 or 10k (see text)
R3	270k
R4	100k
R5	180k
R6	330k
R7	30Ω
R8	4k7

All 0-25W 5% carbon film

Potentiometers

VR1	1M multiturn cermet preset, top-adjust
VR2	500k multiturn cermet preset, top-adjust
VR3	10k or 20k multiturn cermet preset, top-adjust (see text)

Capacitors

C1, C3	100μ radial elect. 10V (2 off)
C2	100n polyester

Semiconductors

D1	1N4148 signal diode
D2	3mm green l.e.d. (not super-or ultrabright)
D3	8mm green l.e.d.
D4	8mm amber l.e.d.
D5	8mm red l.e.d.
TR1	2N3904 bipolar

IC1	switching transistor
IC2	TL071CN j.f.e.t. op.amp
IC3	TL074CN quad j.f.e.t. op.amp
IC4	4051 CMOS 8-way bilateral switch
IC4	LM7805CT +5V regulator or equivalent

Miscellaneous

RLA	5V d.p.c.o. sub-min. d.i.l. relay, with 2A contacts 220V d.c./250V a.c. (see text)
ME1	VU meter; 100μA meter or 3-5 digit volt – meter (optional – see text)

Printed circuit board available from the *EPE PCB Service*, code 470; ABS plastic case, size to choice; 8-pin d.i.l. socket; 14-pin d.i.l. socket; 16-pin d.i.l. socket; 8mm l.e.d. mounting bezels (3 off); d.c. power socket, chassis mounting; 10m to 15m quality screened microphone cable; 1m x 1mm dia. enamelled copper wire; on/off switch (optional – see text); 1m metal stake, for "ground earthing"; 3m p.v.c. piping for antenna; cable ties; M3 nuts and bolts (6 off); M3 solder tags (4 off); epoxy glue; link wire; solder pins; solder etc.

A quality power supply is recommended, between 7V and 35V d.c. A chassis mounting d.c. power socket should be mounted on the case for this purpose and a red (positive) and black (negative) lead attached to its solder tags; the red lead connecting to the centre pin. The "free" ends of the leads should be soldered to the positive (+VE) and negative (–V(0V)) pads

on the p.c.b. The author used no on-off switch, since this is a monitor, and is essentially kept on all the time.

Construction – Antenna

The general idea of the antenna make-up is shown in Fig.8. It is constructed of seven lengths of approximately 1mm diameter enamelled copper wire, soldered together

as one at the base. The tips are sharpened with a fine file, so as to improve sensitivity. These seven copper "javelins" are each 70mm long from the point at which they separate from their base, and they form a 70mm diameter circle at their tips in an "umbrella fashion".

At their base, the copper "javelins" are soldered to the core of a 15m to 20m length of quality screened microphone cable. This *must* have a good screen, which cheap substitutes sometimes do not have. The cable's core, at the antenna end of the cable, together with its insulation, protrudes from the screen by 100mm as shown. That is, 100mm of the outer screen and outer insulation is cut away – see Fig.8.

The copper "javelins" are fixed into the top of a length of p.v.c. piping by inserting them in a bung, and fixing this in the pipe with some epoxy glue. The microphone cable is then tied to the pipe with a cable tie to secure it. The whole assembly is

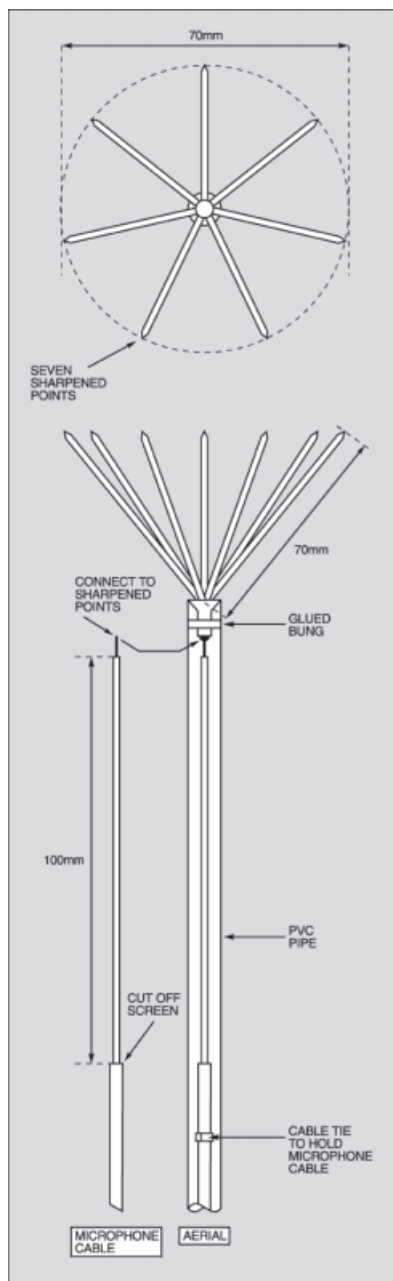


Fig.8. Construction details for the prototype antenna.



Monitor front panel layout.



Case layout and wiring to off-board components.

mounted about 2.2m (at its tips) off the ground, and preferably half a metre or more away from any exterior wall. It is of no consequence whether it is located in an open or leafy area, so long as it does not come into direct contact with flora.

Directly beneath the antenna, at the ground, a section of the microphone cable's screen is exposed (to "show through" the insulation), and is securely connected to a metal stake in the ground (see photograph). The metal stake is hammered half a metre or more into the ground.

For safety purposes, the remaining length of microphone cable (several metres) is buried in the ground, and its far end taken to the Thunderstorm Monitor printed circuit board. While these safety measures would probably be unnecessary, it would be preferable to err on the safe side.

If the Thunderstorm Monitor should be used in a block of flats, the most sensible way to go would be to mount the aerial and earth on the ground (again burying part of the cable in the ground), and to run a quality, screened microphone cable up to the circuit in one's flat. Bear in mind, though, that there might be more electromagnetic interference in a block of flats, and e.g. the operation of a washing machine next door could seriously upset the Monitor.

Setting Up and Use

The Thunderstorm Monitor is best set up by trial and error. In fact, there would be hardly any other way to establish the average daily minimum and maximum atmospheric charge in a particular area.

First of all, before applying power, turn back VR3 (anticlockwise) as far as it will go. This would typically be 25 full turns at the most. Turn up (clockwise) VR2 as far as it will go (again, typically 25 turns). Then connect the power supply. The red l.e.d. should illuminate, and the relay click closed.

If you are using a meter, turn up preset VR3 until the meter reaches its maximum deflection – or until it reaches 200mV if a voltmeter is used (or whatever maximum figure you might wish to use, e.g. 100mV).

Using a G-clamp to secure the Monitor's "earth" lead against the metal "ground" stake.



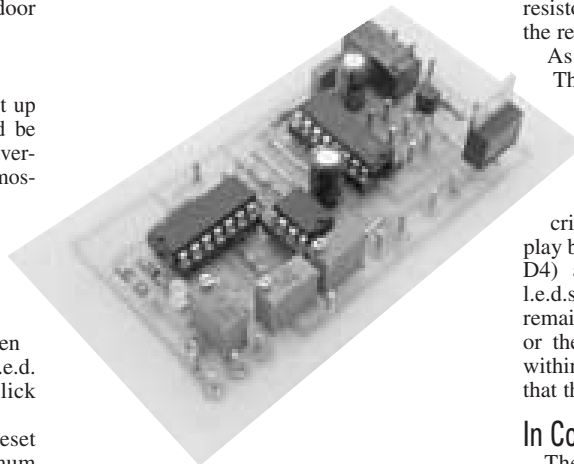
Now you are ready to do an initial calibration of the "traffic light" readout. A multimeter is not essential to setting up, but it would be helpful.

While monitoring the voltage at test point TP1 (C), turn back preset VR2 (anticlockwise). At a certain point (about 3.5V), red l.e.d. D5 should extinguish, and the relay disengage.

At the same time, amber l.e.d. D4 should illuminate – then this should extinguish at about 2.9V. Then green l.e.d. D3 should illuminate, and finally it should flicker on the edge of going out. The voltage at test point TP1 should, at this point, read just over 1.9V.

Note that over most of its range, preset VR2 will show more than 4V or less than 1.6V, and one needs to find the narrow "band" where the voltage at IC1 output pin 6 (at solder pin C) hovers between these two extremes.

After this will come several days if not weeks of observation. If atmospheric charge dips so low that green l.e.d. D3 extinguishes, which it almost certainly will do at first, VR2 needs to be turned up further (clockwise) until D3 again just illuminates. This needs to be repeated only when l.e.d. D3 extinguishes – for the rest, VR2



needs to be left alone. Note again that VR1 merely serves the purpose of matching temperature coefficients, and should be left alone. Do not adjust the circuit during rain or drizzle, or when the ground is wet. Under such conditions, further adjustment needs to be temporarily suspended, no matter what the status of l.e.d. D3.

In the end, one will have an adjustment for the green l.e.d. D3 that more or less corresponds with the daily minimum atmospheric charge – although there may be exceptional days where it dips still lower.

Ordinarily, after adjustment is complete, the Thunderstorm Monitor will nearly always show green. Occasionally, in the author's environment, it showed amber – namely every so many days or weeks, depending on the weather. A red l.e.d. (D5) is a definite indication of an unusually high atmospheric charge, although this need not be accompanied by a thunderstorm.

Your own environment or microclimate might be more prone to thunderstorms or high atmospheric charge, and the circuit might behave differently to how it did for the author.

If your area is particularly "volatile"



Completed antenna head.

(e.g. if you should live on the edge of an escarpment), you could reduce the value of feedback resistor R1 to compress a greater range of atmospheric charge into the same l.e.d. display, or you could adjust the resistor chain R3 to R6 as seems to best suit your situation. As an example, red l.e.d. D5 presently illuminates (in theory) at: $5V \times (R4+R5+R6) \div (R3+R4+R5+R6)$ which equals 3.47V at test point TP1(C). Amber l.e.d. D4 illuminates (in theory) at $5V \times (R5+R6) \div (R3+R4+R5+R6)$ which equals 2.9V at TP1. The values of the resistors could thus be adjusted to change the result of the formula.

As far as possible, keep the Thunderstorm Monitor and its antenna away from any a.c. mains wiring and appliances, and away from human activity.

For the less patient among us, the circuit may initially be tested by critically adjusting preset VR2 to display both green *and* amber (l.e.d.s D3 and D4) at the transition between the two l.e.d.s. Atmospheric charge is unlikely to remain at the same level for long, with one or the other l.e.d. extinguishing – likely within a few minutes. This would confirm that the unit is working.

In Conclusion

The US National Lightning Safety Institute warns, "*Beware of a false sense of confidence from detectors. None of them will detect all of the lightning all of the time.*" The first recommendation of the Institute is – rent a meteorologist! This is apparently the best way to go if you should wish to be free from public liability in particular (apart from any injuries or deaths)!

Having said this, the thunderstorm Monitor will without doubt greatly reduce the risk of injury or death by lightning strike, not to mention the interesting observations of atmospheric charge it will provide.

A final anecdote should well illustrate the inability of humans to assess the likelihood of lightning through our five senses alone.

In the early stages of testing, the Thunderstorm Monitor indicated to the author that a thunderstorm should be overdue. The atmospheric charge had risen unusually high. When no thunder was heard, he walked outside onto the veranda. It was a cool evening, with mist rolling in from the sea – hardly the weather, he thought, for a thunderstorm. Yet while he was still peering into the mist, thunder rumbled across the sky. □

BLUE IS THE COLOUR TO WATCH

Blue lasers can double the playing time of CDs – but is there a colour battle with the reds? asks Barry Fox

THE electronics giants are gearing up for the fight to make blue laser recording the next big thing. There are two systems (Blu-Ray and HD-DVD) which are every bit as incompatible and impossible to combine as VHS and Beta. The fight is also turning into a show down between traditional electronics companies.

Now there is a third contender in the ring. Clever new technology currently reaching the shops doubles the recording time of today's red laser DVD recorders, by letting the disc record twice on the same side. These new double length home recordings will play back on the millions of DVD players already sitting in homes round the world.

So consumers will soon have to choose between two completely new and incompatible blue systems that record a lot, and a compatible red system that records a bit less.

Dual-Layered Scenario

VHS has been around so long that most people forget how it works. Slow moving magnetic tape is scanned by a rapidly rotating head. Although one cassette can store several hours of analogue video, the picture and sound quality is poor when compared to digital DVD. Rewinding the tape takes an age, and finding recordings lost in the middle is infuriating, especially when compared to skipping the laser over the surface of a CD or DVD.

DVD uses a red laser to record 4.7GB of digital data on each side of a 12cm disc. The disc is made by gluing together two – separately pressed – halves of a sandwich, each 0.6mm thick.

Even with digital MPEG compression, 4.7GB is not enough to hold a feature length movie in full quality, with surround sound. Splitting the movie between two sides of the disc is possible, but there is nowhere to put the label and the viewer must get up from the sofa and turn the disc over half way through the movie.

Skipping The Light

So right from Day One the DVD standard has provided for dual layer recording. Two completely different recordings are pressed into the disc material, at slightly different depths, giving a total capacity of 8.5GB, which is enough for even the longest movie. The laser in the player skips focus from one layer to the other, half way through. There may be a slight jerk in the action on screen, but few people notice.

So far dual layer technology has only worked for movie discs pressed in factories. Now Philips, working with Mitsubishi Chemical and its subsidiary Verbatim, has found a way to make dual layer DVD recordings in the home, on a computer burner or consumer deck. The first burners go on sale in a few weeks for just 169 Euros. Home recorders, like VCRs, will go on sale before the end of the year.

"Our target is for dual layer blank discs to cost around $\times 1.5$ the price of today's single layer blanks" says Wim Koppers of the Philips Research lab which developed the system. Single layer blanks already sell for around \$1 and the price is falling. So recording to DVD will soon be a lot cheaper than VHS – as well as giving better pictures and sound and being much more fun.

Tall Order

Making a laser burn two recordings just 55 micrometres apart in depth was a very tall order. Both the recording layers are made from a dye which changes shape and colour when heated by a laser. The upper layer has to absorb half the laser light while it is recording, and let through half the light when the laser is refocused to record onto the lower layer.

Both layers need a silver alloy coating to reflect light during playback. But the reflective coating must also let through enough light to allow recording.

So far the dual layer home system only works with write-once blanks, but Philips believes it can later make dual layer erasables. Whether this is needed, is a moot point, though. If write-once blanks are cheap enough, most people will not bother to reuse erasables – just as few people bother to reuse audio or video tapes.

Blu-Ray

Tomorrow's blue laser systems use the tighter focus of the shorter wavelength light to store around 20GB on a 12cm disc. This is good news for people in the USA and Japan who want to record the high definition TV services there. But for most viewers with ordinary TV, the prospect of buying a completely new and expensive recording system, just to get more time on a disc, is not appealing. Industry infighting makes it even less appealing.

All the traditional consumer electronic companies, led by Philips, Sony, Matsushita (Panasonic) and Sharp, are backing a system called Blu-Ray. The disc

is single-sided, the same size (12cm) as a CD or DVD and the same thickness, 1.2mm. But the recording layer is only 0.1mm thick. The laser only has to "see" through a very thin layer, so there is less risk of beam distortion if the disc is out of true. Blu-Ray stores around 25GB. Because the discs are so different, new pressing plants are needed.

Toshiba and NEC came up with HD-DVD. Double-sided discs are made like DVDs by gluing two 0.6mm discs back-to-back. So HD-DVD discs can be pressed on modified DVD presses. But the laser has to see through 0.6mm of plastics, and beam distortion is more of a problem. So HD-DVD softens focus and reduces storage capacity to 20GB per side.

The DVD Forum, which sets the standards for DVD, has been comparing the two different basic approaches – 0.6mm and 0.1mm. After a change in voting rules, and massed support for HD-DVD from Microsoft, IBM and Intel, HD-DVD won by one vote.

Official Standard

Officially, HD-DVD is now the future blue laser standard. But the Blu-Ray group says it will go ahead anyway, because Blu-Ray is so different from DVD that it does not need the Forum's blessing. Sony is already test-marketing Blu-Ray recorders in Japan.

The new systems have only one thing in common; the potential to make better copies of more music and movies. This is terrible news for Hollywood which has used the short recording time of home disc blanks as a practical weapon against piracy. By spreading a movie over the two layers of a single side, the studios can stop people setting a recorder running before going out to the pub, to find a completed digital clone when they get back. Now that DVD blanks can match the capacity of a pressed movie disc, unattended cloning is possible.

Says Ted Shapiro, General Counsel for Motion Picture Association:

"We aren't against new technology – the DVD is proof that we have embraced it. We are against misuse of new technologies. The DVD system already has copy-protection and the makers of all recorders, single or dual layer, are obliged by their licences to use it. We shall do whatever we can to stop anyone selling any hardware of software that defeats it."

Valve Centenary

On 16 November 1904 Dr John Ambrose Fleming filed his patent application for United Kingdom Patent No. 24,850 – one of the greatest British inventions, generally known now as a "valve" ("tube" in some parts of the world). It functioned as a diode.

Although the rectifying action of an evacuated chamber containing a heated filament and an independent electrode was discovered by Thomas Edison, he did not know what to do with it. Fleming applied the "Edison Effect" to the new technique of wireless telegraphy. Fleming's patents show that much of his work was carried out in conjunction with Marconi. In association with Marconi's company he even filed a patent for a portable two-way wireless – drawn by one or more horses!

The filed Provisional Specification of Fleming's valve patent was entitled Improvement in Instruments for Detecting and Measuring Alternating Electrical Currents, in which: "I John Ambrose Fleming of University College, Gower Street, in the County of London, Doctor of Science, do hereby declare the nature of this invention ... to provide a means by which an ordinary galvanometer can be used to detect and measure alternating electric currents and especially high-frequency alternating currents commonly known as electric oscillations.

"... In a glass bulb, I seal two or more carbon filaments such as are used for the manufacture of electric lamps. These filaments have their own separate terminals ... A high vacuum must be made in the bulb. Two such bulbs are employed ... each associated with a small insulated primary or secondary battery of sufficient voltage to bring one of the filaments to bright incandescence of greater intrinsic brilliancy than if used as an incandescent lamp. The bulbs are connected in parallel with each other and inserted in the alternating current circuit ... In series with one of the bulbs is placed an ordinary galvanometer ..."

A hundred years – and look where we are now. Would Fleming recognise any of it? Well, probably, because improvements on his valve continue to be in widespread use and development, despite the dominance of semiconductors. It has been said, of course, that had Fleming not invented the valve, the already-known attributes of basic semiconductor crystals might have been developed earlier and more significantly, rather than having to wait several decades, resulting in the transistor being invented, and first introduced to the world in 1947.

Doncaster Aeroventure

The Doncaster Aeroventure Military & Aviation Electronics Mart takes place on Sunday 31 October 2004 at the S.Y.A.M. Doncaster Aeroventure site, from 9.00am to 1.00pm. Admission is £2, concessions £1. The event is for constructors, restorers and collectors of military equipment, electrical, radio and radar equipment up to the 50s and 60s, both commercial and military. You are invited to buy, sell and swap pieces of kit, transmitters, receivers, components, connectors, cables, handbooks, testgear, and those odds and ends you've had for years and cannot use!

Maplin Bought

Maplin Electronics has been acquired by Montagu Private Equity, who paid £244 million to its major shareholder, Graphite Capital, and the management team.

Keith Pacey, Maplin executive chairman said, "over the past three years Graphite Capital has supported us as we developed new retail formats and store locations. This is just the start. We are looking forward ... to realise the full potential of expansion opportunities ... at home and abroad."

In 2003, Maplin had a turnover close to £100 million, 14,000 products, 89 retail stores and around 1500 staff.



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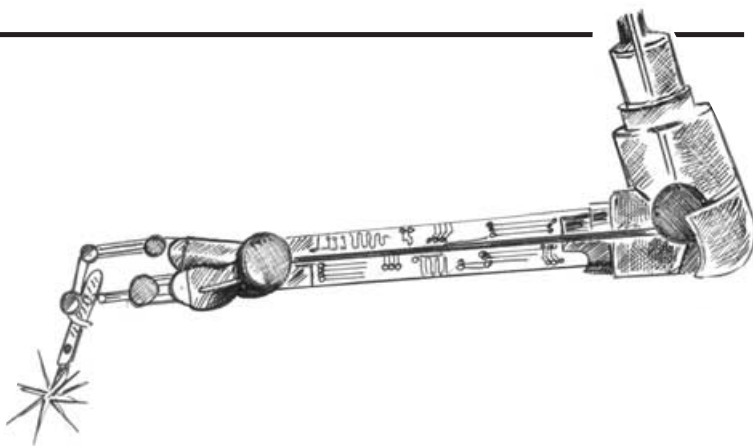


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Circuit Surgery

Alan Winstanley and Ian Bell



This month it's back to basics, discussing current flow, the operation of diodes and Zener voltage reference diodes.

Zener and the Art of Voltage Regulation

I want to switch on a circuit with a supply voltage if it reaches a predetermined threshold voltage. For example, I only want the circuit to be powered from a variable power source if the voltage exceeds 9V or so.

Also, can I ask a definite newbie question... what are Zener diodes? What do they do?

Posted by **DanH** in the EPE Chat Zone.

Our Internet message board at www.epemag.wimborne.co.uk is simple to use and is an open forum where you can discuss electronics-related topics. In this month's *Circuit Surgery* we examine current flow and diode terminology for beginners, explaining how to use Zener diodes along the way.

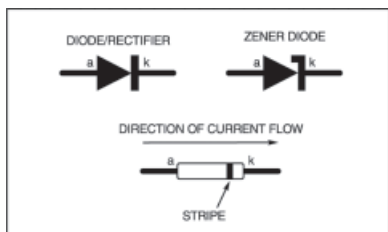


Fig.1. Symbol and appearance of a diode and Zener diode.

A diode is a "unidirectional" device, i.e. it allows current to flow in one direction only. Diodes have countless applications in most electronic circuitry. A semiconductor diode has two terminals as shown in Fig.1. Current can flow through the diode in the direction from anode (a) to cathode (k) in its *forward-biased* mode, but in the reverse direction, current will be blocked; in this latter state the diode is said to be *reverse biased*.

A small sensitive diode designed for use with radio or audio signals, for instance, is classed as a *signal diode* whilst a heavier-duty diode as used in e.g. power supply rectification is termed a *rectifier*. More important characteristics to note: a silicon-

based semiconductor diode displays a forward voltage (V_F) of roughly 0.7V when conducting current. In the case of a standard i.e.d., the forward voltage is typically 1.8V to 2V, and as an added bonus the device emits light when conducting as well! Using a voltmeter to check for a correct forward voltage is an easy way of testing a diode.



A 1N4148 signal diode.



A 5.8V (5V8) Zener diode.

There is always a maximum permissible forward current ($I_{F(max)}$) stated by the manufacturer, which if exceeded may destroy the device. This may be anything from a few milliamperes for a signal diode to tens of amperes for a rectifier. And in the reverse-biased mode, there is a limit called the *Peak Inverse Voltage (PIV)* which if exceeded will cause the diode to break down and possibly be destroyed.

Lines and Curves

In Fig.2a. we show a simple graph that explains the voltage characteristics of an ordinary silicon diode. These graphs are sometimes called *characteristic curves*. If you're unsure how to interpret it, the top right quadrant shows the positive (forward biased) situation. As the diode's forward voltage starts to increase (move right from the centre, along the horizontal axis) the current through the diode (vertical axis) starts to rise.

Increase the forward voltage even more, and the plotted line shows us that after a certain point the forward voltage is fairly constant regardless of the level of forward current passing through the diode. In this condition, circuit designers have to ensure that the forward current is limited to a safe value that prevents the destruction of the diode, e.g. by using a series current-limiting resistor.

The left-hand side of the graph shows us what happens when the diode is *reverse biased*. In this mode the "forward voltage"

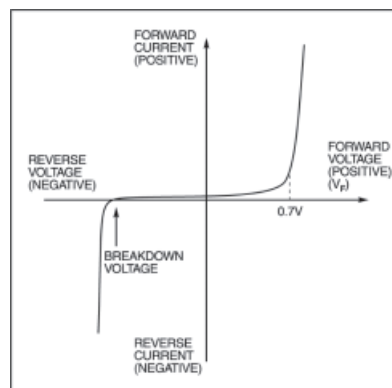


Fig.2a. Voltage characteristic of a silicon diode.

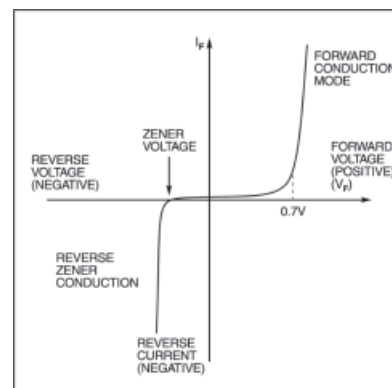


Fig.2b. Characteristic curve of a Zener diode.

seems to be negative, which occurs when the polarity of the voltage across the diode is reversed. As we move towards the left-hand side of the graph, the inverse voltage increases to the point when *avalanche breakdown* eventually occurs and a large reverse current flows, when the device may possibly be destroyed.

A Zener diode is designed to operate in the reverse breakdown region but without the catastrophic effect of total breakdown. The Zener symbol is shown in Fig.1. and the characteristic curve in Fig.2b. When forward biased, Zener diodes behave just like an ordinary diode, but by deliberately reverse biasing it, a reasonably stable reference voltage can be produced when a Zener diode conducts usefully in the Zener breakdown region.

How to use a Zener

In Fig.3 the simplest Zener application is shown. A supply voltage (V_s) is placed across the Zener, which has an all-important limiting resistor R1 placed in series, without which the device will be destroyed. V_{OUT} is the voltage that appears across the Zener diode, which can be used to drive subsequent circuitry. It is very easy and cheap to produce a modest stabilised (or regulated) voltage this way.

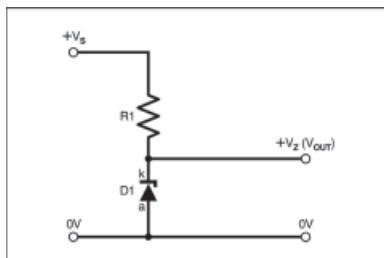


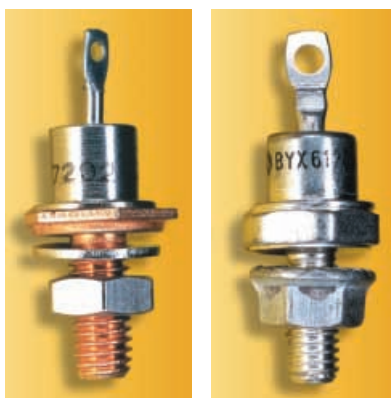
Fig.3. How to connect a Zener diode as a voltage reference. The Zener is reversed-biased as shown.

Even if the supply voltage varies, the Zener voltage remains the same within reason, and the resistor "takes up" any excess voltage. The entire current drawn from the supply also remains at a fixed level.

Some of this current flows through the conducting Zener and the rest is taken by the load connected to the V_{OUT} terminal. This means that when the load draws no current at all, the Zener diode has to be powerful enough to allow the total current to pass through it instead.

The most popular Zener diodes are the BZY55C or old BZY88C range which have a power rating of 500mW, whilst the larger BZX85C (formerly the BZY61C) has a higher 1.3W rating. Voltages available are 2.7V through to 33V or more. It should be noted that a tolerance of $\pm 5\%$ exists so they are not too precise but are good enough for many purposes.

According to the formula $P=IV$, power (P in watts) = Current (I in amps) \times Voltage (in volts), so the maximum power dissipation allowed in a Zener diode is the voltage across the device (the Zener voltage) multiplied by the current flowing through it. A typical 9.1V 500mW Zener diode, for example, therefore has a maximum allowable current of ($I = P/V$) of just 55mA.



(Far left) Stud-mounted diode .
(left) Stud-mounted Zener diode.
(above) Stud-mounted rectifier diode.

Using a 9.1V Zener in Fig.3, if we had, for example, an +18V supply voltage, then the voltage that we must lose or "drop" across resistor R1 is 8.9V. If the maximum current allowed through the Zener is 55mA, then using the formula $R = V/I$ the absolute minimum resistor value should be 162 ohms. The resistor will dissipate V^2/R or just under 500mW so a half-watt resistor would just suffice.

As a rule of thumb, a minimum of 10% of the total current should flow through the Zener leaving the rest available to the load (say 50mA). You can increase the value of the series resistor as desired, but allow say 5mA to 10mA as a minimum diode current. Designing using rough rules of thumb is perfectly adequate for simple circuits like this, but bear in mind the 5% tolerance on D1, and allow for minimum load current/ maximum Zener current situations.

Emitter follower

In order to increase the current value and reduce Zener power dissipation, a simple *emitter follower* set-up can be used as shown in Fig.4. The transistor TR1 can be a low or medium power npn device with, say a 500mA or 1A collector current rating (e.g. 2N2222 or 2N3019). The transistor conducts and the Zener voltage is connected to its base (b) terminal. A 0.6V voltage drop is present between TR1's base and emitter (e) – the emitter "follows" the voltage at the base in this mode, less a diode voltage drop.

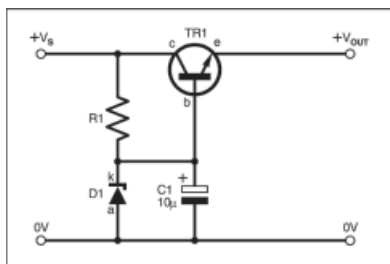


Fig.4. Using an external npn "pass" transistor to increase the current available from the Zener.

Hence a 9.1V Zener produces an 8.5V regulated voltage at TR1 emitter, and TR1's base current is the Zener's load current. Usefully, an electrolytic capacitor placed across D1 smoothes out noise and ripple. The transistor's gain has the effect of amplifying the capacitor's value, so it is similar to placing a much larger electrolytic across the output rails.

The choice of transistor needs some attention: its power rating and collector current must handle the worst-case current drawn by the load. The transistor's power dissipation ($P=IV$) is the voltage across it multiplied by the load current through the device. Assuming an 18V input voltage, an 8.5V output voltage and (say) a 100mA load current, the power dissipated by TR1 would be 950 milliwatts.

A 2N3439 has a rating of 1W and could just about suffice with heatsinking: a better way might be to use a Darlington transistor configuration for TR1. This would reduce the current from the Zener network, and allow a lower power transistor to drive a higher power device. However, using a Darlington pair would mean that 1.2V (two diode drops) would be deducted from the Zener voltage.

Switch-back

Back to the reader's question. If a circuit were only supposed to switch on above a certain supply voltage, the basic transistor-boosted circuit might be worth experimenting with. The Zener would only start to conduct once the supply exceeded (say) 9.1V, but TR1 would only conduct once there was sufficient base current available. For a cleaner switching action, a Zener diode could be used with a comparator (even a simple 741 op.amp) which could be used to trigger at a preset voltage and turn on a load.

Also consider using a three terminal variable voltage regulator such as the LM317. These have a drop-out voltage of about 3V or so, which means that the input must be 3V higher than the output before the regulator can conduct. Hence the load cannot be powered up until the supply rail has exceeded a certain level. A.R.W.

● Starting in the next *Circuit Surgery*, we'll be examining the Universal Serial Bus (USB), describing the specification of the versatile USB port used on almost all modern personal computers.

Circuit Surgery will wherever possible offer advice or pointers to readers, but we cannot guarantee to do so, and the ease with which queries can be sent by email does nothing to help! It is not always possible to offer either quick "snap" or considered answers to every circuit, especially if it would be necessary to build or simulate the circuit, but we do read every letter, reply where we can and we publish a selection of your queries every month. You can send your emails to alan@epemag.demon.co.uk.

Logic Probe

Anthony H. Smith, BSc. (Hons)

A handy tool for tri-state monitoring of logic circuits

WHEN troubleshooting digital circuits, a logic probe provides a quick and easy way of determining the logic level at a particular node. Unlike voltmeters and oscilloscopes which are able to display a range of *analogue* voltage levels, the logic probe is essentially a *digital* instrument that provides a simple yet unambiguous “yes” or “no” indication of the node’s logic level.

Unlike many commercially available logic probes, the one described in this article is a precision instrument, in that it uses analogue techniques to sense the voltage levels, thereby providing an accurate indication of the true logic state. Like the author’s *Volt Checker* last month, this Logic Probe is a pocket-sized instrument housed in a small plastic case which is easy to construct and simple to use.

The probe is powered from the circuit under test by connecting the power leads to the circuit’s positive and negative power rails. Any supply voltage in the range 3V to 15V can be accommodated, thus allowing the probe to be used on a wide range of TTL and CMOS logic families. The logic

level at any node in the circuit is detected simply by touching the probe tip to the appropriate point. A short, detachable, low-impedance ground lead can be fitted which improves performance when probing high frequency signals.

Two Colours are Better than One

The logic state is indicated by a single, *bicolour* l.e.d. mounted on the p.c.b. at the right height to protrude through a hole in the lid. Basically, we need an l.e.d. capable of indicating one of three states, namely low, high and *indeterminate*, where the latter state refers to a voltage level lying somewhere in between the acceptable low and high voltage ranges. Note that this cannot be achieved with a single, standard (unicolour) l.e.d. – at least two standard l.e.d.s would be required.

The bicolour l.e.d., however, comprising two differently coloured light emitting diode chips encapsulated inside the same housing, provides a way of displaying all three states with a single indicator. Furthermore, as we shall see later, the bicolour l.e.d. also provides a rudimentary indication of the *duty cycle* of a pulsing signal.



Before examining the probe’s circuit in detail, we can understand the basic principles by considering the block diagram in Fig.1. The main element is the *window comparator* – this is the precision analogue section that compares the input voltage at the probe tip with two reference voltages, namely $V_{REF(HIGH)}$ and $V_{REF(LOW)}$. These two references represent the threshold voltages for the high and low logic levels, respectively.

The window comparator’s outputs have insufficient current capacity to drive the bicolour l.e.d. directly, so they must be *buffered* to provide increased current drive. The buffer stage itself is powered by a “low dropout” (LDO) voltage regulator that provides a stable supply voltage for the buffers. This ensures that the l.e.d. has a well-defined intensity that remains constant in spite of any changes in the supply voltage to the logic probe itself.

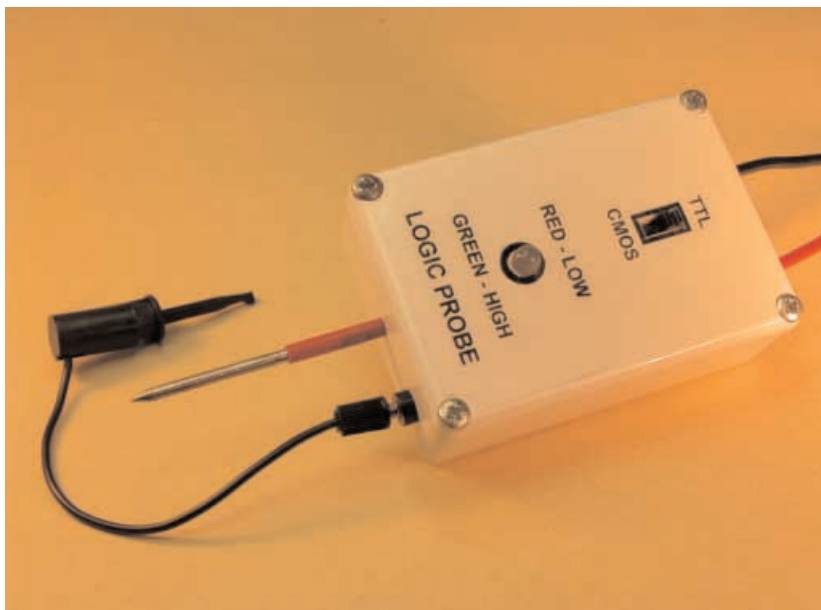
The reference voltages are derived from a potential divider network connected directly across the probe’s supply terminals. This ensures that $V_{REF(HIGH)}$ and $V_{REF(LOW)}$ always “track” the supply voltage of the circuit under test, a requirement which, as we will see shortly, is essential in maintaining a direct relationship between the logic thresholds and the test circuit’s supply voltage.

A “logic family” switch connected to the divider network sets the appropriate threshold levels. This switch, mounted on the probe’s lid, is used to configure the unit for the particular family of logic device under test – either TTL or CMOS.

Just in Case

Two protection mechanisms are included in the probe’s design. The *reverse polarity protection* diode connected in the positive supply line ensures that all of the “delicate” circuits downstream of the potential dividers will not be damaged should the supply leads be connected with reversed polarity. This provides some insurance against “Murphy’s Law” which guarantees that at some time during its life, the probe’s supply leads are sure to be connected the “wrong way around”!

A protection network is also provided at the probe input. This ensures that the



window comparator's sensitive inputs will not be damaged by an *overvoltage* at the probe tip. In fact, the Logic Probe can withstand a probe overload as high as 100V – significantly greater than the protection offered by some commercial probes!

By now, you may be wondering why a precision window comparator is required – why not just use a logic gate instead? To understand why the comparator is necessary, we need to examine the differences between logic *output* levels, and logic *input* levels.

True or False?

The term *digital electronics* refers to a circuit in which only one of two states can be present at a given point. Usually, the terms *high* and *low* are used to represent the *true* and *false* states, respectively, of Boolean logic, although it is also common to find the states referred to as “1” and “0”.

Many devices are capable of producing a digital output: a simple transistor circuit, for instance, can produce one of two different output states when fully “on” (saturated) or when turned “off”; similarly, a relay's contacts can represent a digital signal when open or closed. However, when dealing with logic devices such as gates, flip-flops, latches, and so on, the two logic states are defined by the particular *voltage* levels at the inputs and outputs of each device.

When dealing with most logic families such as the 74-series TTL and 4000-series CMOS, the voltage levels fall within predefined *positive* values, although there are exceptions such as ECL (emitter coupled logic) in which the levels are entirely *negative*. Now, if we consider an *ideal* logic device operating on, say, a positive 5V supply, the output voltage levels representing high and low would be 5V and 0V, respectively – that is, the output voltage would “swing” from one rail to the other.

In practice, however, things are not quite so simple. Since all logic devices are fabricated using *real* (i.e., non-ideal) elements, such as bipolar transistors in the case of 74- and 74LS- series logic, or MOS transistors in the case of 74HC- or 4000- series CMOS logic, the output voltage levels will always depart to a greater or lesser degree from the ideal values.

This is shown in Fig.2, where the allowable “spread” in high and low output voltages is shown for several different logic families operating on a +5V supply. The corresponding input voltage ranges are also illustrated.

It's a Family Thing

If we examine the case of a 74HC device, we see that the allowable high level output voltage, denoted V_{OH} , can fall anywhere between 5V (the ideal case) and 4.5V (the minimum value), whereas the allowable low level output voltage, denoted V_{OL} , can lie anywhere between 0V (the ideal case) and 0.3V (the maximum value). The high and low output voltage ranges for 74HCT, 74C and 4000-series devices are very similar to those of a 74HC device.

Considering, now, the high and low levels for 74- and 74LS- series devices, we see that the spread in V_{OL} is somewhat similar to the other families, whereas the spread in V_{OH} is much wider and can range from 5V to as little as 2.4V!

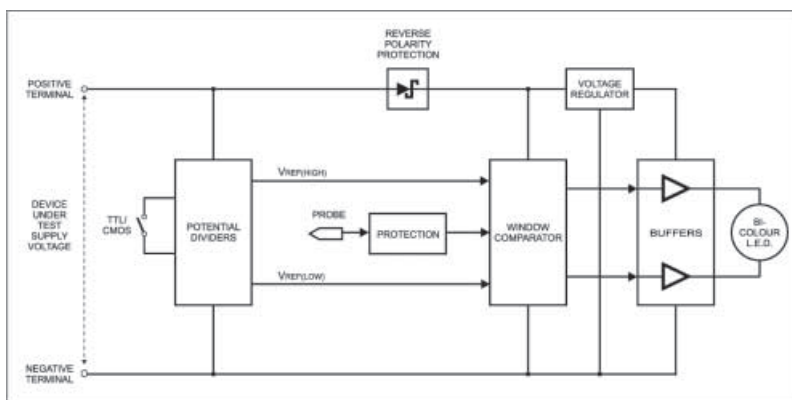


Fig. 1. Basic Principles of the Logic Probe

It's important to bear in mind that the values shown in Fig.2 are fairly generalised, since all logic levels actually depend on several factors, such as temperature, output current, and the exact value of supply voltage. Furthermore, although a device from a particular logic family produced by, say, Texas Instruments, will usually have very similar specifications to a device from the same logic family produced by Philips, it is not uncommon to find slight differences between logic level values from one manufacturer to another.

Also, although the logic levels for 74C- and 4000- series devices are not always exactly the same, they are usually similar enough to allow them to be lumped together in the same group as shown. Finally, remember that the voltages depicted in Fig.2 represent the *worst case* spread in values at an ambient temperature of $T_{AMB} = 25^\circ\text{C}$ for each family; in practice, the *typical* voltage levels are often much closer to their ideal values.

So far, we've considered only *output* voltage levels. If we now examine *input*

voltage levels, we see that the spread in allowable logic levels is much wider than that of the corresponding output logic levels. For instance, the high level input voltage, denoted V_{IH} , for a 74HC device is allowed to be as low as 3.5V, a full one volt lower than the corresponding minimum value of V_{OH} .

Similarly, the low level input voltage, denoted V_{IL} , is allowed to be as high as 1.5V, just over one volt higher than the corresponding maximum value of V_{OL} .

Noise Margin

The difference between the limiting values of input and output logic levels determines the worst case *noise margin* of a particular digital device, in that it defines the maximum amount of noise that could be added to the logic levels whilst still ensuring proper operation. For example, the worst case high level noise immunity of a 74 or 74LS device is around 0.4V, because introducing 0.4V of noise to the minimum high level output voltage (2.4V) to bring it down to 2.0V would still (just) be interpreted as a

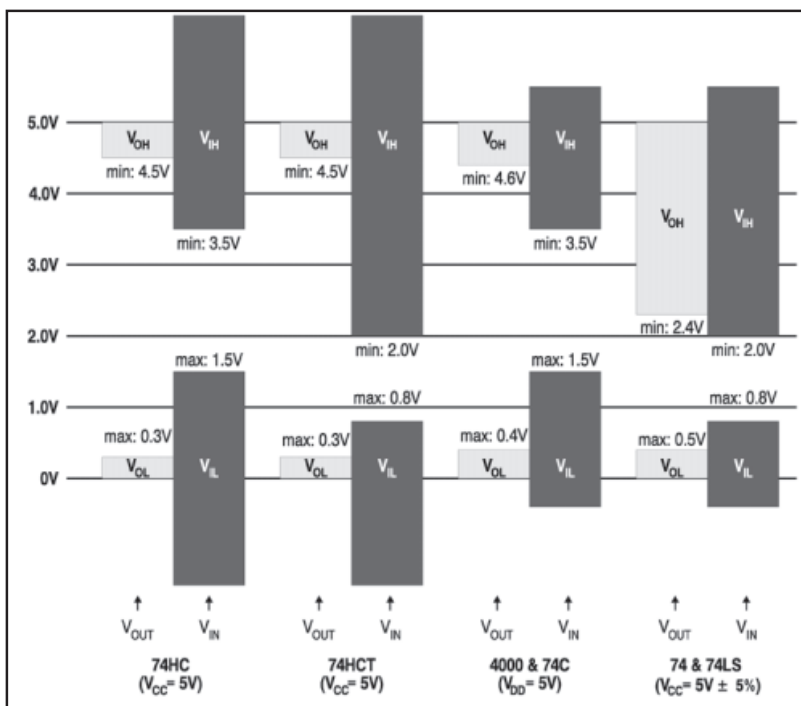


Fig.2 Spread in device output and input logic levels for different logic families ($T_{amb}=25^\circ\text{C}$)

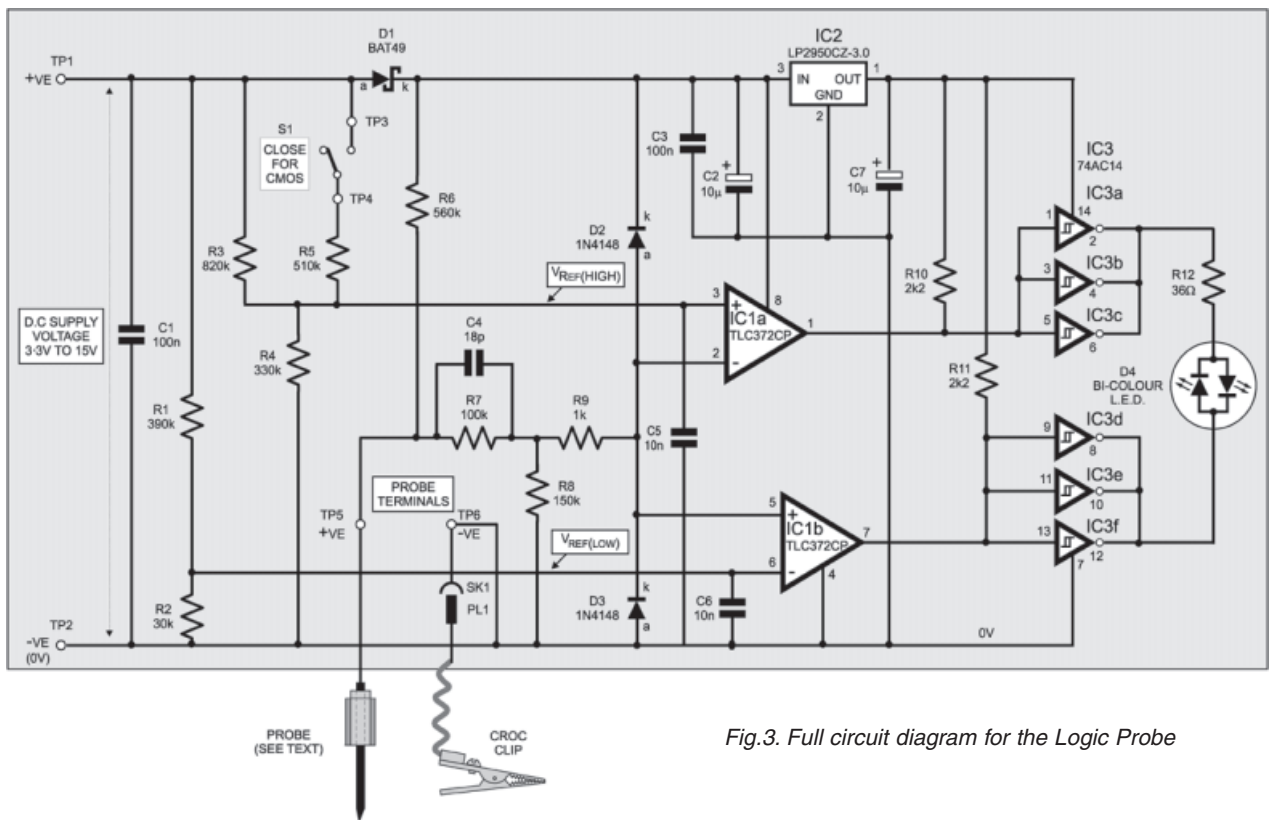


Fig.3. Full circuit diagram for the Logic Probe

high level by a 74- or 74LS- series input. It can be seen that the noise immunity of a 74HC device, on the other hand, is considerably better at around 1.0V.

When using a logic probe, we are primarily concerned with output logic levels, in that we wish to determine whether the logic level at some point in a circuit falls within the acceptable high or low output range for a particular type of digital device. Even though we might probe a signal at the input to a device, what we are actually doing is assessing whether the voltage at the output of the device that generates the signal is within allowable limits. This is why it is not ideal to use a logic gate to determine the logic status of a node.

Windows or Gates

For example, instead of using a window comparator, let's assume we employed a 74HC logic gate as the "measuring" device in our logic probe. Although this would certainly tell us whether the voltage at a particular node was within the correct range of input logic levels, it would not necessarily confirm that the voltage was within the correct output range.

If, for instance, a particular 74HC node voltage in a 5V digital system was sitting at 4.0V, the logic gate in our probe would interpret this as a high level and illuminate the l.e.d. accordingly, even though a voltage of 4.0V is half a volt below the allowable minimum value of V_{OH} , namely 4.5V. Therefore, only by using the precision *analogue* measurement capabilities of a window comparator can we obtain a true and accurate assessment of a digital device's output logic level.

Before leaving Fig.2, it's worth noting that the allowable high and low input voltage ranges actually extend beyond the 5V

and 0V rails! Most 74HC devices, for example, can tolerate a high level voltage that exceeds the positive rail by around 1.5V, and will accept a low level voltage that goes as much as 1.5V below the 0V rail. This degree of latitude allows the device to work properly in the presence of noise and voltage spikes that go outside the voltage rails, and also provides some immunity to the effects of supply voltage tolerance when interfacing devices powered from different sources.

One final point to observe in Fig.2 is that the input voltage range for the 74HCT family is very similar to that of the 74- and 74LS- series devices. In fact, the values of $V_{IH(MIN)}$ (2.0V) and $V_{IL(MAX)}$ (0.8V) are the same for both families. This is no accident: the 74HCT series is a special variant of the 74HC family and is intended specifically for interfacing with devices from the older 74- and 74LS- series. Note, however, that the 74HCT output logic levels are much better than those of the 74- and 74LS- devices, and in fact they are identical to those of a 74HC part.

Circuit Description

The full circuit of the Logic Probe is shown in Fig.3, where IC1, a micropower dual comparator, forms the window comparator, IC2 is the LDO voltage regulator, and hex inverter IC3 provides buffering to drive the bicolour l.e.d. The supply voltage from the circuit under test is applied to positive and negative terminals TP1 and TP2, respectively, and the probe itself is connected to terminal TP5.

The resistor network comprising R1 to R5 generates the high and low reference voltages for the comparator, while R7 to R9 with diodes D2 and D3 provide overvoltage protection for the probe.

The values of R1 to R5 must be selected to produce the correct voltages for $V_{REF(HIGH)}$ and $V_{REF(LOW)}$ corresponding to the high and low output voltages for the appropriate logic family. The levels shown in Fig.2 provide a good starting point, but you should remember that the values shown are applicable only to a 5V supply voltage (V_{CC} or $V_{DD} = 5V$).

How do the levels vary with a change in supply voltage? The bipolar TTL families, such as the 74- and 74LS- series, are easy to deal with because they have a very "tightly" defined supply voltage of $5V \pm 5\%$, that is, V_{CC} can range from 4.75V to 5.25V, and the values of $V_{OH(min)}$ (2.4V) and $V_{OL(max)}$ (0.5V) remain fairly constant over this narrow range.

Wide Supply Range

CMOS logic families, however, can handle a much wider supply voltage range. The 74HC family, for example, will work from a minimum of 2V to a maximum of 6V. Other CMOS families have an even wider supply voltage range: 4000B and 74C devices can operate over the range 3V to 15V.

Fortunately, the output logic levels vary in a fairly linear fashion with changes in supply voltage; in other words, the output level is a fairly constant fraction of the supply voltage. For instance, $V_{OH(min)}$ for a 74HC device is, to a good approximation, nine tenths of the supply voltage, or $V_{OH(min)} = 0.9V_{CC}$, over the full supply voltage range.

A similar approximation holds true for 4000-series devices, although we should remember that in all cases the output levels are affected by loading (the amount of current taken from the output). Provided the loading is not excessive, we may use the 5V supply voltage levels shown in Fig.2 as the basis for calculating the R1 to R5 potential divider ratios.

As far as $V_{OL(max)}$ is concerned, we see from Fig.2 that the values are fairly similar for all the logic families shown, ranging from 0.3V to 0.5V. Therefore, if we allow a small margin to account for tolerances, etc., and take 0.6V as the overall representative value of $V_{OL(max)}$, we can use just one potential divider chain, namely R1 and R2, to generate the corresponding $V_{REF(LOW)}$ reference voltage without introducing unacceptable errors.

Similarly, we see that the values of $V_{OH(min)}$ are very similar for all the CMOS families shown, ranging from 4.5V to 4.6V. Again, therefore, by allowing a little margin, we can take 4.3V as the representative value of $V_{OH(min)}$ for all the CMOS families.

Unfortunately, the value of $V_{OH(min)}$ for the TTL families (2.4V) is much too low to be lumped in with the CMOS values, so we need to be able to switch between the two. This is achieved using switch S1. When the switch is open, potential divider R3 and R4 generates a relatively low value of $V_{REF(HIGH)}$, corresponding to the TTL value of $V_{OH(min)}$. When the switch is closed, R5 is placed in parallel with R3, which has the effect of "pulling up" $V_{REF(HIGH)}$ to represent the higher CMOS level of $V_{OH(min)}$.

However, before calculating suitable values for R1 to R5, we must consider the window comparator's input range.

Comparing the Comparators

Several factors had to be considered when selecting the best device for the window comparator. A dual comparator (two comparators in the same, 8-pin package) was important in terms of cost and board space. Single-supply operation over the range 3V to 15V was essential, and very low input bias current was necessary to minimise loading of the circuit under test. The comparator also needed to be reasonably "fast", meaning that its response time, or *propagation delay*, had to be very small to allow detection of pulse signals at moderately high frequencies.

Ideally, the device should have low power consumption, and it should not be too expensive.

After comparing the specifications of several comparators, the device that best fitted the bill was a TLC372. This dual comparator can operate over a supply range of 2V to 18V, and its input bias current, typically just 5pA, is so small as to be completely negligible. With a response time of a few hundred nanoseconds, it is fast enough to detect pulse frequencies up to several hundred kilohertz, and its total supply current is no more than 400µA. Costing only about £1, the device is ideal for this circuit application.

However, there is one slight problem.

Input Range

All comparators and op.amps have an allowable input voltage range, known as the *common-mode input range*, which specifies the range of input voltages that can be accommodated for correct operation of the device. The common-mode input range of the TLC372 extends from a minimum of 0V to a maximum of 1.5V below the positive supply rail. Thus, for example, when operating on a 5V supply, the TLC372 will work properly with any input voltage in the range 0 to 3.5V; an input

Table.1. Device Output States vs Probe Voltage

Input Logic State	Probe voltage relative to thresholds	Outputs			
		IC1a	IC1b	IC3a/b/c	IC3d/e/f
Low	$V_{PROBE} < V_{REF(LOW)}$	High	Low	Low	High
Indeterminate	$V_{REF(LOW)} < V_{PROBE} < V_{REF(HIGH)}$	High	High	Low	Low
High	$V_{PROBE} > V_{REF(HIGH)}$	Low	High	High	Low

voltage greater than 3.5V could cause erratic or unpredictable behaviour.

This presents a problem, because the logic probe must be capable of detecting voltages that extend right up to the positive supply rail without malfunctioning! Fortunately, this difficulty is easily remedied by *attenuating* the probe voltage such that the comparator's input voltage is always within its allowable common-mode range.

Resistors R7 and R8 provide the necessary attenuation, such that the window comparator's input voltage, V_{IN} , is related to the voltage, V_{PROBE} , at the probe tip by:

$$V_{IN} = V_{PROBE} \times R8/(R7 + R8) \quad (V)$$

and with R7 = 100kΩ and R8 = 150kΩ, we see that $V_{IN} = 0.6V_{PROBE}$. This ensures that the input voltage will always be at least 1.5V below the comparator's supply rail, even when V_{IN} is a maximum. (The attenuator also makes allowance for the effects of the small forward voltage drop that appears across the reverse polarity protection diode, D1.)

Note that fairly large values have been selected for R7 and R8 to ensure that the probe presents a high impedance to the circuit under test, thereby minimising the loading on sensitive nodes.

Scaling

The presence of the attenuator means that the reference voltages generated by the R1 to R5 divider network must be scaled accordingly. We saw earlier that 0.6V was suitable as the overall, representative value of $V_{OL(max)}$ when operating on a 5V supply. Thus, we would require $V_{REF(LOW)} = 0.6V/5V = 0.12V_S$, where V_S is the probe's supply voltage between TP1 and TP2. If we now compensate for the effect of the 0.6 attenuation factor due to R7 and R8, we require $V_{REF(LOW)} = 0.6 \times 0.12V_S = 0.072V_S$.

In other words, R1 and R2 must attenuate V_S by 0.072. Using the preferred values of R1 = 390kΩ and R2 = 30kΩ, the actual attenuation is 0.0714 – close enough!

Following a similar approach for the $V_{OH(min)}$ levels, we find that we require $V_{REF(HIGH)} = 0.288V_S$ for TTL (S1 open), and $V_{REF(HIGH)} = 0.516V_S$ for CMOS (S1 closed). With the switch open, $V_{REF(HIGH)}$ is generated by the R3 and R4 divider, and with preferred values of R3 = 820kΩ and R4 = 330kΩ, the actual attenuation is 0.287.

In the CMOS case when the switch is closed, the attenuation is provided by R3 in parallel with R5 and R4. With R5 = 510kΩ, the actual attenuation is 0.512. Again, close enough to the required values.

Buffering

An additional benefit of the TLC372 comparator is that it has *open drain*

outputs. This means that the output pulls down to 0V when in the low condition, but "floats" to a high impedance state when in the high condition. In the Logic Probe design, this feature is exploited by means of "pull up" resistors R10 and R11 connected to the 3V rail at the output of LDO regulator, IC2.

This approach ensures that the high level voltage at the inputs to the inverter (IC3) can never exceed the inverter supply voltage, even if the window comparator's supply voltage (at pin 8 of IC1) is as high as 15V.

The inverters provide a convenient buffer interface between the comparator outputs and the l.e.d. Connecting them as two groups of three paralleled inverters maximises the current drive to the bicolour l.e.d. D4. Although a 74HC14 device could be used for IC3, a 74AC14 device is preferred because of its significantly better output characteristics (the 74AC14 outputs can sink and source more current than the 74HC14 device).

The relationship between the probe voltage and the various device outputs is shown in Table 1.

When the logic level at the probe is low, the high level at the outputs of IC3d/e/f sources current through the bicolour lamp to the low level at the outputs of IC3a/b/c, illuminating the appropriate l.e.d. chip. Conversely, when the logic level at the probe is high, the inverters' output levels change state and current flows the opposite way through the lamp, thus illuminating the other l.e.d. chip. Resistor R12 limits the current flowing through the l.e.d. and is chosen to produce adequate brightness without exceeding the lamp's maximum current ratings.

Indeterminate

In the third state, when the probe is in an indeterminate state, all of the inverter outputs are low. Thus, current cannot flow in either direction through the lamp, and both l.e.d. chips are "off".

The term *indeterminate* applies to a voltage level that is neither high nor low, and thus represents any voltage that falls in the "no man's land" between the allowable range of voltages for V_{OH} and V_{OL} .

There are three primary causes of an indeterminate state. The first is a broken p.c.b. track between the output of the driver device and the input to the driven device, causing the input to "float" to an unknown level. Naturally, this would only be detected as an indeterminate state when probing the input to the receiving device. A second possibility is a fault with the driver device, which causes its output to "stick" at some non-specific voltage between high and low.

Lastly, any device such as an octal latch or bus transceiver having *tri-state* outputs could produce an indeterminate state when the outputs were put into a high impedance state.

The first and last of these examples illustrate cases where a node is in a high impedance condition. In order to detect this state properly, it is important that the window comparator's quiescent input voltage should assume a level somewhere between $V_{REF(LOW)}$ and $V_{REF(HIGH)}$. This is achieved by resistor R_6 connected between the positive supply rail and the probe tip.

When the probe is "floating" or connected to a high impedance node, the potential divider formed by R_6 , R_7 and R_8 generates a voltage of $0.185V_{S(COMP)}$ at the window comparator input (where $V_{S(COMP)}$ is the comparator's supply voltage). This ensures that the comparator input is above $V_{REF(LOW)}$ and below $V_{REF(HIGH)}$ for any supply voltage, irrespective of the setting of the TTL/CMOS switch, S1. Without R_6 , the comparator input would simply be pulled low by R_8 , thereby erroneously indicating a low level.

Overload Protection

As well as forming part of the input attenuator, resistor R_7 also provides essential current limiting in the event of an overload at the probe tip. Whenever an excessive positive voltage is applied to the probe, diode D_2 becomes forward biased and "clamps" the window comparator's inputs (at pins 2 and 5 of IC1) to a diode drop above the comparator's supply voltage. Similarly, an excessive negative voltage forward biases D_3 which clamps the comparator inputs to a diode drop below the negative supply rail. In each case, R_7 limits the current that flows in either D_2 or D_3 to a safe level.

Note that R_6 is also subjected to any excessive voltage at the probe tip. Therefore, R_6 and R_7 must both have adequate voltage and power ratings to survive an overload. The types specified for the Logic Probe can tolerate an overvoltage as high as 100V. However, we must also consider the rating of capacitor C_4 .

Compensation

Capacitor C_4 provides frequency compensation for the probe's input, and ensures that high frequency squarewaves or pulse trains are not degraded by the presence of stray capacitance at the comparator's inputs.

Without C_4 , resistor R_7 and the stray capacitance would form a low pass filter that would attenuate the higher frequency components of the input signal. The effect on a rectangular, digital signal is to introduce an exponential "rounding" to the rising and falling edges, which can severely distort the waveform's shape and amplitude – particularly at high frequencies.

The presence of C_4 , however, redresses the balance and effectively "neutralises" the stray capacitance. The 18pF value has been carefully selected to compensate the probe without introducing "overshoot" to the input signal's rising and falling edges.

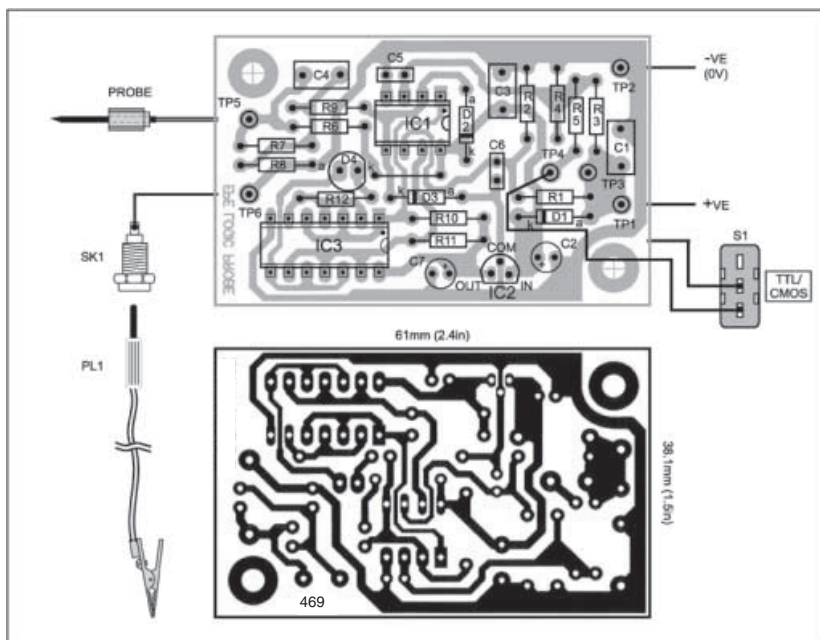


Fig.4. Component layout and master track pattern for the Logic Probe

Note, though, that C_4 will experience the full amount of any overvoltage, **so a properly rated, high voltage component must be used!** Fortunately, low value, high voltage ceramic capacitors are readily available, and the 100V part recommended will allow the probe to tolerate 100V overloads without damage.

Regulators for Drop Outs

The main requirements of voltage regulator IC2 are low power consumption, low output voltage and low "dropout" voltage. A low-power device is necessary to minimise loading on the test circuit's power supply, and a low output voltage is important to allow the probe to work with low supply voltages. Equally important, however, is the regulator's dropout voltage.

The term *dropout voltage* refers to the regulator's input-to-output voltage differential, and is a measure of the device's ability to generate a stable, regulated output voltage even with a low input voltage. Common-or-garden regulators such as the 78L family usually have a relatively large dropout voltage, often in the range 1.5V to 2.0V. This means that a 5V regulator such as the 78L05 needs an input voltage of 6.5V to 7.0V in order to regulate properly.

The LP2950CZ-3.0 regulator used in the Logic Probe is a micropower 3V regulator with a typical dropout voltage of around 0.3V. Taking into account the voltage drop across protection diode D_1 (typically about 0.27V), this allows the regulator to function properly even when the logic probe's supply voltage is as low as 3.6V.

In fact, the prototype logic probe continued to function properly with a supply voltage of just 3.0V. At this level, the regulator's output voltage had dropped from its nominal 3.0V to 2.57V. Nevertheless, the buffers (IC3) behaved normally and the l.e.d.'s brightness was hardly affected.

Choosing an L.E.D.

An inexpensive red/green bicolour l.e.d. is suitable for D_4 . If it is fitted with the

"polarity" shown on the component layout with the flat edge toward the centre of the board, it will indicate red for a low logic level and green for a high level. However, if you would prefer green for low and red for high, simply insert the l.e.d. the other way around (but remember to make appropriate changes to the lid's markings).

The recommended l.e.d., a Kingbright L-57EGW high efficiency red/green type, is readily available and produces good brightness at a forward current of around 20mA. Resistor R_{12} provides the necessary current limiting; a value of 36Ω is the optimum choice for maximum intensity without exceeding the l.e.d.'s maximum current ratings.

Construction

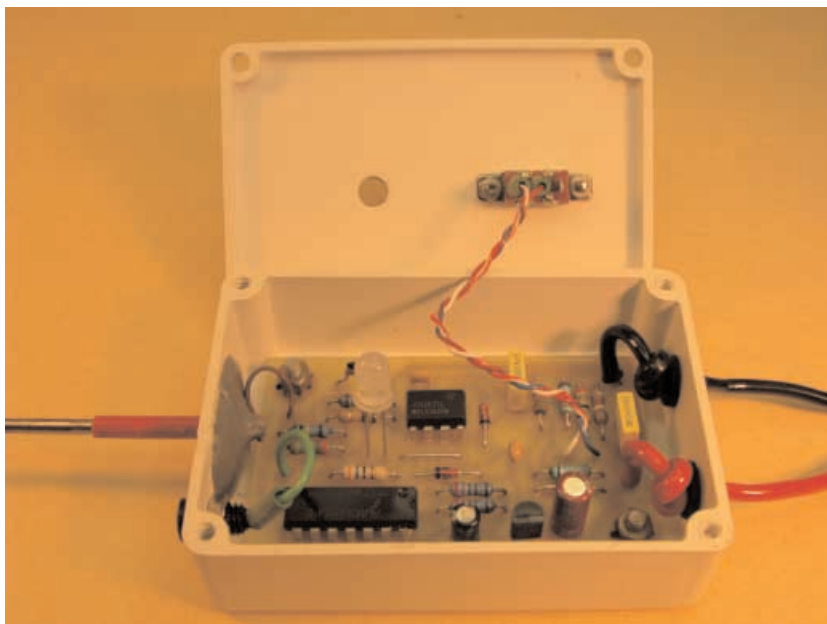
Component positioning and p.c.b. track layout details are shown in Fig.4. This board is available from the *EPE PCB Service*, code 469.

Start assembly by soldering the short link wire into place, then follow with the diodes, resistors and capacitors. Take care with polarity of the diodes and electrolytic capacitors (C_2 and C_7). Next, solder in place the sockets for d.i.l. (dual-in-line) i.c.s, but do not insert them until after you have fully checked your assembly. Finally, solder in the regulator, IC2. Remember to observe antistatic precautions when handling the i.c.s, and take care with orientation.

When soldering the l.e.d. into place, ensure that there is approximately 15mm of lead length between the top surface of the board and the base of the l.e.d. Ensure all component leads are properly cropped and check carefully for solder splashes. There is no need to connect the slide switch at this stage.

Testing and Troubleshooting

After assembling and checking the p.c.b., the circuit should be tested before fixing the board in place in its case. A multimeter and a current-limited variable d.c. power supply (preferably two) will be



required. For the moment, the probe need not be connected to terminal TP5.

Set the d.c. power supply to precisely 5.0V and adjust its current limit to around 40mA. Connect the positive lead to TP1 and the negative, or 0V (ground), lead to TP2. If the power supply goes into "current limit" mode, check the orientation of the i.c.s and the polarity of D2 and D3. If a current-limited power supply is not available, use the multimeter to measure the current taken by the Logic Probe – it should be no greater than 300 μ A, or so, with the l.e.d. "off".

If all is well, use the multimeter to measure the voltage at D1's cathode (IC2's input) relative to the negative rail at TP2: it should be around 4.85V. Next, measure the voltage at IC2's output (pin 3): it should be in the range 2.94V to 3.06V.

The l.e.d. should have remained "off" during these tests. If it glows red or green, check that R1 to R8 have the correct values and have been soldered in place properly. Next, make a temporary connection between TP5 and TP1: the l.e.d. should glow green. Remove the connection and make a temporary connection between TP5 and TP2: the l.e.d. should now glow red. If, for either case, the l.e.d. seems very dim or

extremely bright, check the value of resistor R12.

With the l.e.d. illuminated (either red or green), use the multimeter to measure the current taken by the logic probe: it should lie somewhere in the range 18mA to 26mA.

Threshold Tests

If a second, variable power supply is available, it can be used to check that the window comparator is switching at the correct thresholds. With the logic probe's supply voltage still set to 5.0V, set the second supply's voltage to zero and connect it between TP2 and TP5 (positive terminal to TP5). The l.e.d. should glow red. Gradually increase the voltage from zero until the l.e.d. turns off: at this point, the voltage at TP5 should be around 595mV.

Continue increasing the voltage until the l.e.d. turns on and glows green: the voltage at this point should be about 2.39V. If all is well, connect a temporary short circuit between terminals TP3 and TP4 – the l.e.d. should turn off. Again, increase the voltage at TP5 until the l.e.d. once more turns on and glows green: the voltage at TP5 should now be around 4.26V.

Note that the voltages measured may vary slightly from the values given above due to resistor tolerance and comparator offsets. Provided the differences are no more than 100mV, or so, the p.c.b. can be fitted in the case. However, if you observe large differences, check the values of resistors R1 to R5 and R7, R8.

Casing the Unit

When the p.c.b. has been successfully tested, it can be bolted into place in the plastic case. First, six holes must be drilled in the base. The



Showing the probe bonded to the case

COMPONENTS

Resistors

R1	390k
R2	30k
R3	820k
R4	330k
R5	510k
R6	560k 100V
R7	100k 100V
R8	150k
R9	1k 5% 0.25W
R10, R11	2k2 5% 0.25W (2 off)
R12	36 Ω 5% 0.25W

All 0.25W 1% metal film unless marked

Capacitors

C1, C3	100n polyester or ceramic, 5mm pitch (2 off)
C2	10 μ radial elect. 25V
C4	18p ceramic disc, 5%, 100V, 5mm pitch
C5, C6	10n polyester or ceramic, 2.5mm pitch (2 off)
C7	10 radial elect. 6.3V

Semiconductors

D1	BAT49 Schottky diode
D2, D3	1N4148 signal diode (2 off)
D4	bicolour, red/green l.e.d. (see text)
IC1	TLC372CP dual comparator
IC2	LP2950CZ-3.0, voltage regulator
IC3	74AC14 hex inverter

Miscellaneous

S1	s.p.s.t. (or d.t.) slide switch panel mounting (see text)
SK1	1mm socket, panel-mounting
PL1	1mm plug

Printed circuit board, available from the *EPE PCB Service*, code 469; plastic case 70mm \times 50mm \times 25mm (see text); M2 6mm countersunk screws plus nuts (2 off); M3 12mm countersunk screws plus nuts (2 off); M3 1mm fibre (or nylon) washers (2 off); M3 lock washers (2 off); min. red and black crocodile clips or test probe (1 off each); small rubber or PVC grommets to suit case panel; steel nail, approx. 60mm \times 2mm (see text); epoxy resin or similar adhesive; 3mm silicone sleeving as required; flexi-wire for probes (two colours); connect-

Approx. Cost
Guidance Only

£14
excl. case

location of the two holes in the bottom is critical to ensure correct alignment of the l.e.d. with the hole in the lid. Fig.5 outlines the position of the l.e.d. hole, and also shows the relative positions of the two countersunk holes in the base (shown dotted) which should be approximately 3mm in diameter. The l.e.d. hole in the lid should be just over 5mm in diameter to accommodate the recommended 5mm l.e.d.

The probe itself is made from a steel nail, insulated along part of its length, and bonded to one end of the case. In one end of the case, drill a hole exactly in the centre to

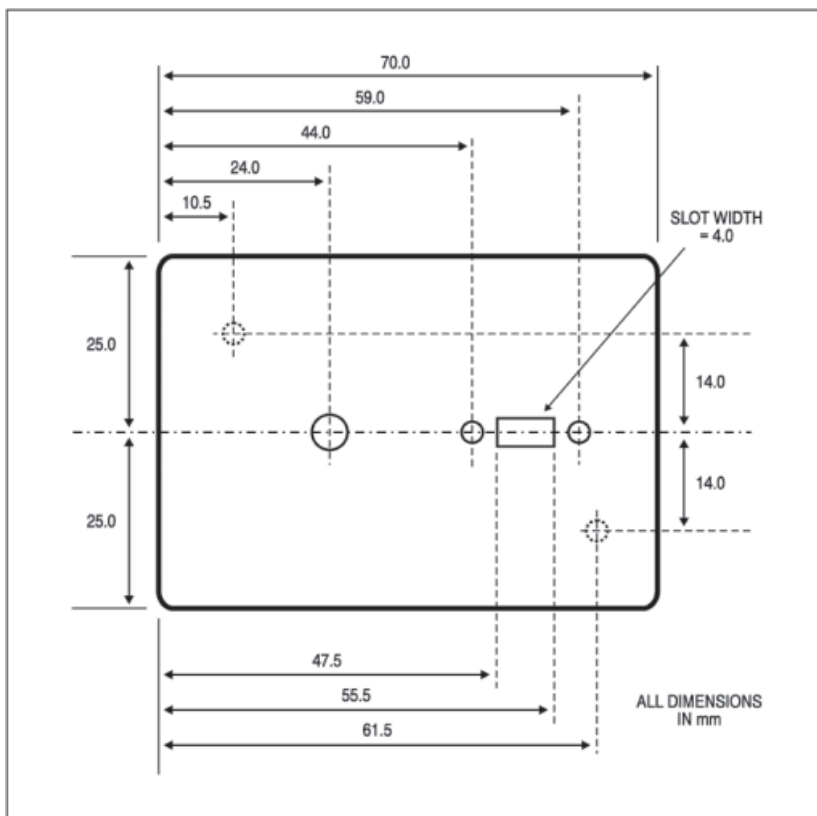


Fig.5. Location of front panel holes.

accommodate the probe. The hole diameter should be approximately 3mm, the same as the outer diameter of the sleeving; the inner diameter of the sleeving should be chosen to provide a tight fit for the nail.

Sleeving helps to provide a snug fit for the probe and imparts an aesthetic appearance. It also provides insulation at the upper part of the probe, which can be handy when probing densely-populated boards. The actual length of sleeving is not critical – it can be fairly long and extend down toward the tip of the probe if you wish.

Approximately 15mm to the right of the probe hole, drill another hole to accommodate the 1mm “ground” socket, then fix the socket in place. In the opposite end of the case, drill two holes to accommodate the grommets for the supply leads.

Beheaded and Roughed Up

Find a steel nail approximately 60mm long that will fit comfortably inside the sleeving and, if necessary, shine it up using emery paper or wire wool. Cut off the nail’s head and solder a short length of wire to the “headless” end (you may need a high power soldering iron for this). Insert the nail into the sleeving, then position the sleeving in the hole such that approximately 5mm of the “wired” end of the nail protrudes inside the case.

Using a file or knife, “roughen up” the inside of the case around the probe hole to provide a good key for the adhesive. Then, keeping the probe perpendicular with the side of the case, apply a suitable adhesive such as epoxy resin around the end to bond the probe securely in place. Ensure the resin does not foul the adjacent ground socket.

While the resin is hardening, drill the l.e.d. hole in the lid, then drill two small holes for the slide switch screws and countersink them carefully. Finally, cut a slot for the slide switch “toggle”. The best way to achieve this is to drill a series of small holes around the perimeter of the slot, punch out the plastic, then file the edges flat so that the slot is perfectly rectangular.

Fix the switch in place using two countersunk screws such that the screw heads do not protrude above the surface of the lid. Next, apply lettering to the lid, such as Letraset (www.lettraset.com/uk) followed by a protective spray-on coating.

Let’s Twist Again

Solder two wires each approximately 70mm long to the switch terminals, one to the centre (common) terminal and the other to the terminal nearest the l.e.d. hole. Twisting the wires together produces a neat arrangement and helps minimise the effects of interference. The tested board can now be prepared for fitting inside the case.

Solder a short length of wire to terminal TP6 ready for connection to the ground terminal, then temporarily mount the board in the case, using fibre washers. Position the lid on the case to check that the l.e.d. protrudes through the hole correctly. If the lid cannot be seated properly, de-solder the l.e.d., shorten the lead length above the board, re-solder and repeat the process until the l.e.d. is at the correct height.

Now, remove the board and prepare the supply leads for connection by stripping about 5mm of insulation from the end of each. Twist and tin ready for soldering into the board. Use “flexiwires” for optimum

durability. Insert the stripped end of each wire through a grommet and use a cable tie to provide strain relief. Solder the slide switch wires into the board at terminals TP3 and TP4, then solder the probe wire to terminal TP5.

Next, solder the supply leads into the board making sure the black lead goes to the negative terminal, TP2, and the red lead goes to terminal TP1. Finally, bolt the p.c.b. into place remembering the fibre washers, and solder the short wire from terminal TP6 to the ground socket. Replace the lid and screw into place.

Connect red and black crocodile clips or test probes to the supply leads, and assemble the short ground lead using a 1mm plug and miniature black crocodile clip or test probe. The logic probe is now ready for use.

Using the Logic Probe

To use the probe, set the TTL/CMOS switch to suit the particular logic family, then connect the supply leads to the positive and negative (0V) rails of the circuit under test, preferably at a point as close as possible to the device or node being probed. Remember that the probe will work over a supply range from 3-0V up to a maximum of 15V, with 18V being the absolute maximum.

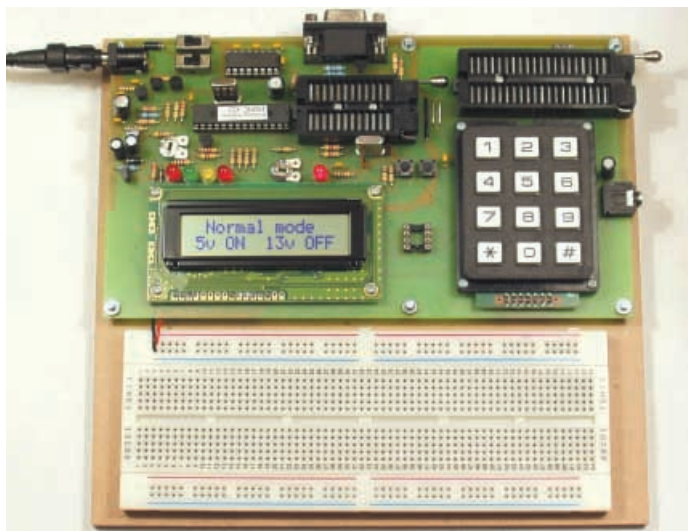
When probing “static” (d.c.) logic levels, the short ground lead is not required. However, for a.c. signals, the ground lead should be used in addition to the probe’s negative supply lead and should be connected to a ground point as close as possible to the pulsing node. Although not essential, the short lead can help to minimise the effects of noise and ringing, particularly for high frequency signals, by providing a low-inductance ground path.

The probe responds to low frequency squarewave signals by flashing the l.e.d. between red and green. As the frequency increases, the flash rate also rises until at around 40Hz, or so, the eye cannot distinguish the individual colours and they “blend” into one. For a pulse train having a low duty cycle, the l.e.d. appears predominantly red; as the duty cycle increases, the colour passes through amber (at roughly 50% duty cycle), then appears yellowish, until finally appearing mainly green at high duty cycles.

Although intended mainly for d.c. and low frequency applications, the probe can detect and indicate squarewave signals with frequencies in excess of 800kHz. □



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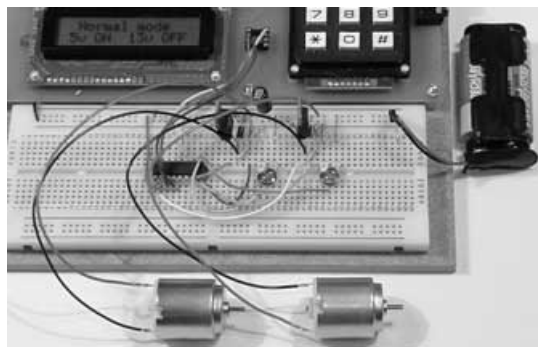
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Regal Restoration

Ambitious projects look set to bring back the voices of Queen Victoria, Florence Nightingale and Abraham Lincoln in digital clarity. Andy Emerson reports.

IN recent years digital remastering of old recordings has achieved significant sonic improvement to old tapes and disc masters, restoring richness and dimension to tracks that previously sounded thin and weak. Used properly, powerful computer processing successfully eliminates hum and crackles, boosts and restores attenuated high frequencies, corrects the sibilance caused by skewed tape azimuth and cures many more undesirable effects that afflict less-than-perfect speech and music.

These achievements are now being overshadowed by new techniques that are taking sound restoration to the very limits of feasibility. Two cutting-edge projects in the USA are attempting to bring back sounds considered lost for all time, bringing back the voices of eminent Victorians and possibly even solving the mystery of who shot US president John Kennedy in November 1963.

Sound fellows

The problem with early sound recordings, made mainly on wax cylinders, is their vulnerability. Poor handling and storage (breakages and the growth of mould) have spoilt the recordings, whilst the stylus needle used for playing them causes further damage.

Scientists Vitaliy Fadeyev and Carl Haber, whose normal work is in subatomic particle research at the Lawrence Berkeley National Lab in California, have solved the dilemma in an ingenious piece of technology transfer. To read these old recordings they are using special microscopes to scan the grooves without any physical contact and developing software that can convert those shapes into sound.

The technique is entirely non-invasive and began with experiments to extract high quality sound from old shellac discs made in the 1950s. The scientists programmed a precision optical metrology system to map and photograph the undulating grooves etched on these old records.

As Haber explains, "A stylus measures a groove by one point, essentially where the stylus sits. The data we take is taken at least a factor of ten if not at a higher sampling or resolution than the stylus measures. So if you have ten times as much information, you have that much more of a chance to recover something. And we could even maybe go 20 or 30 times and increase our chances even more so."

Scratches and dust "interference" can be edited out of the images, which are then transferred to computer and turned into a sound file that is a cleaned-up version of the original. The US Library of Congress in Washington is so impressed

with the results that it is funding the scientists to perfect their process in order to regain access to the substantial number of recordings of America's audio heritage that are in danger.

Unamused

According to a BBC report the men are excited at the possibilities of giving voice once more to cylinders said to contain recordings of Queen Victoria, poets Alfred Tennyson and Walt Whitman, nurse Florence Nightingale, actress Sarah Bernhardt and Germany's First World War leader Kaiser Wilhelm.

In the case of Queen Victoria "said to" may be the operative words, since there is doubt over the authenticity of the wax cylinder owned by the Science Museum in London. The recording is dated 1888, in which year there is certainly documentary evidence that a recording machine was demonstrated to Queen Victoria. Some words of the 20-second recording can be made out: "My fellow Britons..." at the beginning and "...I have never forgotten" at the end, although processing has not recovered any more so far.

But as Nigel Bewley of the British Library Sound Archive points out, there is no certainty that the recording is of Her Majesty and she might have instructed an aide to make the recording on her behalf. There is also a suggestion that she recorded a message for the King of Ethiopia, destroyed according to her wishes after it was played to the king, and certainly no copies or remnants of this have surfaced up to now.

Kennedy Conundrum

Where were you when JFK was assassinated? That may be the first question that comes to mind when the subject is raised but far more important is the number of people involved. Although the official inquiry concluded that Lee Harvey Oswald was a lone gunman, another committee decided 15 years later that shots were fired from two different locations, starting a never-ending succession of conspiracy theories.

Lawrence Berkeley National Laboratory scientists are also working on the only known audio recording of the actual assassination. This recording, a report in *The Guardian* states, was made at police headquarters of a radio message from a police motorcycle, just as Kennedy's motorcade entered Dealey Plaza, Dallas, where the president was shot.

The fortuitous record was made on a Dictaphone machine, a decidedly non-hifi device for office dictation that recorded not by magnetic means but mechanically onto

a continuous belt of transparent plastic material. The manufacturer referred to these belts as "Dictabelt Records", and the recordings were created by cutting a groove in the belt with a needle. The process was marketed as "the sound you can see", with "Dictabelt Visible Record" printed along the edge of the belts.

Old plastic material can become brittle and repeated playing of the recording left the Dictabelt worn and damaged. After it was donated to the National Archives in 1990, its weak state led the technical staff there to decree that no further efforts be made to replicate its sounds through mechanical means. The controversy over the number of shots that were fired and how many people were involved in the killing remained unabated, prompting the sound conservationists to investigate how the enfeebled sound could be recovered by some other means.

Quoted in the newspaper, an archivist at National Archives, Leslie Waffan, said he believed not only that the sound could be recovered but also that, using digital analysis to map the sounds, the scientists could remove extraneous noise such as static and distant voices to clarify the gun shots.

The task has been entrusted to the same Carl Haber and Vitaliy Fadeyev, who will begin scanning the grooves of the Dictaphone belt electronically to create a digital image of the sound patterns. Once that is achieved, Mr Waffan said, the scientists could "clean it up, like peeling layers off an onion to get down to the sound floor" of the recording. And that, he said, could reveal how many shots were fired.

Sheer magic

What about recordings that have been erased completely though? It seems nothing is impossible according to a report in *Railnews*, the staff newspaper of Britain's railways. To secure the prosecution of ten thugs whose attack on a rail passenger left him fighting for his life, British Transport Police officers turned to closed circuit TV recordings and discovered the vital tape had been wiped for re-use.

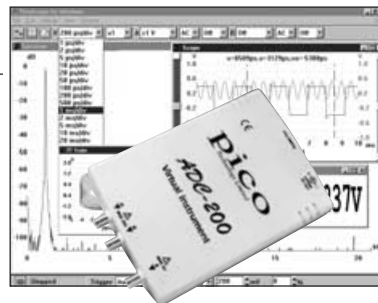
Experts at the BBC, ITV and various forensic laboratories stated that recovering the footage was impossible. But undaunted, Detective Chief Inspector Alastair Cummings submitted the precious tape to the FBI's headquarters in Quantico, Virginia. After three days of fruitless work, grainy images suddenly appeared and thanks to dedicated work by American experts a viewable copy of the footage and a number of still-frame images were resolved, sufficient to secure the successful prosecution of the culprits.

INGENUITY UNLIMITED



Our regular round-up of readers' own circuits. We pay between £10 and £50 for all material published, depending on length and technical merit. We're looking for novel applications and circuit designs, not simply mechanical, electrical or software ideas. Ideas *must be the reader's own work* and **must not have been published or submitted for publication elsewhere**. The circuits shown have NOT been proven by us. *Ingenuity Unlimited* is open to ALL abilities, but items for consideration in this column should be typed or word-processed, with a brief circuit description (between 100 and 500 words maximum) and full circuit diagram showing all component values. **Please draw all circuit schematics as clearly as possible.**

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WIN A PICO PC BASED OSCILLOSCOPE WORTH £586

- 100MS/s Dual Channel Storage Oscilloscope
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If you have a novel circuit idea which would be of use to other readers then a Pico Technology PC based oscilloscope could be yours. Every 12 months, Pico Technology will be awarding an ADC200-100 digital storage oscilloscope for the best *IU* submission. In addition, a DrDAQ Data Logger/Scope worth £69 will be presented to the runner up.

CCO Metal Detector – New Seekers

TO the best of the author's knowledge, the metal detector circuit shown in Fig.1. represents another new genre. In principle, it is based on a transformer coupled oscillator (TCO), a well known oscillator type. This essentially consists of an amplifier which, by means of a transformer, feeds the output back to the input, thus sustaining oscillation.

The circuit is presented merely as an experimental idea. With some care, an old Victorian penny should induce a clear shift in tone at 160mm in a crystal earpiece, and a perceptible shift in tone at up to 250mm.

In Concept

The concept differs from beat frequency operation (BFO) in that its performance far outstrips that of BFO. Also, unlike BFO, it is dependent on the balance of two coils to boost sensitivity. However, it differs from IB (induction balance) in that its Rx (receiver) section is active rather than passive, being an integral part of a transformer (or coil) coupled oscillator. Also, unlike IB, the circuit employs a beat frequency oscillator to produce an audible tone.

Furthermore, the CCO detector does not require the critical placement of coils as IB does, with a few centimetres' movement this way or that being permissible – on condition that a suitable audible heterodyne is tuned in. Also, unlike IB, its sensitivity is not localised around the intersection of the two coils, but covers the full area of both. This means that, while not ideally suited to pinpointing finds, it lends itself well to sweeping an area. As with BFO and IB, it also offers discrimination between ferrous and non-ferrous metals.

Circuit Details

In Fig.1, the TCO transformer is replaced by two search coils, L1 and L2. These have the same action as the transformer in a TCO, L1 being the "transmitter", and L2 the "receiver". On the basis of its similarity with a TCO, the author has named this metal detector a Coil Coupled Operation (CCO) Metal Detector.

Search oscillator IC1a oscillates at around 500kHz, depending on the positioning of the coils on the search head. The presence of metal induces changes both in the inductance and coupling of the two coils, thereby inducing a shift in oscillator IC1a's frequency.

Note that IC1 is an unbuffered (suffix UB)

CMOS device. Also, oscillator IC1a is itself unbuffered (it uses no buffer gate) so as to yield a more nuanced signal at IC2's inverting input pin 2. Resistor R1 serves to lightly bias the input of oscillator IC1a to half the supply voltage, thus assisting oscillation, and potentiometer VR1 provides tuning. Resistor R2 limits current through coil L1, while capacitor C1 serves as a coupling capacitor for L2.

A second oscillator, IC1b, together with buffer IC1c, serves as a beat frequency oscillator, oscillating at around 2.7MHz. This higher frequency avoids frequency lock, and also increases sensitivity. An LC oscillator was chosen here for its stability, to avoid problems with drift.

The two signals from IC1a and IC1b/IC1c are mixed through comparator IC2, to produce an audible tone in crystal earpiece X1.

The two coils are each made of 50 turns 30swg (0.315mm) enamelled copper wire, wound on a 120mm diameter former. Each has a Faraday shield, which is connected to 0V as shown. The coils are positioned on the

search head to partly overlap one another, in such a way as to find a good heterodyne. Further tuning is done by means of VR1.

Oscillator IC1a will sustain oscillation no matter which way the coils are orientated – however, orientation does affect performance. The correct orientation may be determined experimentally by flipping one of the coils on the search head. Ideally, the coils will finally be potted in polyester resin.

The CCO Metal Detector may be greatly simplified if a Medium Wave radio is used to provide the beat frequency. In this case, only IC1a is required. The output at IC1a pin 2 is connected to a screened cable (the screen being connected to 0V), which is clipped to the radio aerial – then the radio is tuned until a suitable heterodyne is found.

The author presents the CCO Metal Detector merely as a bare bones idea, and looks forward to seeing its further development in the future. Happy hunting!

Thomas Scarborough,
Cape Town, South Africa

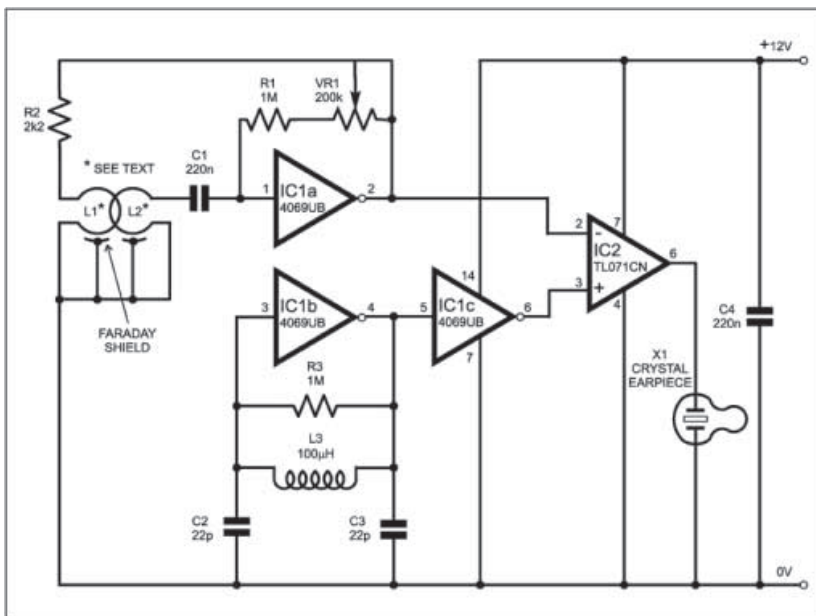


Fig.1. Circuit diagram for the CCO Metal Detector.

Robo Voice Effects - – Talking Robots

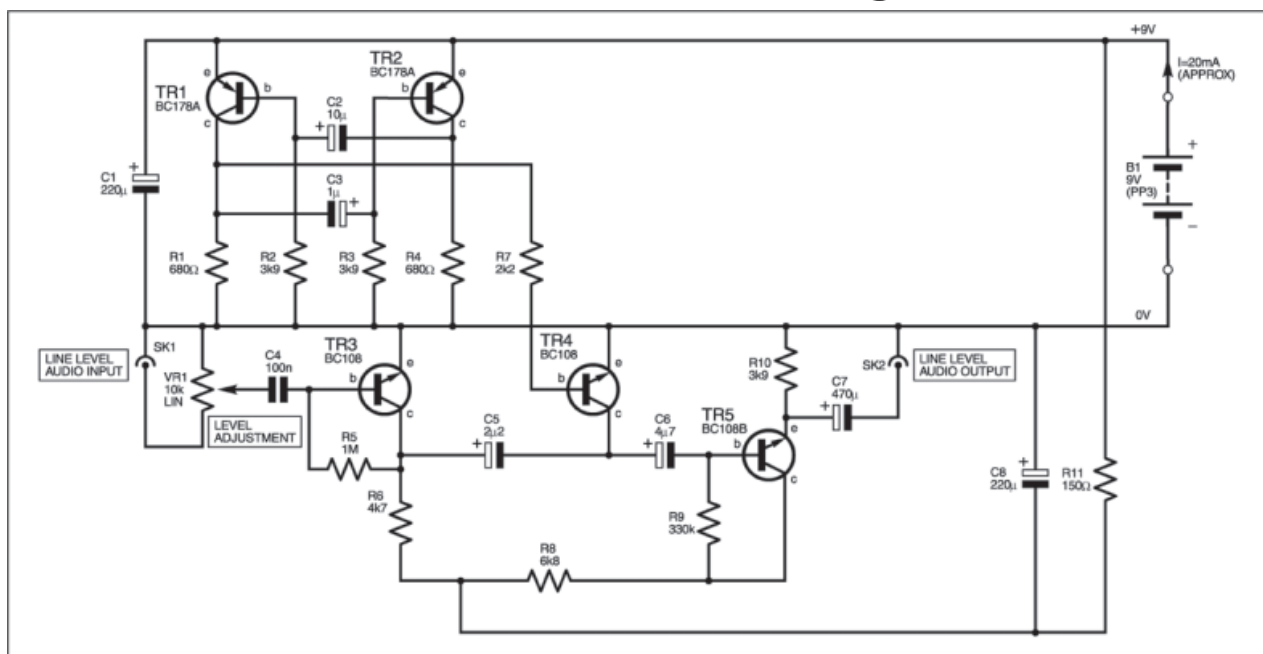


Fig.2. Complete circuit diagram for the Robot Voice Effects.

THE fact that time division multiplex telephone systems are now used proves that you can have intelligible results with an audio channel that is open for only some of the time. This is used in our project but by interrupting the audio channel at a much lower rate (67Hz) we achieved an effect rather like a science fiction robot voice, being quite metallic and artificial sounding.

The circuit diagram shown in Fig.2. will produce novel Robot Voice Effects from, for

example, a Line level input signal from a microphone preamplifier and give a Line level “voice” processed output.

The circuit is quite straightforward with transistor TR3 acting as a voltage amplifier to raise the level of the incoming audio signal, which is routed through a muting circuit based on transistor TR4. The output from TR4 is then buffered by an emitter follower using transistor TR5.

The muting circuit is driven by a rectangu-

lar waveform obtained from an astable multivibrator based on transistors TR1 and TR2. This 67Hz drive has a mark-to-space ratio of 1:2.

If the final Line output signal of this circuit is fed to a piece of equipment which also incorporates a graphic equaliser, and a little trial and error, the results can be even more effective.

M.Robertson and M.Bashir, Chasetown.

Visual Capacitance Gauge – A Measured View

A MULTIMETER frequently has no capacitance meter, and a capacitor frequently has no markings. These two facts together make a capacitance meter a useful device to have at hand. However, such devices tend to be relatively costly.

The simple capacitance gauge circuit diagram shown in Fig.3 will measure capacitance between 100pF and 1μF – determining this with the aid of a front panel control knob pointer above a calibrated scale. It is a Visual Capacitance Gauge, which *extinguishes* i.e.d. D1 at the precise point on the scale which matches the value of the capacitor. This has advantages over the usual audio capacitance bridge, which either requires an earpiece (with a cable to get tangled), or might disturb with its sound.

A standard op.amp relaxation oscillator, IC1a, produces a square wave at output pin 1. Its frequency may be approximately calculated by the formula $f = 0.72 / (R3 \times C1)$. In Fig.3, this represents about 7kHz. This feeds a standard capacitance bridge, which comprises potentiometer VR1, resistor R5, capacitor C2, and the "capacitor under test" (C-TEST). When the bridge is balanced, no signal voltage is present across resistor R6. With IC1b being wired as a comparator, i.e.d. D1 therefore fails to illuminate. At all other times (when the bridge is not balanced), i.e.d. D1 remains illuminated.

The range of the gauge is defined by the value of capacitor C2 – although in practice

this will not be exact, so that the scale is best calibrated through trial and error. So, for instance, to obtain a range of 0 to 100nF, C2 would be a 100nF capacitor. Needless to say, the accuracy of the gauge is dependent on the accuracy of the capacitors "under test" when the scale is calibrated, and ideally C2 will also be a perfect value. In fact, this applies to all the components of the bridge.

If the pointer of VR1's knob is turned, and i.e.d. D1 fails to extinguish, then the wrong range has been selected, with the value of C-TEST likely being higher than the value of capacitor C2. A selector switch may be used to access several ranges, and crocodile clips may be used to attach the capacitor under test to the circuit.

**Thomas Scarborough,
Cape Town, South Africa.**

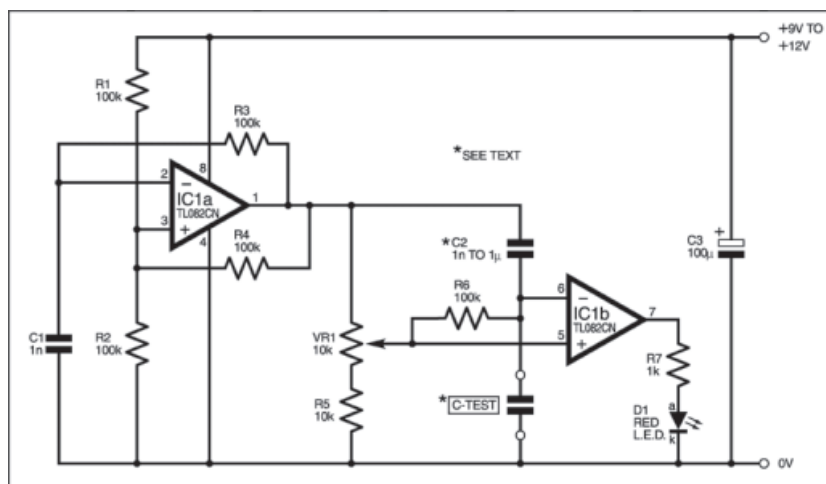


Fig.3. Visual Capacitance Gauge circuit diagram.

M.W. Amplitude Modulator

Stef Niewiadomski

Enjoy your listening as you used to through your radios of bygone eras!

A POPULAR pastime amongst amateurs is renovating and listening to old valve or transistor radios. These radios are usually a.m. only, tuning the Medium and Longwave bands, with maybe a Shortwave range. With the advent of high-quality stereo f.m. transmissions on VHF, and more recently DAB radio, a great deal of music and other material is unavailable to these radios. For those who like this "antique" sound quality, this situation is to be regretted!

The unit described here helps to make amends for this – it takes its input from the audio output of an f.m. or DAB receiver, or other modern audio source, and regenerates it into an a.m.-modulated format in the Medium Wave band suitable for feeding into the aerial input of your old radio. No modifications to the signal source equipment are needed.

Oscillator Circuit

The circuit diagram in Fig.1. shows the variable frequency oscillator (VFO) and buffer stages of the unit. Transistor TR1 forms a conventional Hartley oscillator tuned by variable inductor L1, in parallel combination with fixed capacitor C4 and variable capacitor VC1.

The adjustable core of L1 provides a coarse tuning setting and VC1 allows fine frequency tuning of about $\pm 50\text{kHz}$. Small variable capacitors are rather expensive, so VC1 can be omitted if preferred, and all frequency adjustment made via L1, although less easily.

Transistor TR2 forms a buffer stage to isolate the VFO from the load of the Modulator/Power Amplifier (PA) board. Resistor R2 and capacitor C6 decouple the supply for TR2. The output from TR2 is developed across r.f.c. L2 in conjunction with C7 and R4. It is a.c. coupled by capacitor C8 and taken via miniature r.f. coax cable to the Modulator/PA board.

In the prototype, 2N3819 *n*-channel f.e.t.s were used for TR1 and TR2, but since the frequency of operation is low, almost any other *n*-channel f.e.t.s can be used. However, take care to check their pinouts since they may differ.

Radio frequency choke (r.f.c.) L3, plus resistor R1, Zener diode D1, and capacitors C1 and C2 produce a noise-free, stabilised supply for TR1.

Modulator Circuit

The circuit diagram for the Modulator/PA and lowpass filter stages is shown in Fig.2. The signal from capacitor C8 in Fig.1 is brought into r.f. level control VR1, a.c. coupled by C9 and fed to the base (b) of transistor TR3, which is d.c. biased to 0V by R6. The collector voltage of TR3 is supplied by the modulated output

from audio amplifier via the r.f. blocking components L4 and C21, more on which presently.

The output from the collector (c) of TR3 is taken to a lowpass filter via blocking capacitor C11. Under quiescent conditions, that is with no audio input to IC1, TR3's collector sits at about mid-rail voltage (6V). This relatively low collector voltage is not ideal for linear amplification and the waveform at this point is distorted and

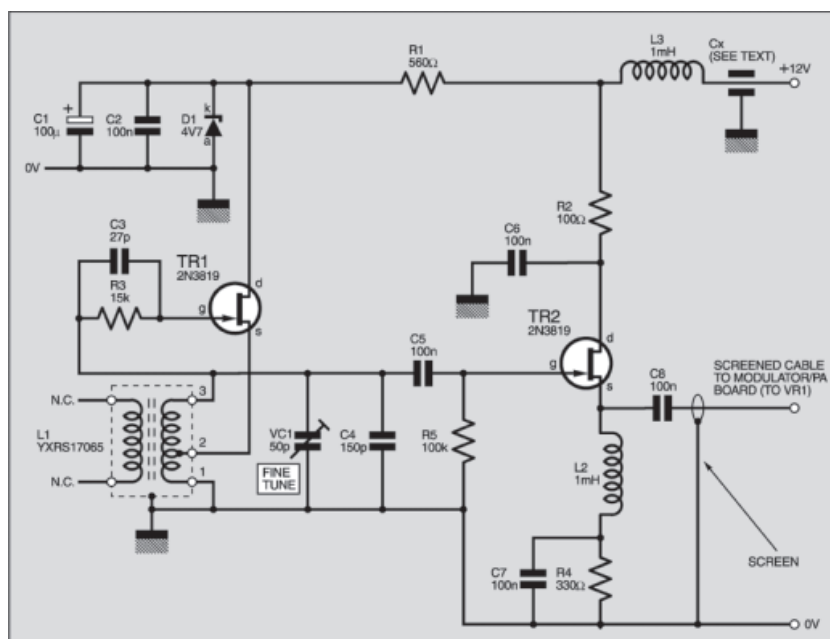


Fig.1. Circuit diagram for the variable frequency oscillator (VFO) and buffer stages.



harmonic-rich, hence the need for a low-pass filter. The audio quality was found to be very good from the radios with which the unit was tried.

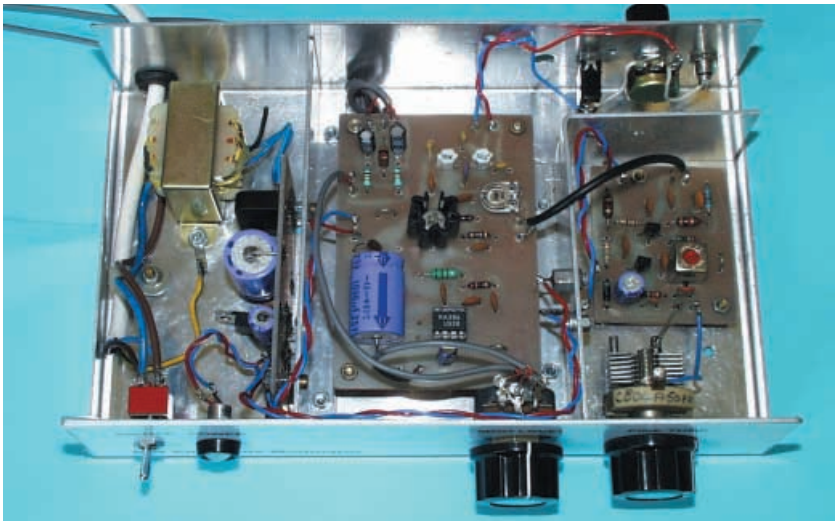
Components L5, L6 and C12 to C15 form a 5-pole Chebyshev 1dB lowpass filter with a cut-off frequency of about 700kHz. This is used to give a fast roll-off to attenuate the unwanted harmonics generated by TR3.

A simple output attenuator is formed by potentiometer VR2 and switch S1. When S1 is closed, VR2's selected setting affects the amplitude of the output signal. When S1 is open the setting of VR2's wiper has almost no effect on the output signal level. The output from the unit with the attenuator set to minimum attenuation is about 600mV peak-to-peak.

Two inputs to IC1 have been provided in a simple stereo mixer format, via C16 and R8 for one channel, and C17 plus R9 for the other, combining at the "top" of modulation level control VR3. The combined signal is a.c. coupled to IC1 via C18. Inductor L7 attenuates any r.f. picked up along the connecting cable.

The mono output from IC1 pin 5 modulates the r.f. signal from the oscillator circuit in Fig.1. Resistor R10 and capacitor C22 help to prevent instability at the LM386 output. Inductor L8 prevents any r.f. from the unit radiating from the power line and back into the radio or CD player-driving the unit.

Normally pins 1 and 8 of an LM386 amplifier are connected via a 10uF capacitor. This has the effect of raising the gain of the LM386, but in this design it has been omitted since there is already plenty of gain available to modulate TR3. Adding the capacitor would have the detrimental effect of increasing the hiss of the circuit. Nonetheless, the p.c.b. includes tracking for this capacitor, so the constructor can experiment if desired.



Power Supply

The M.W. Amplitude Modulator can be powered directly from a 12V battery. However, it may alternatively be powered from a mains driven power supply, such as that shown in Fig.3, which provides a regulated output of 12V d.c.

Mains power is input via switch S2 to mains transformer T1. The secondary 12V a.c. output is rectified by REC1 and smoothed by C23. It is then regulated down to 12V d.c. by IC2, whose output is smoothed by C24 and C25. Power-on indication is provided by l.e.d. D2, buffered by R11.

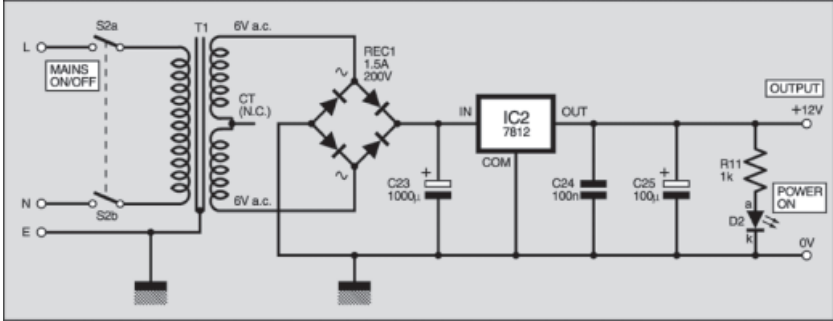


Fig. 3 Suggested mains power supply circuit diagram.

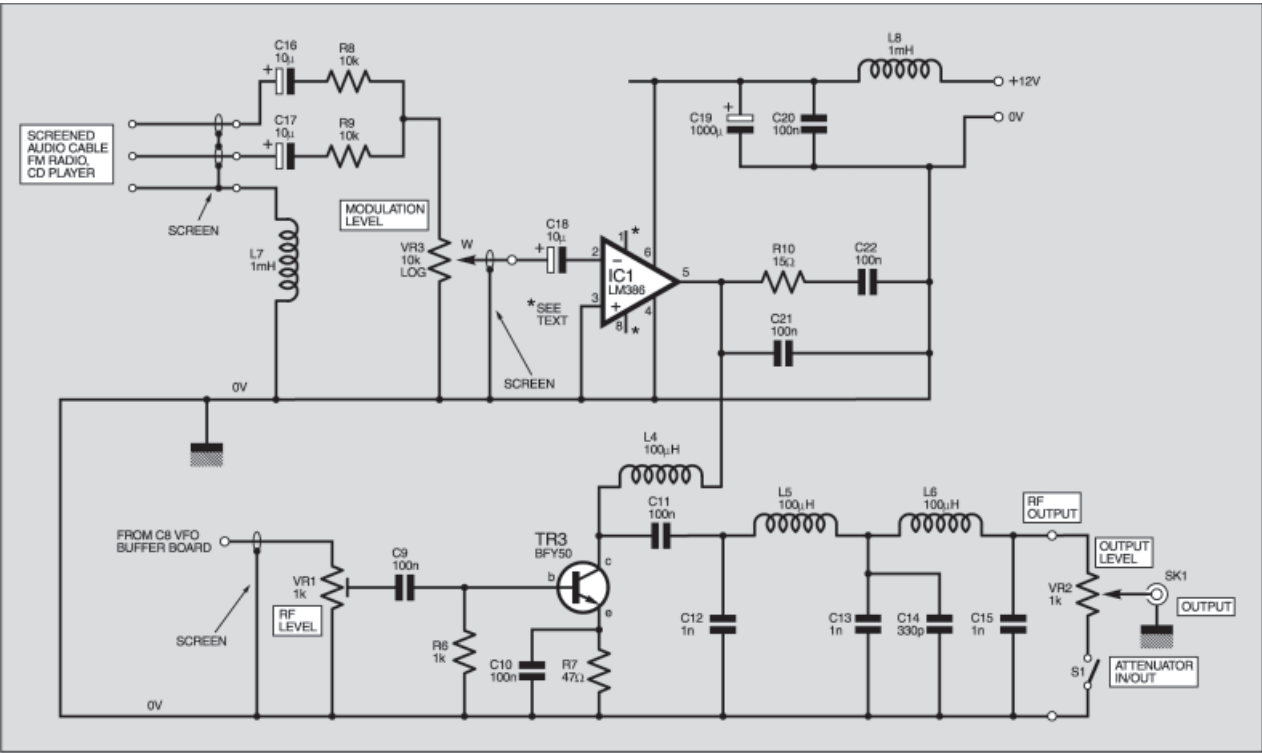


Fig.2. Circuit diagram for the Modulator/PA stages for the M.W. Amplitude Modulator

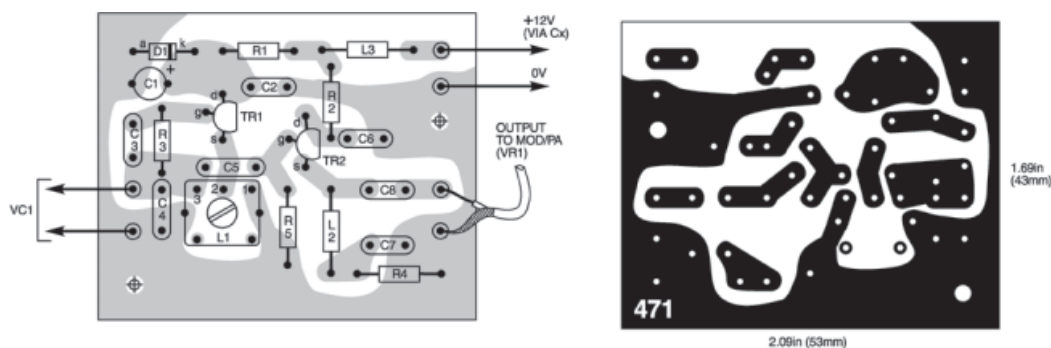


Fig.4. Printed circuit board topside component layout, wiring details and full-size underside copper foil master for the VFO. Keep the wires to the Fine Tuning capacitor as short as possible.

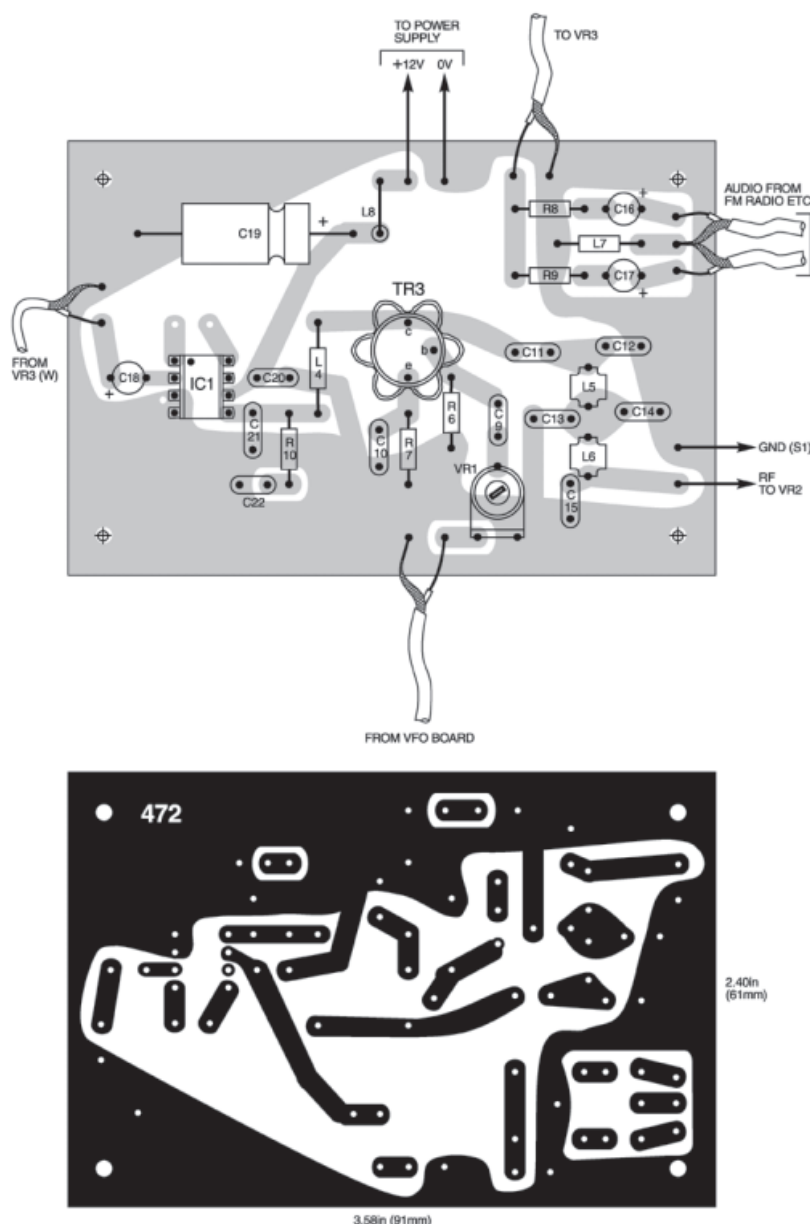


Fig.5. Modulator printed circuit board component layout, wiring and full-size copper foil master pattern.

Construction

Note that the mains power supply should only be built by those who are suitably qualified or supervised.

Also note that in the UK, and in many other countries, it is an offence to transmit on the Medium Wave without a broadcast license, even at the low powers generated by this unit. Care should therefore be taken to eliminate any radiation by connecting the unit to the MW radio using screened cable.

COMPONENTS

Resistors

R1	560Ω
R2	100Ω
R3	15k
R4	330Ω
R5	100k
R6	1k
R7	47Ω
R8, R9	10k (2 off)
R10	15Ω
R11	1k

All 0.25W 5% metal film or better.

Potentiometers

VR1	1k min. carbon preset
VR2	1k rotary carbon, lin
VR3	10k rotart carbon, log

Capacitors

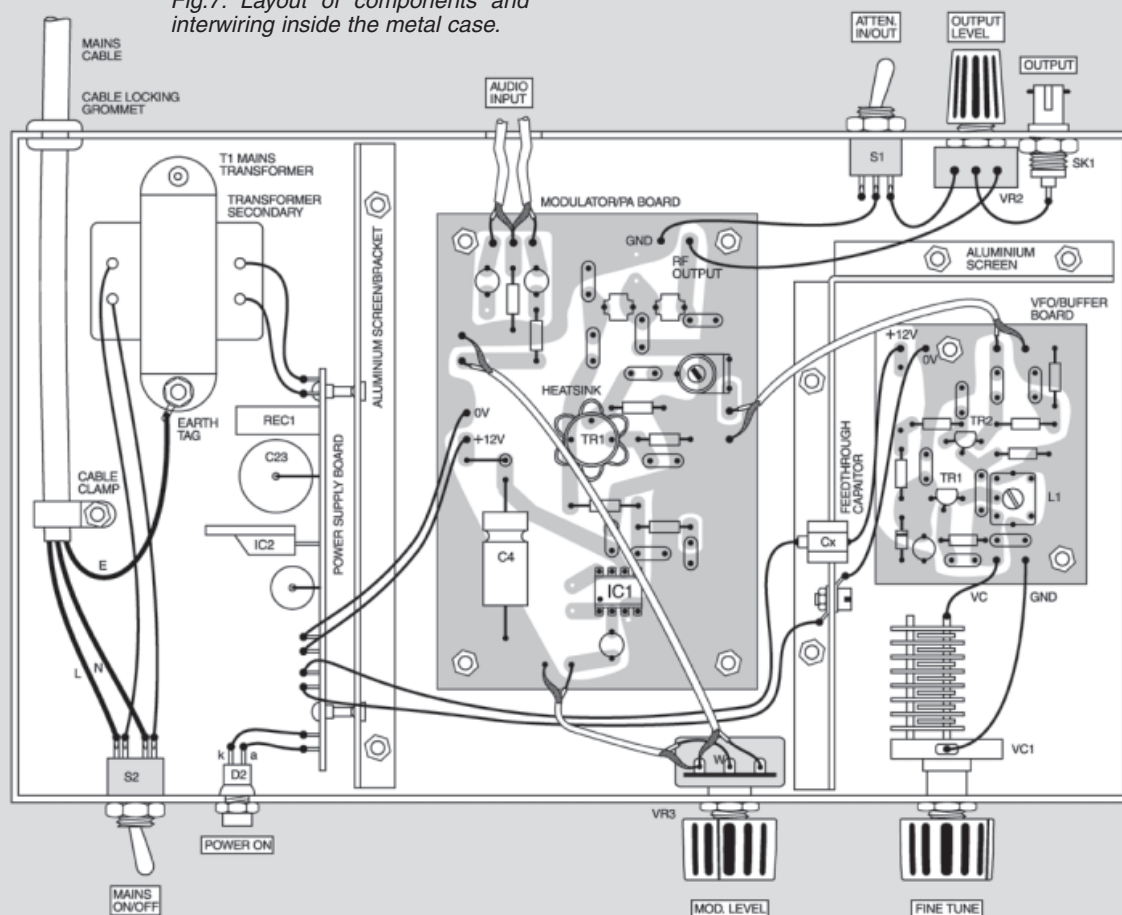
C1, C25	100μ radial elect. 16V (2 off)
C2, C5 to C11	100n ceramic disc
C20 to C22, C24	(12 off)
C3	27p ceramic disc
C4	150p ceramic disc
C12, C13, C15	1n ceramic disc (3 off)
C14	330p ceramic disc
C16 to C18	10μ radial elect. 16V (3 off)
C19	1000μ radial elect. 16V
C23	1000μ axial elect. 25V
VC1	50pF variable
CX	Feedthrough type

Semiconductors

D1	4V7 400mW Zener diode
D2	red l.e.d.
IC1	LM386 power amp i.c.
IC2	7812 +12V 1A volt age regulator

See
SHOP
TALK

Fig.7. Layout of components and interwiring inside the metal case.



- REC1 200V 1-5A bridge rectifier
 TR1, TR2 2N3819 *n*-channel f.e.t. (see text) (2 off)
 TR3 BFY50 *npn* transistor

Miscellaneous

- L1 Toko YXRS17065 variable inductor
 L2, L3, L7, L8 1mH r.f. choke (4 off)
 L5, L6 100 μ H r.f. choke.
 PL1 Toko 7BS or 7BA (2off)
 3-5mm stereo jack plug
 S1 min. s.p.d.t.
 S2 toggle switch
 SK1 d.p.d.t. toggle switch, mains rated
 T1 phono socket
 T1 min. mains transformer, 6V-0-6V 250mA secondary

Printed circuit boards, available from the EPE PCB Service, codes 471 (VFO), 472 (Modulator), 473 (PSU); metal case, 200mm x 125mm x 50mm; heatsink for TR3; knobs (3 off); min. screened audio cable; screened r.f. cable; 8-pin d.i.l. socket; terminal pins; 3-5 stereo jack plug capacitor; connecting wire; 3-core mains cable; panel mounting cable lock grommet; cable clip; screening angle aluminium 40mm high; p.c.b. mounting nuts and bolts; solder tag; nuts and bolts; solder, etc

Approx. Cost
 Guidance Only

£36
 excl. case

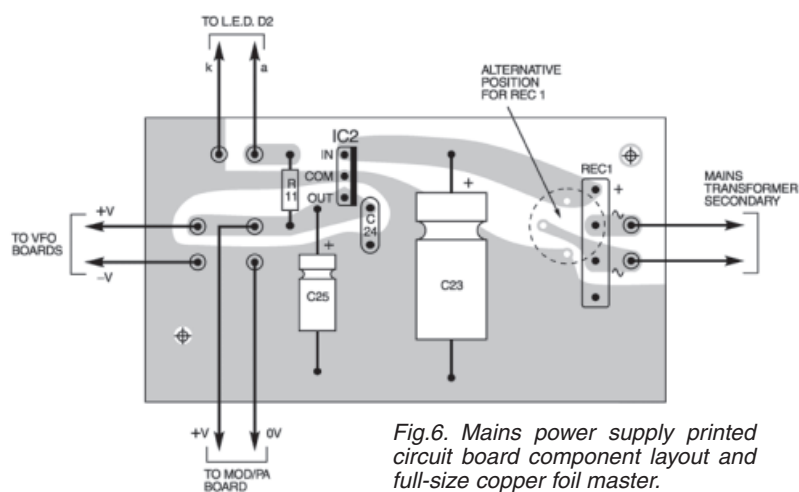
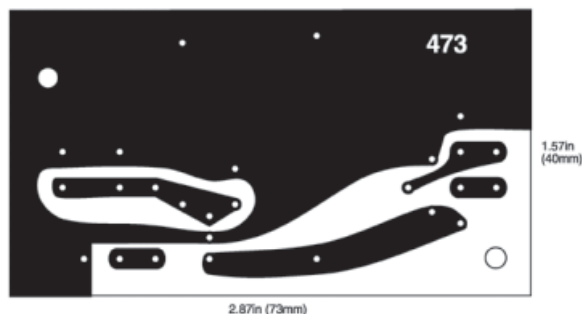


Fig.6. Mains power supply printed circuit board component layout and full-size copper foil master.



The prototype was built on three printed circuit boards (p.c.b.s) and housed in a metal case to screen the circuit. These boards are available from the *EPE PCB Service*, codes 471 (Modulator), 472 (Output) and 473 (PSU).

Component layout and tracking details for the boards are shown in Fig.4 to Fig 6. Assemble the components in ascending order of size, taking care to correctly orientate the semiconductors and electrolytic capacitors. Insert 1mm terminal pins to facilitate inter- and off-board wiring.

Assembly

The general arrangement of the boards and chassis-mounted components in the case is shown in Fig.7.

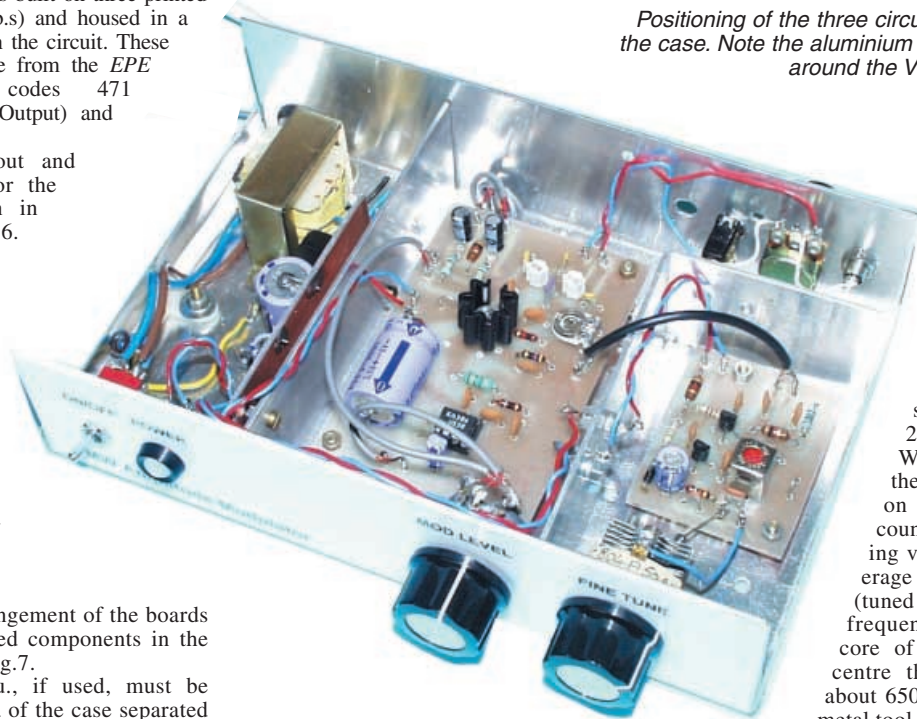
The mains p.s.u., if used, must be mounted in an area of the case separated by a metal partition, to which the p.s.u. board is securely mounted.

A mains-rated double-pole switch must be used for S1 and the Earth wire of the 3-core mains lead must be securely connected to the metal case via an earth tag. The mains lead must pass through the rear of the chassis via a cable-locking grommet.

The transformer is mounted on the chassis, close to the rear of the case as shown. The power supply p.c.b. is mounted on its side on a piece of angle aluminium (40mm high \times 120mm long). It must be securely mounted on the partition.

A similar piece of aluminium angle was used to enclose the VFO/Buffer board along with the Fine Tuning

Positioning of the three circuit boards inside the case. Note the aluminium screen partition around the VFO/Buffer p.c.b.



If an oscilloscope is available check the output from the VFO/Buffer board. This should be about 2V peak-to-peak. While measuring the VFO frequency on a frequency counter, or monitoring via a general coverage or MW receiver (tuned to the required frequency), adjust the core of inductor L1 to centre the frequency at about 650kHz. Use a non-metal tool for this. Rotating VC1 should vary the frequency between 600kHz and

700kHz.

Modulation

Set VR1 on the Modulator board to about mid-way (the setting does not seem to make a big difference to the output waveform), and the Modulation Level control VR3 to minimum. Attach the scope to socket SK1 and check for a good sine wave at the VFO frequency.

If you have an a.f. signal generator, connect it to the audio input of the Modulator board and slowly advance Modulation Level control VR3. The output waveform should show the classical amplitude modulated waveform. If a scope is not available check the frequency of the unit's output on a frequency counter or MW receiver. It should be the same as the VFO frequency. Be extra careful not to select a harmonic frequency.

In Use

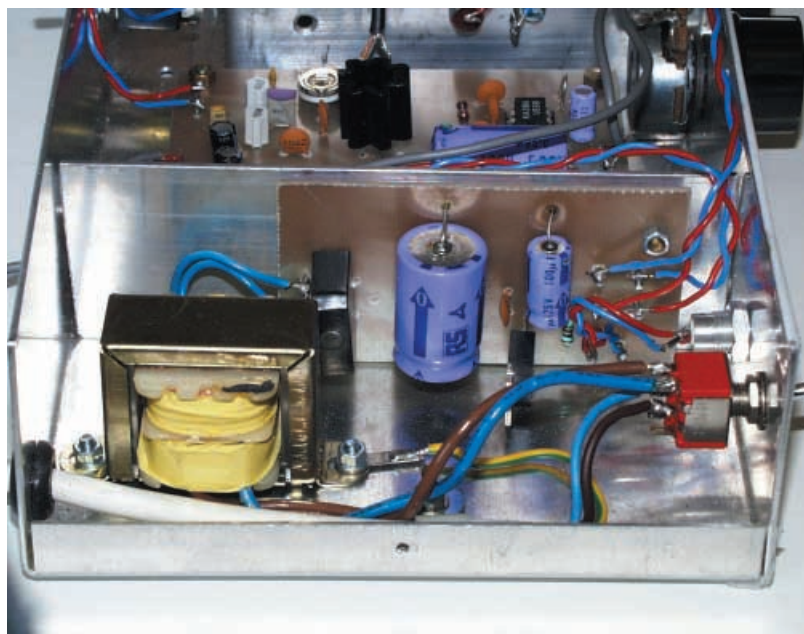
When all seems to be satisfactory, set the attenuator network control VR2 to maximum. Connect the unit's output at socket SK1 to the aerial input of a MW receiver via screened cable. Connect the signal inputs via stereo plug PL1 to the headphones output of an audio source. This should automatically turn off the source's internal speaker. Adjust the source volume control to a reasonable listening level.

Tune the receiver to the unit's frequency, about 650kHz, and adjust the Modulation Level control until the audio can be heard. Advance this control to just below the level when distortion starts. This is when the unit is being over-modulated. The attenuator control may need adjustment depending on the sensitivity of the MW receiver. Fine-tuning of the unit's frequency can be done using variable capacitor VC1. □

capacitor VC1. An optional screw-in feedthrough capacitor (Cx) feeds the +12V supply to the board and a piece of miniature coax cable connects the Buffer stage output to the PA stage via a hole in the aluminium screen.

Setting Up

Thoroughly check all the boards and the inter-board wiring. Switch on the mains power and check that l.e.d. D2 lights and that the power supply's output from regulator IC2 is close to +12V. Immediately disconnect the power and recheck your assembly if there is a problem.



Close up view of the power supply components. Make sure the circuit board is bolted securely to the side of the screening panel. Note also the Earth solder tag bolted under one of the transformer fixing bolts.

READOUT

Email: john.becker@wimborne.co.uk

John Becker addresses some of the general points readers have raised. Have you anything interesting to say? Drop us a line!

All letters quoted here have previously been replied to directly.

WIN AN ATLAS LCR ANALYSER WORTH £79

An Atlas LCR Passive Component Analyser, kindly donated by Peak Electronic Design Ltd., will be awarded to the author of the *Letter Of The Month* each month.

The Atlas LCR automatically measures inductance from 1 μ H to 10H, capacitance from 1pF to 10,000 μ F and resistance from 1 Ω to 2M Ω with a basic accuracy of 1%.



★ LETTER OF THE MONTH ★

More on Magnetometry

Dear EPE,

First of all, well done to John Becker for an excellent article, the *PIC Magnetometry Logger* (July/Aug '04). His PIC and processing software were particularly interesting. I have been operating a number of gradiometers using the Speake sensors over the past 18 months and can offer a few extra bits of information that might help anyone who wishes to concentrate on magnetometry for archaeology.

The Speake FGM3 sensors need lots of signal conditioning to get optimum sensitivity and repeatability. If you are expecting to see data resembling the highly detailed gradiometer scans in the archaeology journals then this is very difficult to achieve. Typical surveys present data in the range of ± 5 nT to see details of banks, ditches, post holes, etc. If the Speake signal processing chip is used you can expect approximately 10nT per count at the highest sensitivity. For more detailed surveys you will have to work hard on signal processing and stability in the hardware.

The two most important hardware properties are mechanical and thermal stability. John Becker's solution for the former, the aluminium angle mount, is a very cost effective solution. To do much better one has to consider low expansion, very stiff composite materials such as grp and carbon fibre. Thermal stability, more particularly the minimising of any temperature difference that may arise between the two sensors, is very important.

The sensors must have nearly identical environments as far as thermal isolation is concerned. They dissipate about a tenth of a watt on their own so they will slowly heat up depending on how isolated from the environment they are.

There are differences between samples of sensors so try to get a pair from the same production batch and use a voltage regulator/filter on each sensor.

With good mechanical-thermal design and signal conditioning that allows measurement of a shift of less than 1Hz in about 70kHz (actually the equivalent measurement of period) then reasonably stable measurements can be made down to about ± 1 nT. At this point it gets very hard work indeed to maintain stable measurements in the field since very small tilts and the vibration from walking or brushing against vegetation become measurable! Frequent nulling will be necessary, particularly in the first half hour or so while the sensors stabilise.

Finally, my biggest surprise was the amount of data needed for a high quality gradiometric survey for archaeology. You will need about four measurements per metre in a traverse. The traverses can be one metre apart, but even so this generates lots of data so be prepared for big memories and long waits for downloads, unless you go to very high Baud rates or USB.

There are lots of things to try and plenty of scope for some innovative approaches here. Bill Speake is very helpful and very willing to share what he learns from all the sensors out in the field. With John Becker's excellent introduction, there should be some interesting measurements coming out of gradiometer surveys in the future.

Dr William E. Martin, Boxmoor, Hemel Hempstead, via email

Many thanks Bill for the useful information, and your kind words. Yes, Bill Speake is very helpful, as I have found personally, and from feedback through readers.

Pi and L.E.D. Rectifiers

Dear EPE,

I've just been reading Tony Smith's special feature, *Light Emitting Diodes* Part 1 (Sept '04). I have a query regarding the example calculation under the subtitle of Half Wave Rectification (p.658), where Fig.5c is used. This circuit has two diodes which will perform full wave rectification of the current through R1 and the formula used in the example is for a half wave circuit, so perhaps the formula used in this example should have 2π in the denominator instead of just π , which would be correct for 180 degrees or π rads of diode conduction in the half wave circuits?

Lee Hewitt, via email

Tony replies:

The three circuits in Fig.5 each provide a different way of rectifying the current through the l.e.d. The circuits in Fig.5a and Fig.5b are very similar in that current flows through R1 and the l.e.d. only on positive half cycles of the a.c. voltage waveform. The circuit in Fig.5c is slightly different in that current flows through R1 on both half cycles of the a.c. waveform. In this respect, the current in R1 is certainly full wave rectified.

However, the current through l.e.d. D2 is not full wave rectified. In fact, current flows through the l.e.d. only on positive half cycles. On negative half cycles, current flows via D1 which effectively clamps D2. Therefore, no current flows through the l.e.d. on negative half cycles, and so the formula for R1 (which is a close approximation to the ideal value) is correct for all circuits in Fig.5.

Therefore, in Fig.5c, it is only necessary to consider full wave effects when calculating the appropriate power rating for R1.

Tony Smith, via email

Standard Practice

Dear EPE,

Regarding Des Mayes comments (*SuperAb Farads*, Oct '04), the trouble with international standards is that each country wants its own version used and the politicians decide on yet another unworkable compromise.

When I ran a standards lab, I had a digital voltmeter that could measure a single cell battery to seven decimal places, but at that level the battery behaved more like a thermometer than a voltage source. It's easy to make and calibrate a precision instrument, but take it out of its cosy temperature controlled environment and it's all over the place.

Mostly it is the government inspectorates who are obsessed with accuracy and repeatability. But what about the costs that go with striving for conformity and perfection? For example, calibration gear to test a humble black Avo meter cost about £4000 about 20 years ago. But five years later, to test a cheap £20 digital voltmeter on the market with specs of 1% error, there was no test gear available at any price to accurately check them. The only option was to send each unit to the NPL lab, for their £150 certificate every year.

George Chatley, via email

Interesting comments, George. I wonder if you're stirring up a hornet's nest?

Charging Primary Cells

Dear EPE,

In reply to George Chatley on the charging of zinc/carbon batteries. Around the late 50s I used to recharge my cycle batteries and it was very successful. There were a number of articles in the technical magazines on the subject. Basically the charging circuit consisted of a simple full-wave rectifier shunted by a resistor, thereby providing dirty d.c.

Current was controlled at around 15mA (depending on the cell type). The charge current must be such that gassing is not produced. If it is then at best the cell will expand, at worst, explode! *Wireless World* once reported that the deposition of zinc was better than that produced in manufacture. *Electronics World* March '01 had a more sophisticated circuit design using pulse techniques.

Now that George has reminded me of this wheeze I shall recommence recharging my cells. Incidentally, looked at as a Green Issue, by recharging cells we reduce the number bought and therefore the number consigned to waste disposal dumps.

Peter Mitchell, by email

In fact, Peter, many years ago EPE published a revolutionary charger for standard batteries, and which I believe found world-wide acclaim. Too long ago for me to try looking up details. And there are indeed safety issues involved and such recharging should not be undertaken without fully understanding those issues.

Grey Cell PICing

Dear EPE,

Just a quick note to thank John Becker and Robert Penfold. I have just prototyped a PIC programmer which borrows heavily from their individual contributions to *EPE*. I have used JAVA to program the front end because it can access the COM port directly, Robert's RS232 driver to communicate with the PIC and John's 5V/12V generator from *Toolkit MK2* to provide the programming voltage.

This means, of course, there is a least one cell of grey matter still active!

Nick Biggs, via email

That's nice to know Nick – and may even prove you've still got lots of grey-cells!

EPE READER ONLINE COMPETITION

WIN MICROCHIP DEVELOPMENT TOOLS!

Everyday Practical Electronics is offering its readers the chance to win five development tools from Microchip. Worth over \$2,100

The first prize is an MPLAB ICE2000 In-Circuit Emulator (ICE) and the four runner up prizes are Microchip's new PICkit 1 Flash Starter Kits.

For the chance to win one of these development tools, log onto **www.microchip-comp.com/epe** and enter your details in the on-line entry form.

All entries must be made on-line before November 15th 2004



The **Microchip MPLAB ICE2000** is a high-end, full-featured emulator that provides higher-performance emulation capability for PICmicro MCUs, reducing development and debugging time.

MPLAB-ICE 2000 is worth \$2000 and is small, portable and lightweight. It offers real-time in-circuit emulation to maximum speeds of up to 33MHz and emulation down to 2.0 volts. It is CE compliant, features full speed emulation, low voltage operation, software configurable voltage and clock, parallel port interface, interchangeable processor modules and device adapters, and unlimited software breakpoints. It has a 32K by 238-bit trace, and includes sophisticated trace analysis, complex breakpoints, and the ability to monitor internal registers.

The emulator system runs on the Windows-based MPLAB Integrated Development Environment (IDE), which gives devel-

opers the capability to edit, compile and emulate from a single user interface. The MPLAB desktop provides the development environment and tools for developing and debugging applications as a project, allowing quick movement between different development and debugging modes.

The new **PICkit 1 Flash Starter Kit** is a low-cost (\$36), easy-to-use programmer, evaluation and development kit for the company's 8-pin and 14-pin Flash-based microcontrollers. Supporting the PIC12F629, PIC12F675, PIC16F630 and PIC16F676 devices, the PICkit 1 Flash Starter Kit gives users the benefits of creating advanced microcontroller designs for a very low price.

The kit includes a 3-inch by 4.5-inch printed circuit board featuring a USB-powered programming tool that runs on a personal computer. The board's evaluation area features eight I.e.d.s, one potentiometer, one switch and a sample 8-pin PIC12F675 Flash device. The development area features a snap-off prototype board that enables users to connect external circuitry to the microcontroller for quick set-up of an application-specific prototype. Programming the PICmicro Flash microcontroller is provided by the standalone graphical user interface.

The kit also includes a CD-ROM containing a user's guide with tutorials and example software code, the MPLAB Integrated Development Environment with HI-TECH PICC Lite C compiler, Microchip's *Software and Hardware Tips n' Tricks for 8-Pin Microcontrollers* and a USB interface cable.



Competition entries must be made on-line before November 15th 2004.

The names of the prizewinners will be published in the January 2005 issue of *EPE*.

Practical Electronics 40th Anniversary

John Becker

A brief commemoration of our ancestral sister's origin!

SOME of you long-term addicts to hobbyist electronics may well be astonished that it is actually 40 years since the first edition of *Practical Electronics* was published! No, not *EPE*, but *PE*, our erstwhile sister publication. It was the November 1964 edition that started the ball rolling as far as we are concerned.

Around that time, as this ripened commentator recalls, the principle magazines which he read were *Wireless World*, *Practical Wireless*, *Practical Television* and *Radio Constructor*. The strength of interest in hobbyist electronics in that period was enormous. So much so that it is understood that *PE* partly came about because *PW* could not cope with the number of advertisers who wished to use it as a profitable market-place.

At the time of *PE*'s 25th anniversary, Fred Bennett, its founding editor, recounted how he had been an editorial assistant on *PW*, then published by George Newnes: "Towards the end of that year (1962) Managing Editor, Bert Collins (successor to F.J. Camm, the founder of the Practical Group of magazines) informed me that there was the prospect of an editorship and instructed me to set about the planning of a new title, which was to be called *Practical Electronics*."

"For six or seven years (following its launch) we enjoyed a leading and unchallenged position. In 1971 we launched *Everyday Electronics* and about that time the first serious opposition came into view. 'Bandits! Tally ho!'" (Fred had been in the RAF during WW2!). "The battle for the hobbyist market had begun. But that's another story".

Continuity

Dave Barrington, *EPE*'s Deputy Editor, was right in at the start alongside Fred. Dave had been working on *PW* and moved across to *PE* with him, and so of those of us on *EPE*'s Editorial team, Dave is more familiar with the objectives and heritage of our current pride and joy, than any

of us. Mike Kenward, our Editor and owner, was offered a job on *PE* by Fred in 1968, as technical sub-editor – "A job that was to lead to a career in publishing which I had never even considered", says Mike. And look where it lead him!

John Becker (your current story teller and *EPE* Tech Ed), was then in a career that had nothing to do with electronics, Film making. But he was a dabbling hobbyist in electronics, and was enthralled to buy and read *PE*'s first issue, an action that would eventually lead him to give up Films for Farads!

Alan Winstanley, our Online Editor, was still a schoolboy when *PE* was launched. He devoutly went on to learn electronics through *EE* when it arrived. Soon he was writing articles for us, as he still does. Alan's greatest

achievement for us is that he was the inspired innovator of our well-interfaced website (www.epemag.co.uk).

Clive ("Max") Maxfield and Alvin Brown, who run our Online site from "across the pond", became involved with us through Alan (who had met them in a web-based newsgroup some years previously). The relationship was to lead to the introduction of our second website (www.epemag.com) through which you can pay for and download current and back issues of *EPE*. We believe we were the first magazine to offer this facility.

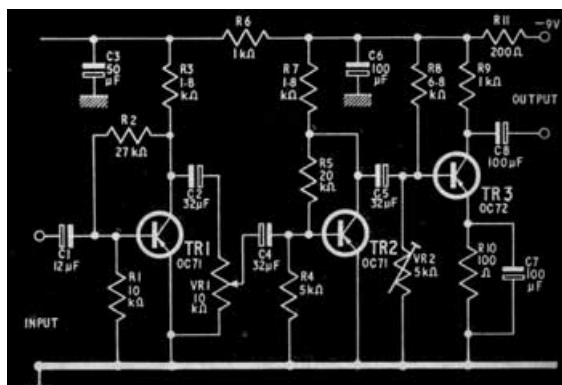
Pooled efforts

PE and *EE* ran side-by-side under Fred's guidance for many rewarding years. In the meantime, IPC Magazines had acquired these and other titles, in due course resulting in a change of editorial location from London to Poole. Fred chose not to move, and Mike was offered *PE*'s Editorship in Poole. *EE* remained with Fred in London – for the time being, it too eventually came into Mike's hands at Poole.

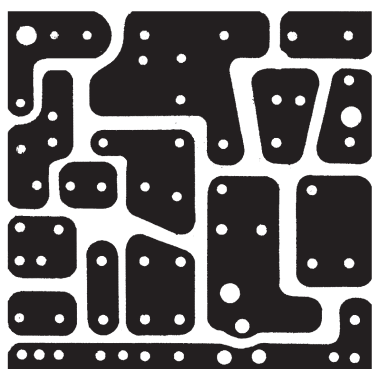
But then the political and social climate began to change, and people started to drift away from electronics into, principally, the rising fascination presented by personal computers that were beginning to make a market impact. All the hobbyist electronics magazines, including the Bandits, of whom there were several by then (although *EE* had already bought the title to *Hobby Electronics*), saw a decline in readership.

IPC, interested in "bottom-line" returns, decided to sell off many of its "specialist" titles, *PE* and *EE* included. Mike seized his opportunity and bought *EE*, and took Dave with him, in 1986. *PE* went to an independent publisher, back in London, where JB was soon invited to edit it – a long story that! – which he did for four years until the end of 1990.





Early PE circuit diagrams were printed white on black to emulate engineering “blue prints” and (below) p.c.b.s of the time were reminiscent of Meccano designs!



Following JB's departure, *PE*'s fortunes declined, and eventually Mike bought it – integrating it with *EE*, under the combined title, which we still hold, of *Everyday Practical Electronics – EPE*. Mike then invited JB to join the team in 1994.

Following the acquisition of *PE*, many of the Bandits continued to decline as well, while *EPE* flourished. Mike bought the title of one of them, adding its readership to ours – *Electronics Today International*.

It's interesting to observe, though, that whereas it was computers that originally caused the initial decline in hobbyist electronics, it is now *EPE*'s attention to “practical” computing techniques, especially with respect to integrating PCs and PIC microcontrollers with other electronic technology, that *EPE* continues to attract a sizeable readership. History continues to be made in the present tense!

You can read a fuller history of *EPE* via the Resources click-line on our main web site.

Opening Contents

Amongst the contents of *PE*'s first issue were: a 5 Watt Integrated Amplifier; Simple Geiger-Muller Ratemeter; V.H.F. Broadcast Receiver; Morse Practice Oscillator; *Electronic Didjeridoo* – the traditional acoustic version of which was then being played to great acclaim by a certain Rolf Harris!

Interestingly, that design, by A.J. Basset, used transistors, albeit *pnp* germanium types. At the time, valves dominated the hobbyist scene, and *PE* was being innovative by using transistors. Furthermore, most d.i.y. designs in, say, *PW* and *WW*, were based on tag strips. *PE*, though, published a printed circuit board for the Didjeridoo, but the likes of

which are reminiscent of Meccano parts (see left). It's also fascinating to see that the circuit diagrams were printed white on a black background – no doubt to suggest an equivalence with “blue-prints” that engineers used.

Other features in that issue included *Sound on Tape* (tape recorders were in widespread use, and were large; *Semiconductors for Automobiles* (but it was some time before d.i.y. designs for electronic ignitions appeared, to remain popular for many years); *A New Look at the Electron*; *Beginners Start Here*, the forerunner of our regular *Teach-In* series – in which resistance and current flow were indicated by a filament bulb (i.e.d.s were not yet in common use) battery powered via a variable resistor made from the heating element of an electric fire.

Open Sesame

One news item in Nov '64 reported that radio hams were causing problems and that “complaints about garage door interference on the amateur bands are increasing. Perhaps an ultrasonic or even sonic system might be better ... (but) Stirling Moss finds his sonically operated garage door is liable to respond to brake squeaks from certain passing vehicles!”

For Whom...

There was also concern being expressed by bellringers that “recorded bells played over an amplifying system are becoming more the vogue ... Is electronics always the benefactor we believe, or does it have a more sinister role?”, queried John Valence in his *Detached Particles* column.

Improved Memory

Another news item shows that large scale memory devices as used in modern electronics were a long way off:

“An electronic memory device designed at the Institute of Electronics Automation and Telemechanics of the Georgian Academy of Sciences, U.S.S.R., is based on the optical memorising of information”. (It's noteworthy that there was *any* external knowledge of what the Russians were doing then, with the Cold War at a peak).

“A fine film of calcium chloride covering a transparent screen records the signals of an electronic ray. Travelling over the screen in a preset direction, this ray records information in the form of dark and light dots. It is stated that this new type of optical memory has great advantages over electronic-ray tubes or photo-sensitive materials now used in memory devices. ... (the screen) can hold over 10,000 signs per centimetre of surface. The time

Forward-looking advertisers took advantage of the new PE as a potentially good market-place, which it proved to be!

taken to record information is in the order of tens of milliseconds.” (And to think that the first Moon landing was just five years hence, and that computers and memories were needed to control that mission.)

Wiring Boards

Beginning to make an impact on the hobbyist market then was Veroboard, as featured in another news item:

“A typical example of how developments in industry are finally passed on to the amateur experimenter is the case of Veroboard or Vero Plain Board. Veroboard is made from conventional s.r.b.p. board clad with strips of copper and a regular hole matrix is pierced in the copper. Extremely low-cost printed circuit layouts can be designed by this method, without any messy chemicals or photography being involved.”

Sliding Maths

Amazing too that mathematical calculations, whether for space flight or school use, were performed on slide rules, as typified by the advert for a Designer's Slide Rule on the *New Products* page. General-use electronic calculators were still some years away – it was in 1972 that *PE* highlighted the first single-chip calculator i.e.

One cannot but help wonder how primitive our modern leading-edge technology will appear to our descendants.



One of the leading electronic component catalogues of the time.

Light Emitting Diodes – Operation and Applications

Anthony H. Smith, BSc. (Hons)

Part 3 – Boosters, Alternative Flashers and Multicolour L.E.D.s



LAST month, we looked at l.e.d. flasher units based on astable oscillators using logic gates. In this, the penultimate installment in our examination of l.e.d.s and driver circuits, we look at alternative flasher circuits, and examine “booster” circuits capable of driving l.e.d.s from very low voltages. We also discuss bicolour and tricolour l.e.d.s.

We start, however, by dealing with last month’s poser: considering that a red l.e.d. can have a forward voltage of 1.6V or more, how is it possible to flash such an l.e.d. from a voltage as low as 1.0V?

Single Cell

For reasons of cost, size and weight, many electronic products such as toys and novelty goods must operate on a single cell battery, making it difficult to power an l.e.d. For example, a single alkaline cell, even when fully charged, only has a terminal voltage of around 1.5V and will thus produce little more than a dim glow in a red l.e.d. The problem is compounded when using a NiCad (Nickel-Cadmium) cell, which has a nominal terminal voltage of just 1.2V. Nevertheless, with a little ingenuity, a single cell can be used not just to illuminate, but to flash an l.e.d. Fig.1 shows how this can be achieved.

Schmitt inverter IC1a together with capacitor C1 and resistor R1 form a conventional astable oscillator (see Fig.6.1, *The Schmitt Trigger* Part Six in *EPE* April '01 for more details). The addition of R2

and transistor TR1 driven by the second inverter stage (consisting of IC1b, IC1c and IC1d in parallel) produces a pulse train with relatively low duty cycle at point X.

When IC1a’s output is high, the output of the second inverter stage is low, thereby holding TR1 “off” such that R2 has no effect on C1 which simply charges up via R1. However, when IC1a’s output goes low, the voltage at point X goes high, thus turning TR1 “on”. Resistor R2 now appears in parallel with R1, and since its value is much less than that of R1, C1 discharges rapidly. The result is a series of relatively narrow positive-going pulses at point X.

Whenever the pulse train is at a low level, the cathode (negative terminal) of storage capacitor C2 is pulled down to 0V allowing it to charge up via R4. Provided the low level is of sufficient duration, C2 charges up fully such that the voltage across it, V_{C2} , is equal to the battery supply voltage, V_B . During this time, point Y is high such that the l.e.d. is reverse biased and has no effect on the circuit.

At the end of the low period when point X goes high, the cathode of C2 is pulled up to the positive supply potential, V_B , and the voltage at its anode (positive terminal) instantaneously rises to:

$$V_{\text{ANODE}} = V_B + V_{C2} = V_B + V_B = 2V_B.$$

Since point Y is now low, a voltage of $2V_B$ appears across the series connection

of R5 and the l.e.d. Therefore, with $V_B = 1.5V$, we get 3V across R5 and l.e.d. D1, more than enough to generate a bright pulse of light. Resistor R5 is required to limit the peak l.e.d. current to a safe value.

Pump Action

The storage capacitor is rapidly depleted of charge during the flash, so when point X returns to a low level, C2 charges up again via R4 and the process repeats producing a continuous series of l.e.d. flashes. The circuit behaves as a *charge pump*, in that the charge stored in C2 while point X is low is “pumped” into the l.e.d. when X goes high.

Inverters IC1b, IC1c and IC1d are paralleled to provide maximum current drive when charging C2. Although the circuit will function with a 74HC14 device, the 74AC14 is preferred due to its superior output characteristics.

A fairly large value of C2 is needed to store enough energy to produce adequate l.e.d. brightness during the flash period. R4 must be small enough to permit rapid charging of C2, but not too small or it will waste power while the l.e.d. is illuminated.

Values of $C2 = 330\mu F$ and $R4 = 1k\Omega$ are good starting points. Transistor TR1 should be a small-signal type with good current gain: a device such as the BC108C or BC550C is a good choice.

Timing components C1, R1 and R2 determine the flash rate; although the values are not critical, some experimentation may be necessary to get the best results. With $C1 = 3.3\mu F$, $R1 = 680k\Omega$ and $R2 = 68k\Omega$, and with a battery voltage of 1.5V, the test circuit produced an l.e.d. “on” duration of 150ms, and an “off” period of 1.55s. Remember that the “off” period must be long enough for C2 to charge fully, otherwise the l.e.d.’s flash will be somewhat anaemic.

Since the 74AC14 is only recommended for operation down to a minimum supply voltage of 2.0V, reliable operation cannot be guaranteed at 1.5V. In practice, however, the test circuit continued to function with the supply voltage low as 1.0V with little change in the flash rate, although the l.e.d. intensity was somewhat reduced. An alternative Schmitt inverter that could be used is the SN74LVC14A, a low-voltage device guaranteed to work down to 1.65V.

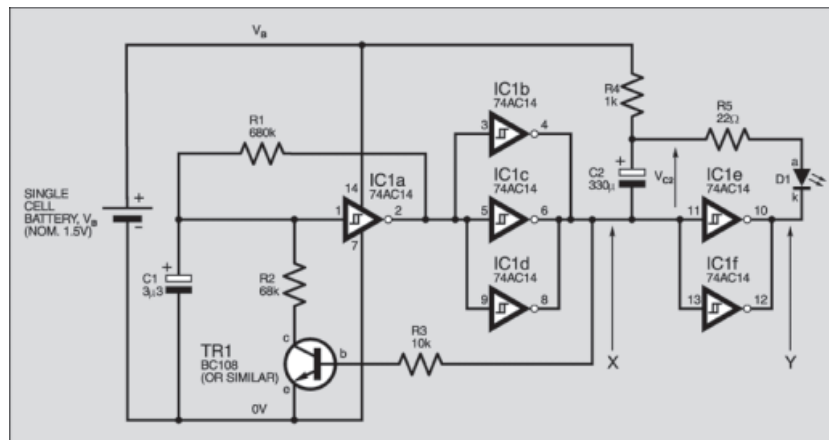


Fig. 1. Single-cell l.e.d. flasher circuit.

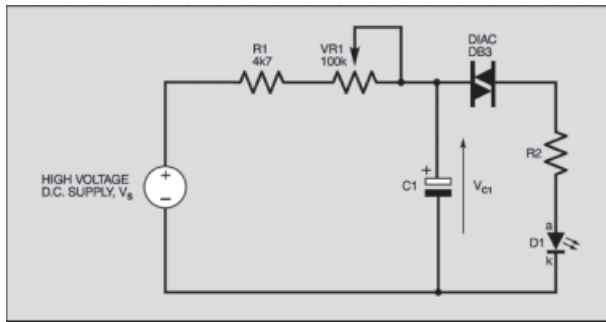


Fig.2. High-voltage DIAC-controlled I.e.d. flasher.

High-Voltage Flasher

Just as flashing an I.e.d. from a low voltage supply can be something of a challenge, designing a flasher circuit to work from a very high d.c. voltage, such as a rectified mains supply, can impose a different set of problems. Which is the best approach? Is it better to “drop” the voltage to, say, 5V or 12V with a voltage regulator and then use a conventional flasher circuit, or should we attempt to work directly from the high voltage supply?

The circuit in Fig.2 illustrates a relatively simple way of flashing one or more I.e.d.s from a d.c. voltage as high as 100V or more. The main element in the circuit is the *diac*, a semiconductor device which acts as a voltage-controlled switch.

If a low voltage is connected across a diac, it behaves rather like an open switch, and very little current flows through it. However, if the voltage is increased above a threshold known as the *breakover voltage*, denoted V_{BO} , the device enters a “negative resistance” region where the current through it increases enormously.

The diac is often used in pulse-generator circuits for driving thyristors and triacs. However, in Fig.2, it is used as a capacitor-discharge device with C1 to form a *relaxation oscillator*. When the high voltage supply, V_s , is first turned on, capacitor C1 starts to charge via R1 and VR1; at this point, the diac is not conducting and the I.e.d. is “off”. As C1 charges, its voltage, V_{C1} , gradually increases until it reaches the diac’s breakover voltage, V_{BO} , at which point the diac turns “on” and conducts a pulse of current into the I.e.d.

However, this sudden flow of current partly discharges C1, causing its voltage to fall below the level needed to hold the diac on. Therefore, the diac and the I.e.d. turn off, C1 starts to charge once more, and V_{C1} again increases until it exceeds V_{OB} , at which point the process repeats. The result is a series of flashes whose duration and rate (frequency) are determined mainly by the particular value of V_{BO} , by the magnitude of the supply voltage, and by the RC time constant formed by $R1 + VR1$ and C1.

Unlike diodes and transistors, diacs are not very abundant devices and choice tends to be fairly limited. However, the DB3 part used in the circuit is readily available and inexpensive. Its V_{BO} value ranges from 28V minimum to 36V maximum, with a typical value of 32V. Clearly, the circuit shown in Fig.2 will not function if the supply voltage is less than V_{BO} , so V_s needs to be at least 40V or more to guarantee proper operation.

from the mains with suitable rectification and smoothing.

Note, however, that the circuit provides no galvanic isolation and certain nodes could reach a fatally high voltage. Therefore, unless all parts of the circuit can be properly insulated, it should not be operated at voltages greater than 50V.

For a particular value of C1, the flash rate may be adjusted using variable resistor VR1. For example, with $C1 = 22\mu F$ and V_s set to 50V, the test circuit produced a flash rate of 20Hz (one flash every 50ms) with VR1 at its minimum (zero) setting. With VR1 at its maximum (100k Ω) setting, the flash rate was just 1Hz (one flash per second). A ten-fold increase in C1 to 220 μF produced a proportionate ten-fold reduction in flash rate.

Resistor R2 is necessary to limit the I.e.d.’s peak current to a safe value, and also provides a means of adjusting the duration of the I.e.d.’s “on” time. A relatively small value of R2 produces a high peak current that rapidly discharges C1 resulting in a narrow pulse. A larger value of R2 reduces the peak current but extends the width of the flash pulse. For the particular type of I.e.d. used, R2 should be chosen to limit the current pulse to a value less than the maximum peak rating. Usually, a value of 220 Ω is a good starting point, but this may need to be increased depending on the I.e.d. type.

Although just one I.e.d. is shown in the circuit, several I.e.d.s can be connected in series. The actual number is limited mainly by their individual forward voltages and by the diac’s V_{BO} rating. Alternatively, an audible sounder could be connected in series with the I.e.d. so as to provide a “beep” each time the I.e.d. flashes.

PUT Life in Your Flasher

Another flasher circuit capable of operation at fairly high voltages is shown in Fig.3, where the switching element used is a programmable unijunction transistor, or PUT for short. Like the diac, the PUT is part of the SCR (silicon controlled rectifier) family of voltage controlled switches. However, the PUT differs from the diac in that its switching volt-

Voltage Ratings

The upper limit of the supply voltage is determined by the components’ maximum ratings. In particular, C1’s voltage rating must be greater than V_s to ensure safe operation under all conditions. Provided the components are properly rated, the high voltage supply can be derived directly

age (or “trigger” voltage) can be programmed by means of a resistive divider connected to its gate terminal.

A thorough analysis of the PUT is outside the scope of this article, but you can understand its basic switching mechanism by examining the behaviour of the flasher circuit. The potential divider formed by R3 and R4 sets the gate voltage, V_G , at the gate terminal, g. Resistor R1 and capacitor C1 are timing components which control the rate of rise of the anode voltage, V_A , at the anode terminal, a, measured with respect to 0V. Current-limiting resistor R2 determines the peak current that can flow in the I.e.d.

When the d.c. supply voltage is initially applied, C1 is discharged such that the anode potential V_A is lower than V_G . The PUT is therefore “off”, and a relatively high impedance exists between its anode and cathode, denoted k. In this state, the device behaves like an open switch. As C1 begins to charge up via R1, the anode voltage, V_A , rises exponentially relative to 0V.

Trigger

Eventually, when V_A exceeds V_G by a few hundred millivolts, the device triggers, or turns “on”, allowing current to flow from anode to cathode. This causes a pulse of current to flow through R2 and into the I.e.d., which briefly flashes. At the same instant, the gate voltage, V_G , is “pulled down” to a voltage just above the cathode potential.

During the “on” portion of the cycle, the voltage between anode and cathode is around 700mV to 800mV, and C1 rapidly discharges into the low impedance seen “looking into” the anode terminal. Provided R1 is fairly large, the bulk of the current that flows into the I.e.d. is due to the charge stored in C1. Once this has been depleted, there is insufficient current left to bias the PUT “on”. Consequently, the device turns “off” and goes into its high impedance state, and the I.e.d. goes out. The gate voltage, V_G , now quickly returns to its initial “static” level, C1 begins to charge up again, and the process repeats.

For given values of R3, R4 and supply voltage, V_s , the oscillation frequency, or flash rate, is determined mainly by the values of R1 and C1. The intensity and duration of the I.e.d.’s flash are dependent largely on the value of C1: a relatively high

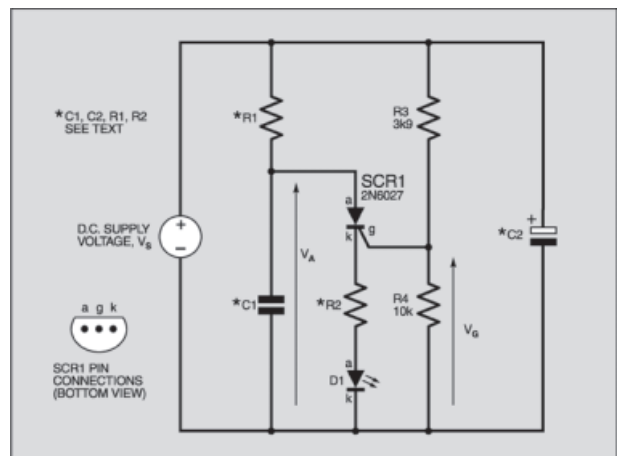


Fig.3. L.E.D. flasher based on a programmable unijunction transistor (PUT).

value allows a larger current pulse to flow, and the capacitor takes longer to discharge, thereby lengthening the duration of the flash. Thus, for a particular $R1/C1$ time constant, it is best to maximise $C1$ and minimise $R1$. However, $R1$ must not be too small or the PUT may latch into its "on" state and the oscillator will stop running. For supply voltages up to 20V, a value of $R1 > 100k\Omega$ should be adequate.

Choice of Device

Like the diac, the range of available PUTs is somewhat limited, but the 2N6027 and 2N6028 devices are fairly common and inexpensive. As with the diac flasher, resistor $R2$ must be large enough to limit the peak l.e.d. current to a safe level.

Provided the component values are sized accordingly, the flasher will operate over a range of supply voltages from around 5V up to several tens of volts. Operation with V_s lower than 5V may be insufficient to drive the l.e.d. properly, or may produce a rather weak flash. The l.e.d. itself should be chosen to give good brightness at low current levels. Decoupling capacitor $C2$ may be required if V_s is derived from a poorly regulated or noisy supply.

The circuit works well when powered from a 9V supply (e.g. a PP3 battery). With $V_s = 9V$ and $R2 = 100\Omega$, the test circuit produced a flash rate of approximately one flash per second with $R1 = 100k\Omega$ and $C1 = 10\mu F$. With $R1$ increased to $560k\Omega$, the rate decreased proportionately to one flash every 5-6 seconds.

Making $C1$ very large can produce very low flash rates. For example, with $R1 = 560k\Omega$ and $C1 = 150\mu F$, a rate of around one pulse every one hundred seconds can be obtained. This behaviour makes the circuit ideal in long-range timer applications.

Flashers To Go

If you're not fussy about the particular flash rate and you want a simple, ready-made flasher, an "off the shelf" flashing l.e.d. may be the best solution. Essentially, a flashing – or "blinking" – l.e.d. looks pretty much like a standard l.e.d. in terms of shape, size and colour. Internally, however, the light emitting diode chip is supplemented by an integrated circuit which flashes the l.e.d. at a fairly constant rate, usually around 3Hz (three flashes per second).

Unlike a standard l.e.d. which is essentially a current driven device, the flashing l.e.d. requires a d.c. voltage supply, usually somewhere in the range 3V to 15V depending on the particular type. The Kingbright L-36 range, for instance, offers a selection of 3mm red, green or yellow l.e.d.s which flash at around 2Hz and operate over a 3-5V to 13V supply range. The Temic TLBR5410, on the other hand, is a 5mm red l.e.d. that flashes typically at 3Hz and can accommodate a supply voltage ranging from 4-75V to 7V.

Flashing l.e.d.s offer several advantages: no circuit design is required – simply power them up and off they go; minimal inventory – only a single item needs to be stocked; space saving – only a single part is required, ideal for densely packed printed circuit boards.

Flash in the Pan?

However, in spite of their benefits, they do not provide a global panacea for all flashing indicator requirements. A significant disadvantage is that few, if any, flashing l.e.d.s offer a way of "trimming" the flash rate. Furthermore, the limited voltage range might not suit your application. Current drain might also be a problem – the typical supply current can range from around 10mA to as much as 70mA for certain types, which may be too much for some applications. Finally, only a limited range of colours, sizes and package styles is available.

Nevertheless, with a little creativity, a flashing l.e.d. can be used as the controlling element in a system that flashes any number of l.e.d.s. A rudimentary example is shown in Fig.4a, where a flashing l.e.d. is connected in series with one or more standard (non-flashing) l.e.d.s. Despite its obvious simplicity, the circuit requires a carefully controlled supply voltage capable of supporting all the l.e.d.s in the chain without exceeding their individual voltage ratings. Furthermore, the "off" current of the flashing l.e.d. (which can be as high as a few milliamps for certain types) may cause an unacceptable glow in the standard l.e.d.s in the "off" state.

A better solution is shown in Fig.4b, where the *npn* transistor $TR1$ is used as a switching element controlled by a flashing l.e.d. When the flashing l.e.d. is "off", $TR1$ is also "off" and the standard l.e.d.s ($D1$ to D_n) connected to its collector are all "off", too. When the flasher turns on, it supplies base drive for $TR1$, which turns on and illuminates all the standard l.e.d.s. The circuit has the advantage that several standard l.e.d.s can be flashed from a fairly low supply voltage, and the current through each l.e.d. can be tailored to suit the particular type by appropriate selection of its series resistor ($R1$ to R_n).

The value of base resistor R_B must be low enough to ensure that $TR1$'s base-emitter junction is not forward-biased by the flashing l.e.d.'s "off" current. For a device that has an "off" current of a few hundred microamperes, a value of a few kilohms would be suitable; using the Temic TLBR5410, on the other hand, which has a maximum "off" state current of 2mA would require a value of around 220Ω for resistor R_B .

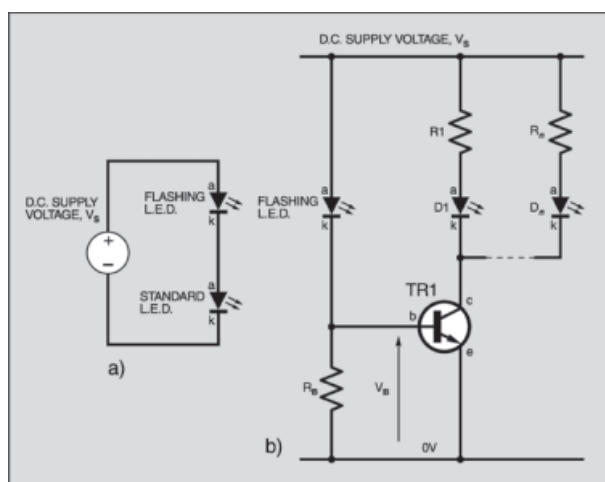


Fig.4. Flashing multiple l.e.d.s using a single flashing l.e.d.

Bicolour L.E.D.s

The ability to accommodate more than one "chip" inside an l.e.d. package is exploited in *multicolour* l.e.d.s, which contain two or three light emitting diodes of different colours. One example of a *bicolour* l.e.d. is shown in Fig.5, which illustrates a red/green device. The construction of the bicolour lamp is essentially the same as the single-colour l.e.d. described in Part One of this series. However, instead of a single light emitting die, the bicolour version contains two chips, one mounted on each of the terminal posts. It can be seen that each post forms the cathode of one l.e.d. and the anode of the other.

The whole assembly is housed in a molded plastic or epoxy encapsulation, sometimes with a magnifying dome lens at the top. The cathode of one of the l.e.d.s is usually identified by a slightly shorter lead and/or by a flat surface on the side of the molding. Note that other package styles and colours (e.g. red/yellow and green/yellow) are available.

It can be seen from the bicolour l.e.d.'s symbol in Fig.5 that this particular arrangement is essentially two l.e.d.s connected in *inverse parallel* inside a common housing. Depending

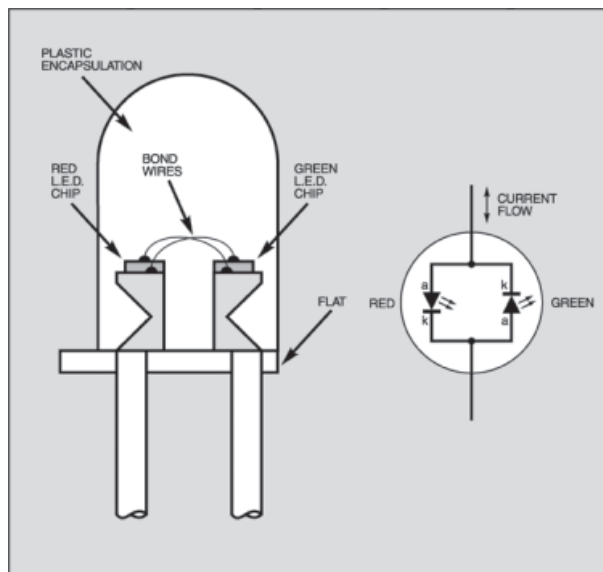
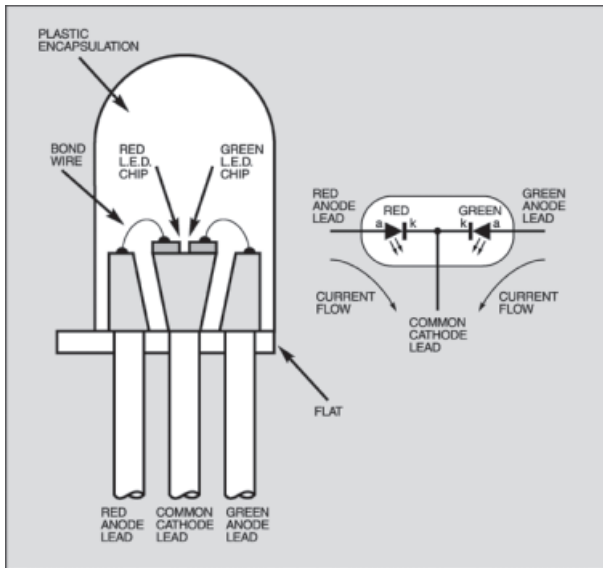


Fig.5. Two-lead bicolour l.e.d.



on the direction of current flow through the device, either the red or the green l.e.d. will be illuminated. Therefore, the lamp can indicate one of three states, namely (i) both l.e.d.s “off”; (ii) red l.e.d. “on”; (iii) green l.e.d. “on”.

Three-Lead Version

An alternative type of bicolour l.e.d. is shown in Fig.6; this three-lead version is more commonly referred to as a *tricolour* l.e.d. In this example, the cathodes of the two light emitting chips are connected to the same, or “common”, cathode post, while the anode bond wires are connected to two separate anode terminals. Again, a red/green example has been illustrated, but other colours are available.

In order to illuminate either l.e.d., current must flow in the direction shown in the symbol from anode to common cathode. Therefore, the lamp can indicate one of four states, namely (i) both l.e.d.s “off”; (ii) red l.e.d. “on”; (iii) green l.e.d. “on”; (iv) both l.e.d.s “on”. Case (iv) is unique to the three-terminal bicolour l.e.d.: by illuminating both l.e.d.s together, the lamp displays a third, or intermediate, colour – hence, the term “tricolour”.

For instance, if both the red and green l.e.d.s shown in this example were illuminated together, the colours could “mix” to form orange. This effect can be demonstrated using the simple arrangement shown in Fig.7, where potentiometer VR1 is used to vary the brightness of each l.e.d. chip. With the wiper (moving contact) of VR1 set to the “red” end (that is, at the red l.e.d.’s anode), almost all of the current in R1 flows through the red l.e.d., and very little current flows through the potentiometer and into the green l.e.d. The result is that the colour emitted by the lamp is predominantly red. Conversely, if the pot’s wiper is moved to the “green” end, almost all of the current flows in the green l.e.d. and the lamp appears predominantly green. If, however, the wiper is set to the midway position, the current in R1 splits and is shared in a roughly equal manner by each l.e.d. Consequently, the two colours mix and the lamp emits an orange hue.

By varying the wiper’s position, it is possible to generate any colour tone ranging from “full” red to “full” green, with an

almost infinite number of intermediate tones in between. The values chosen for R1 and VR1 depend on the type of tricolour lamp used, and on the supply voltage, V_s . With a 5V supply, the values $R1 = 330\Omega$ and $VR1 = 1k\Omega$ should produce good results, although some experimentation may be required to get the best effects. Note that R1 is necessary to prevent either l.e.d. from “short circuiting” the supply voltage when the pot’s wiper is at either of its end positions.

All the Colours of the Rainbow

Bicolour and tricolour l.e.d.s like those shown in Fig.5 and Fig.6 that encapsulate just two l.e.d. chips can only produce a particular range of colours. However, in recent years, lamps containing *three* l.e.d. chips have started to appear. The advent of blue l.e.d.s has made it possible to create lamps with red, green and blue chips – the three primary colours of light. These lamps are usually referred to as *multicolour* or *full colour* l.e.d.s.

Like the three-lead tricolour l.e.d., the full colour lamp usually has a common cathode terminal and individual terminals for each of the anodes, although six-lead types encapsulating three, completely separate l.e.d.s are also available. By driving each of the l.e.d.s with its own forward

current, it is possible to vary the red, green and blue light output in any desired combination. Thus, by mixing the light from the three chips, the lamp can be made to produce any colour in the visible spectrum, even white light.

Of course, mixing the primary colours in this way is not new – the technique has been used for many years in colour television sets and computer monitors to produce a full colour display. However, by combining thousands of powerful, individually-controllable, full colour l.e.d.s, it is possible to fabricate huge video screens and advertising billboards, such as the ones seen in city-centre displays and sports stadiums.

Bicolour Lamp Demonstrator

The circuit in Fig.8 may be used to demonstrate the different effects that can be obtained from a two-lead, bicolour l.e.d. Using just a single 74HC132 (quad 2-input NAND Schmitt trigger), the circuit allows each l.e.d. to be turned on and off individually, or to be flashed at a rate determined by timing components C1 and R1.

IC1a, C1 and R1 form a “gated” astable multivibrator similar to the one shown in Fig.8 in Part Two. When the gating signal at input A is low, the output of IC1a goes continuously high and enables gates IC1b

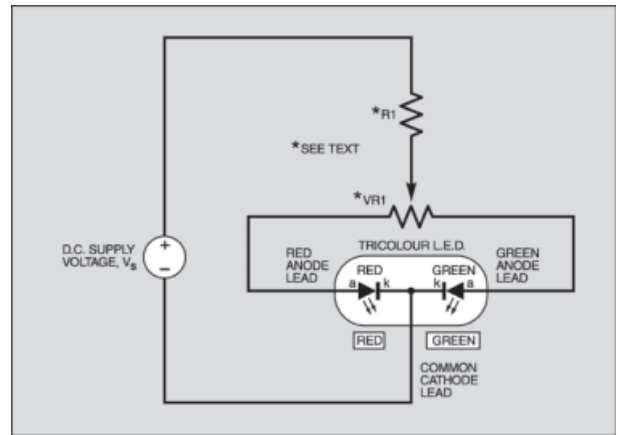


Fig.7. (above) Generating a range of colours from a tricolour l.e.d.

Fig.6. (left) Three-lead bicolour (or tricolour) l.e.d.

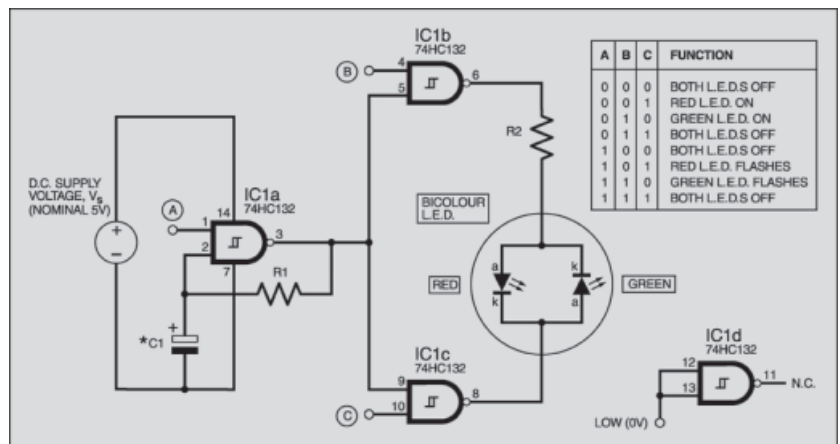


Fig.8. Expanding the use of a two-lead bicolour l.e.d.

and IC1c. In this condition, either of the l.e.d.s may be illuminated by taking input *B* or input *C* high as shown in the truth table shown here in Fig 8. Note that when *B* and *C* are at the same logic state – either both high or both low – the l.e.d.s are both “off” because there is zero voltage potential across the R2/l.e.d. series combination.

When the signal at input *A* is taken high, the astable starts to oscillate and delivers a squarewave signal to gates IC1b and IC1c. Now, whenever inputs *B* and *C* are at opposite logic levels, either the red or the green l.e.d. flashes as indicated in the table. The flash rate is determined by the values of C1 and R1. With C1 = 10µF and R1 = 100kΩ, the selected l.e.d. flashes approximately twice a second (2Hz).

Resistor R2 should be selected to produce optimum l.e.d. brightness for the particular type used. It can be seen from the truth table that the eight different input combinations produce five unique states, one of which, the “both l.e.d.s off” state, occurs four times. Effectively, by adding two flashing states, the circuit expands the usefulness of the two-lead bicolour l.e.d. from just three states to five.

Trick of the Light

We showed in Part Two how *pulse width modulation* (PWM), can be used to vary an l.e.d.’s light intensity by pulsing it on and off at different duty cycles. This technique can be exploited in a slightly different way with a bicolour or tricolour l.e.d. to produce a variable range of light tones.

The circuits in Fig.9 show how this can be achieved. In Fig.9a, a tricolour red/green l.e.d. connected to a common cathode resistor is driven by *antiphase* logic signals. In this application, the term “antiphase” simply means that the red l.e.d. is “on” while the green l.e.d. is “off”, and vice-versa.

A variable duty cycle signal input to IC1a is used to mix the colour of the two l.e.d.s. The phrase *duty cycle* refers to the amount of time that the signal is high as a fraction of the total signal period:

$$\text{Duty Cycle} = \frac{\text{High Time}}{\text{High Time} + \text{Low Time}} (\%)$$

Due to the inversion provided by IC1a and IC1b, the signal driving the green l.e.d. is *in phase* with the input signal, whereas the signal driving the red l.e.d. is *out of phase*. Therefore, if the input signal’s duty cycle is high, the green l.e.d. flashes “on” for a relatively long period, then the red

l.e.d. flashes “on” for a much shorter period. If the input signal frequency is fairly low (a few hertz), this effect is clearly visible.

However, increasing the frequency to a much higher value, say a few hundred hertz or more, produces an interesting effect. The human eye can no longer distinguish between the individual flashes, and effectively *integrates* the rapidly pulsing colours into one, single colour; in a way, it is a form of trickery – the eye is fooled into believing that the colours have mixed, even though the red and green l.e.d.s are never actually “on” at the same time!

Therefore, for a high duty cycle, the lamp colour appears mainly green (because the green l.e.d.’s flash duration is much longer than that of the red l.e.d.), whereas a low duty cycle makes the lamp colour appear mainly red (because the red l.e.d. is “on” for a longer duration than the green). With a 50% duty cycle, each l.e.d. is illuminated for exactly the same length of time and the colours are effectively “blended” in equal proportion to produce orange.

Infinite Range

By adjusting the duty cycle from low to high, the lamp’s apparent colour may be varied over an almost infinite range of shades from red, through orange, yellow and finally to green. Although the overall effect is the same as that achieved using the circuit of Fig.7, the mechanisms involved are completely different. Whereas the l.e.d.s in Fig.7 are both illuminated *simultaneously* to produce a true mix of colour, the l.e.d.s in Fig.9a are *never* illuminated at the same time, and only an *apparent* mix of colour takes place.

Although we saw earlier that the two-lead bicolour lamp can indicate any one of three states, the PWM technique provides a means of adding a fourth “quasi” state, whereby the l.e.d.s can be pulsed to produce a mix of colours. This is shown in Fig.9b, where the two-lead lamp is connected “across” the second inverter. This means that a variable duty cycle signal appears across the device, causing alternate flashing of the l.e.d.s where the relative duration of each l.e.d.’s pulse depends entirely on the input duty cycle.

Again, even though the l.e.d.s are never illuminated simultaneously, the eye effectively blends the colours together to produce any shade ranging from red through to green. As with the circuit of Fig.9a, the sig-

nal frequency must be high enough to fool the eye; if it is too low, the lamp will simply appear to flash alternately from red to green.

The bicolour l.e.d.’s ability to display various shades of colour is exploited in this month’s accompanying constructional project, a *Logic Probe*, in which a bicolour l.e.d. is used to indicate both low and high logic states, and also the duty cycle of a pulsing logic signal.

Practical Considerations

Although Fig.9 shows 74HC14 or 74AC14 inverters, the same result could be achieved by using two NAND gates connected as inverters borrowed from the 74HC132 in Fig.8. Note that the first inverter (IC1a) in each circuit in Fig.9 is not essential and is only required to buffer the input signal if it is derived from a high impedance source. For a low impedance source, such as the variable duty cycle pulse generator depicted in Fig.10 in Part Two, the first inverter can be dispensed with.

The value of resistor R1 should be low enough to produce adequate l.e.d. brightness without exceeding the maximum current rating. Remember, too, that the logic gates themselves have limited output current capability, so again R1 must not be too small: the minimum value is around 470Ω for a 74HC part, and about 180Ω for a 74AC device.

In each of the PWM schemes shown in Fig.9, one of the l.e.d.s is reverse biased while the other is forward biased. This presents no problems for the circuit in Fig.9b, where the illuminated l.e.d. effectively “clamps” the reverse voltage of the other l.e.d. to $-V_F$, where V_F is the forward voltage of the forward biased l.e.d.

In Fig.9a, though, no such clamping takes place, and the reverse voltage of the “off” l.e.d. is roughly equal to the logic gate’s high level output voltage less the forward voltage of the “on” l.e.d. For a supply voltage of 5V, this poses no difficulties. However, if the circuit were constructed using 4000-series inverters operating on, say, a 15V supply, the “off” l.e.d.’s reverse voltage could easily exceed its maximum reverse voltage rating, leading to potential breakdown of the reverse biased junction.

The need to regard the l.e.d. not just as a light source, but also as a diode, may be emphasised by considering what would happen if the l.e.d.s in Fig.9 were replaced by incandescent bulbs. If low-current red and green bulbs were substituted for the l.e.d.s in Fig.9a by omitting R1 and connecting each bulb to 0V, the circuit would still function, albeit less efficiently.

This is not true, however, of the circuit in Fig.9b. If the l.e.d.s were replaced by red and green bulbs, the circuit simply would not work – both bulbs would be illuminated all the time, irrespective of the input signal duty cycle! That the circuit will only function properly using l.e.d.s highlights one of the l.e.d.’s unique – and sometimes neglected – properties, namely that it is a *unipolar* light source and will emit light only when biased with the correct polarity.

Boost Your Battery

We conclude this month’s article by looking at two more circuits capable of operating any l.e.d. – even blue and white types – from a supply of 1V or less. This

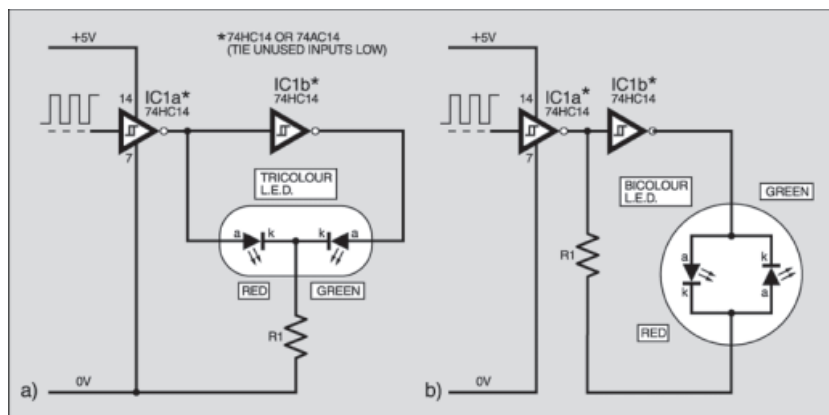


Fig.9. Two pulse width modulation techniques for producing a range of colours.

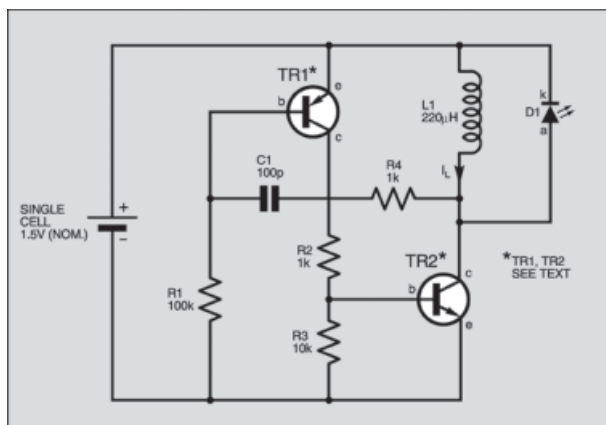


Fig. 10. Voltage boosting I.e.d. driver.

makes them ideal for single-cell, battery-powered applications such as flashlights and miniature beacons. However, unlike the circuit in Fig.1, which depends on charge stored in a capacitor, these circuits rely upon the energy stored in the magnetic field of an inductor.

The first inductor-based circuit, shown in Fig.10, uses just two transistors and a handful of passive components and really could not be much simpler. When battery power is first applied, *pnp* transistor TR1 is biased "on" by its base resistor, R1. This, in turn, provides base drive for *npn* transistor TR2 via resistor R2 which drives TR2 into saturation (it turns fully "on").

Current I_L now starts to flow through inductor L1 and into TR2 but, unlike the current in a purely resistive load, I_L does not immediately assume a static value, but instead gradually "ramps up" at a rate determined mainly by the supply voltage, V_S , and by the value of L1. During this time, the I.e.d. is reverse biased, and has no effect on the circuit.

The current continues to ramp up until it reaches a peak value, $I_{L(peak)}$. This is the maximum value that can be sustained by TR2 – its finite gain means that its collector current cannot increase indefinitely.

Flyback

Consequently, I_L ceases to increase, resulting in a back-e.m.f. across the inductor. At this point, the voltage across the inductor reverses polarity, and the resulting flyback voltage raises the I.e.d.'s anode to a positive voltage, higher than V_S , which is sufficient to forward bias the I.e.d. The flyback voltage is also coupled through R4 and C1 to TR1's base, causing both TR1 and TR2 to turn off rapidly.

The inductor current now circulates around L1 and the I.e.d., and as the energy stored in L1 decays, the current ramps down to zero. At this point, the inductor voltage reverses polarity again, and the negative-going change is coupled through C1, rapidly turning on TR1 and, in turn, TR2. Current again begins to ramp up in L1, and the process repeats.

The circuit forms a *voltage booster* which oscillates at a rate determined by several factors, particularly by the values of V_S , L1 and R2, and also on the current gain (h_{FE}) of TR2 and the forward voltage of I.e.d. D1. With the component values shown, the oscillation frequency is typically in the region of 50kHz to 150kHz. On

This means that even blue and white I.e.d.s, whose V_F can be greater than two or three volts, can be driven from a single-cell voltage as low as one volt. The circuit can also be used to drive several I.e.d.s connected in series.

Know Your Limits

Do not imagine, though, that the booster could be used to illuminate your house from a single battery by driving a series string of hundreds of white I.e.d.s! It has limitations, and cannot deliver boundless light energy. Bear in mind that the I.e.d. is illuminated by the energy stored in the inductor on each cycle: the greater the forward voltage of the I.e.d. (or I.e.d.s), the sooner this energy gets used up. In other words, a high V_F means that the I.e.d. is illuminated for a relatively short fraction of each cycle. Therefore, the greater the forward voltage, the dimmer the I.e.d. becomes.

Despite its limitations, the circuit can produce excellent results, provided the components are chosen carefully. TR1 should be a small-signal (low power) *pnp* transistor with good current gain; a device such as the BC178C, BC557C, or similar, is suitable. A small-signal part with good current gain is also adequate for *nnp* transistor TR2. Although general-purpose devices such as the BC108C or BC547C should be satisfactory, better results can be obtained using a *low-saturation* part, particularly if a high peak I.e.d. current is required.

Using a transistor with low collector-emitter saturation voltage, $V_{CE(sat)}$, ensures that almost all of the supply voltage appears across L1 when TR2 turns on, thus maximising the energy stored in the inductor. A good choice of low-saturation transistor for this application is the Zetex ZTX689B, available in E-line package.

Saturation

Saturation of a different kind must be considered when choosing the inductor. When a d.c. voltage is applied across an inductive component such as a coil or transformer winding, the current through the coil increases at a constant, linear rate. In theory, the current will continue to ramp up indefinitely. In practice, however, a real coil can only store a finite amount of energy in its magnetic field, and when the limit is reached the core is said to be *saturated*. At this point, the current increases dramati-

cally, a pulse of current with a peak value equal to $I_{L(peak)}$ flows through the I.e.d., and because this happens thousands of times every second, the I.e.d. appears to be continually illuminated, even though it is really pulsing "on" and "off" very rapidly.

Since the I.e.d. is forward biased by the inductor's flyback voltage, the circuit will work with any type of I.e.d. no matter what its forward voltage, V_F , may be.

ically, limited only by the resistance of the coil and any resistance in the external circuit.

As a rule of thumb, an inductor current rating of around 200mA, or more, should be sufficient to prevent saturation for the booster circuit shown in Fig.10. The actual inductance value is not critical: 220 μ H is a good starting point, but most values in the range 100 μ H to 330 μ H should prove satisfactory. Miniature inductors fabricated using an open, ferrite bobbin construction are readily available in this range, and most of them have suitable current ratings.

The component values shown should produce good results with most I.e.d. types. Remember, though, not to exceed the I.e.d.'s peak current rating, otherwise its lifetime could be shortened or it might even be destroyed outright.

The peak current can be measured using an oscilloscope and a low-value current sense resistor connected between TR2's emitter and 0V. A 1 Ω resistor is most convenient: with the oscilloscope sensitivity set to a suitable millivolt range (e.g.: 20mV/division or 50mV/division), the waveform across the resistor will represent the inductor current in milliamps (e.g.: 20mA/division or 50mA/division).

The actual waveshape should be triangular with a fairly linear rising edge. (If the rising edge appears distorted with an "exponential" appearance, this is usually a sign that the inductor is saturating.) The "apex" of the triangle represents the peak current that flows in the I.e.d. and should be less than the maximum rating quoted in the I.e.d.'s specifications.

A test circuit constructed using the component values shown in Fig.10 produced excellent results with a white I.e.d. The I.e.d.'s intensity was very bright with the supply voltage, V_S , set to 1.5V, and remained good down to 1.0V. With $V_S = 1.5$ V, the peak I.e.d. current was approximately 50mA.

The peak current, and hence the I.e.d.'s brightness, can be increased by reducing the value of R2. For example, reducing R2 to 510 Ω increased the peak current to around 72mA. The circuit was found to start up properly with V_S as low as 0.8V, although the I.e.d. was rather dim at that level. Remember that the I.e.d.'s cathode is connected to the positive rail, not its anode (if the I.e.d. appears dim or does not illuminate at all, there's a good chance it has been connected the wrong way around!)

How Low Can You Go?

Although Fig.10's booster works well down to 1.0V, it "runs out of steam" when the supply voltage falls below 900mV, or so. Nevertheless, for those of you who like to wring the last few millivolts out of your battery, the circuit in Fig.11 depicts an alternative voltage booster devised by the author (see reference at end), which continues to illuminate the I.e.d. even when the supply voltage has fallen to around 500mV.

Unlike the circuit in Fig.10, which is *self-oscillating*, the booster in Fig.11 relies upon a separate astable oscillator formed by IC1, C2 and R1. The circuit exploits the ultra-low operating voltage of a "single gate" Schmitt inverter, such as the Texas SN74AUC1G14 or the Fairchild NC7SP14.

Unlike devices from other logic families such as the 74HC or 74AC series, which are only specified for operation down to

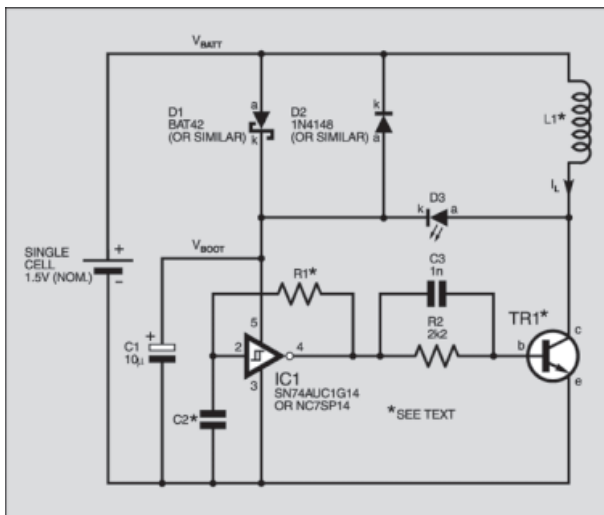


Fig.11. Ultra-low voltage bootstrapped I.e.d. booster.

2.0V, the SN74AUC1G14 and NC7SP14 are guaranteed to work at very low supply voltages. The SN74AUC1G14, for example, has a recommended operating voltage range of 0.8V to 2.7V, whereas the NC7SP14 will operate from 0.9V to 3.6V.

When battery power, V_{BATT} , is first applied, Schottky diode D1 conducts and the Schmitt trigger astable starts to oscillate at a frequency determined by timing components C2 and R1. When IC1's output is high, transistor TR1 turns "on" and current begins to ramp up in inductor L1. At the end of the high period, when the current in L1 has reached its maximum level, $I_{L(peak)}$, the inverter output goes low,

remains so for as long as the circuit continues to oscillate.

Bootstrapping

The resulting *bootstrapped* supply voltage for IC1 ensures that the astable continues to operate even when V_{BATT} falls to very low levels. The term "bootstrapping" is often used to describe any kind of circuit in which a particular function has the effect of "pulling the circuit up by its bootstraps".

Values for C2 and R1 should be chosen to produce a time constant in the microsecond range, such that a small inductance can be used for L1. A test circuit built using the values C2 = 68pF, R1 = 39kΩ, and L1 =

TR1 turns "off" and the voltage across L1 reverses polarity.

The resulting flyback voltage immediately raises TR1's collector voltage above V_{BATT} and forward biases the I.e.d. and D2, which appear in series. This action illuminates the I.e.d. with a maximum forward current equal to $I_{L(peak)}$, and at the same time raises IC1's supply voltage, V_{BOOT} , to a diode drop above V_{BATT} . Diode D1 is now reverse biased and

47μH produced an operating frequency of around 150kHz with $V_{BATT} = 1.0V$. This resulted in a peak inductor current of around 65mA and produced excellent brightness in a white I.e.d. Even with V_{BATT} as low as 500mV, the resulting peak current of 33mA produced reasonable I.e.d. intensity.

The inductance value should be as low as possible to maintain a high peak current – and hence adequate I.e.d. brightness – at the lowest supply voltage. However, L1 should not be too small or the peak current could exceed the I.e.d.'s maximum current rating when V_{BATT} is a maximum.

Like the circuit in Fig.10, the inductor should be adequately rated to ensure it does not saturate at the highest value of peak current, and transistor TR1 should have very low saturation voltage in order to minimise losses and produce optimum I.e.d. brightness.

Next Month

So far in this series, we have dealt with the I.e.d.'s main functions, namely to emit light and to pass current in a single direction. Next month, in the concluding part of the series, we examine two more intriguing uses for the I.e.d., and we take a look at a few of the special purpose integrated circuits that have been developed specifically for driving light emitting diodes.

In the meantime, why not build the accompanying Logic Probe, see page 772.

Reference

Light a white I.e.d. from half a cell, Anthony Smith, *EDN Europe*, June 2003, p.67.

SHOP TALK

with David Barrington



Thunderstorm Monitor

No obvious components stand out as being special "hard-to-find" items in the listing for the *Thunderstorm Monitor* project. The exception is, of course, the VU meter which, as the author suggests, you will need to shop around to find one at the best price for your pocket. We suggest you try Jaycar (www.jaycarelectronics.co.uk or ☎ 0800 032 7241) or Bull Group (☎ 0970 7707520 or www.bullnet.co.uk)

The choice of relay is left to the individual, but the contacts must be able to handle the needs of any additional warning device and a protection diode be included/added against back-e.m.f. The one in the model came from RS Components (☎ 01536 444079 or rswww.com), code 422-7029. If you are looking for a three-wire 3.5 digit voltmeter, the author used the Lascar EMV 1025S-01 also from the above company, code 419-9356.

The printed circuit board is available from the *EPE PCB Service*, code 470 (see page 825).

M.W. Amplitude Modulator

Being a "radio project" it follows that some of the components needed to build the *M.W. Amplitude Modulator* may be difficult to track down locally. The small air-spaced 50pF variable capacitor seems to be from the Jackson C804A series and was originally purchased from Maplin (☎ 0870 264 6000 or www.maplin.co.uk), code FF45Y. They also supplied the mains transformer, code YN14.

We have not seen any listing for the optional feedthrough capacitor but we suggest you try contacting Chevet Book Supplies (☎ 01253 751858 or www.chevet-supplies.co.uk), who also specialise in old radio components. They also currently list a 50pF+50pF double-gang, air-spaced, tuning capacitor at a reasonable price which could possibly be used in this project.

The Toko YXRS17065 variable inductor and 7BS or 7BA range of r.f. chokes should be obtainable from JAB Electronic Components (☎ 0121 682 7045 or www.jabdog.com), mail order only, or from Sycom, Dept EPE, PO Box 148, Leatherhead, Surrey, KT33 9YW (☎ 01372 372587 or www.sycomcomp.co.uk). You will need to order by quoting the type number for the inductor and the value and range for the chokes.

The three printed circuit boards are available from the *EPE PCB Service*, codes 471 (VFO), 472 (Mod.) and 473 (PSU). See page 825.

Logic Probe

After comparing several comparator devices, the author decided that the TLC372CP micropower dual comparator was the one for the *Logic Probe* circuit. Not being too familiar with the TLC372, we understand it is listed by Farnell (☎ 0870 1200200 or www.farnellinone.co.uk), code 404-305. They also supplied the 74AC14PC hex inverter i.c., code 383-545.

Most inexpensive red/green bicolour I.e.d.s should work in this circuit and most of our components advertisers should be able to offer a suitable device, or even the specified Kingbright L-57EGW bicolour I.e.d.

The small printed circuit board is available from the *EPE PCB Service*, code 469 (see page 825).

Smart Kart 2

No new hardware or component problems have been reported concerning the *Smart Kart* buggy project. The only feedback we have received so far has been from J&N Factors (☎ 01444 881965), who inform us that they have some sheets of Paxolin that could be used for the decking material on offer at a special price. Ring the above number for further details.

This month's article deals with manoeuvres and software requirements and no further components are needed until Part 3. However, for those readers unable to program their own PICs, a preprogrammed PIC16F84 microcontroller can be purchased from Magenta Electronics (☎ 01283 565435 or www.magenta2000.co.uk) for the inclusive price of £5.90 each (overseas add £1 p.p.). The software is available on a 3.5in. PC-compatible disk (Disk 7) from the *EPE Editorial Office* for the sum of £3 (UK), to cover admin costs (for overseas charges see page 825). It is also available for Free download from the click-link on the *EPE* website at www.epemag.co.uk, follow path PICs/SmartKart.

PLEASE TAKE NOTE

PIC Magnetometry Logger

(July '04)

Page 474, Fig.6. The FGM3 legends for SIG OUT and GND have been transposed. GND is pin 2 and SIG OUT is pin 3. The wiring connections to the p.c.b. should be transposed to match.

Glitch Free Switching

(Oct '04 IU)

Page 695, Fig.3. Capacitor C1 should have a value of 10nF (0.01μF) and NOT 100nF as shown.

PIC N' MIX ANDREW JARVIS

Our periodic column for your PIC programming enlightenment

Introducing Some New PICs to TK3 – the 16F87xA Family

TIME now to introduce some new PICs to *EPE PIC Toolkit TK3*. Over the next few months we'll add in some of the most requested types and explain a little about how to develop with them. We'll also investigate why enabling them isn't as straightforward as it might first appear, dust down what must be the least used socket on the *TK3* board and finally query the consistency of some programming documentation. By the time we're through there should be a dozen or so new chips to play with.

To join in, you're going to need the latest release (version V2.22, new this month) of *TK3's* software, available to download free from our Downloads site (via www.epemag.co.uk). Further down the line there's the possibility of a few minor hardware modifications, but we'll leave that excitement for now. Instead we'll start on perhaps more familiar ground with the PIC16F87xA, which is an abbreviation for any of PIC16F873A, 874A, 876A and 877A, devices which nestle comfortably into the existing *TK3* sockets without change.

What's in "A" Name?

Some PICs have become increasingly conspicuous by their absence from the *TK3* support list and none more so than the PIC16F877A, which supersedes the earlier non "A" PIC16F877 version. This latter chip features quite heavily in *EPE* projects and is becoming increasingly difficult or (relatively) expensive to get hold of, in favour of the newer version.

Unfortunately, there's more to substituting the "A" version than editing the list of PIC types with the new specification, even though the two chips are functionally and pin-to-pin compatible. Appending the new details to *TK3's* file **TK3PICTypes.txt** (which is used as the basis for the "Select PIC Types" screen) using the older chip as a template is a good place to start, but as a few of you have already found – will inevitably fail.

This is because the significant difference between the two devices is not with the PIC16F877A feature set (which is in *TK3* terms identical), but with the algorithm that must be followed by *TK3* to correctly load the device with program code. While PIC feature changes (like Program or Data Memory size) can to some extent be facilitated by altering the **TK3PICTypes** text file, new algorithms always require updates to the *TK3* software itself to accommodate the differences.

Luckily, the algorithms are good for many devices within the same "family" and implementing more of them means that we'll bring in lots of new devices for you to program via *TK3*. (Just to be clear, the programming algorithms discussed here are only the concern of the device programming software, in this case *TK3*, and are not something that you need to work into your own projects).

Code Migration

A little investigation into the price differences between the PIC types reveals that you can save up to about £2 in some cases by migrating your code to the newer "A" type; that's in addition to the other benefits. PIC16F87xA devices have a 20MHz clock input, giving them a 200ns instruction cycle period. There are no 4MHz or 10MHz parts produced, and pinouts are compatible with earlier versions.

In the majority of cases (including *EPE* projects) the code migration path from the PIC16F87x to the PIC16F87xA is simple enough with the likelihood of only two changes required to your ASM code.

If the ASM file you want to migrate uses an **include** directive then you'll need to update this by simply appending an "A". For example change the command line **include P16F877.inc**, to **include P16F877A.inc**. Remember to add the new **include** file into your path.

Gotcha

The second possible change is more of a gotcha because it can lead to much head scratching (well, it did in my case!). Look out for code where the "List" directive is used, with a processor specified. For example:

List P=16F877, R=Dec

The List directive controls the assembly process, so when *TK3* finds the processor type set within the code, it changes the global PIC type setting to that specified (if it is different from the current one) before continuing. If you are porting from an '87x to an '87xA and miss this gotcha, the likelihood is that the code will assemble with no problem, but its hex file will fail to "Send" to the device.

Despite your choice of 87xA from the "Select PIC Types" dialogue before assembling the code, *TK3* will actually change the PIC type back to 87x because it has found the PIC type stated in the ASM file to be an 87x, not an 87xA. There are unlikely to be assembly errors because the PIC types are functionally so very similar – but "Send/Verify" errors will occur because the programming algorithms are incompatible and *TK3* tries to use the '87x rules to update an '87xA device. This can be very misleading and it's easy to believe there's a hardware problem when verification errors continue to appear for no apparent reason.

There are some clues along the way that flag this potential problem before it occurs. First, the current PIC type on the main screen will correctly update to the "new" value when the List directive is encountered, and second, you'll get a message in the assembly dialogue to say "PIC type set to [new value]". I com-

pletely failed to notice these messages first time around, probably because I'm usually just looking to see if there are assembly errors. (*It's been highlighted in yellow now. Ed.*) Be sure to append the "A" in any case where you find a List directive in the code with a specified processor – it could save a lot of trouble.

ID Idea

In lieu of this experience it was considered that it would be a good idea to get John Becker to add device recognition into the *TK3* software. With this in place the software would actually query the chip to determine its type and compares it with the selected *TK3* PIC type, flagging any differences. Certainly useful, but unfortunately not all PIC types have their ID embedded into them (recent ones do, but not earlier ones, such as the PIC16F84 for instance), and device recognition is not therefore invoked.

Each of the examples above shows the 877, but they're equally valid for the other family members too. The words like "possibly" and "unlikely" have been used so far to describe potential code changes. In fact you'll only really have work to do if you have existing PIC16F87x software (ASM/HEX) that writes to FLASH program memory, in which case you'll have further changes to make because the "A" device requires writes to be made in 4-word blocks instead of 1-word blocks.

Note this is not the same as writing to EEPROM data memory, which is done much more frequently (in *EPE* projects at least) and remains unchanged. You'll only be writing to FLASH program memory if you have code that dynamically reprograms the chip like a bootloader (*no EPE projects so far have this software function. Ed*)

There are a couple of other functional changes, and some electrical and timing differences too. Microchip document DS39591A (PIC16F87x to PIC16F87xA Migration) gives full details.

What a Difference an "A" Makes

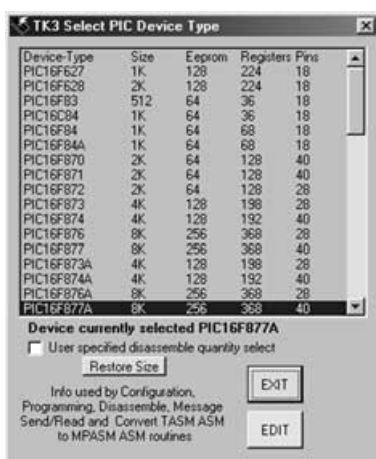
Without wishing to delve too far into the detail of the software changes needed to support the PIC16F87xA, there are a few interesting observations to be made.

The (older) PIC16F87x device is programmed a single word (program instruction) at a time, which makes it easy to program while the hex file is being parsed, which is what *TK3* does. Discontinuous locations are populated simply by incrementing the PC to any desired position, then programming the instruction word. This actually makes *TK3* quite fast when compared with some other programmers, which appear to program the entire memory range regardless of program size.

The "A" version, however, wants eight consecutive bytes at a time, which is harder to achieve. For example, what happens if the object code does not align to an 8-word boundary, or if an ORG directive changes the program origin to require the population of non-sequential addresses? TK3 has not before had to consider how to program locations for which there is no object code.

The solution implemented is to read the hex file up front and store it in a data structure that mirrors the PICs program memory and in which all locations are first initialised with the value 0x3FFF. As the hex file is read various addresses are overwritten until parsing is complete so that, during programming, eight consecutive words can always be loaded (but some of them may be blank).

In an attempt to maintain the TK3 speed differential, some optimisation has been added to figure out the most efficient memory range to



TK3's PIC selection screen showing the PIC16F87xA devices.

program. (It is now understood why other programmers cover the entire address range! This would make it far easier, if slower.)

Incidentally, when a device is completely blank, all bits are set to "1" – this is what happens after a bulk erase (and when you program FLASH memory, bits are reset from 1 to 0). Value 0x3FFF is the hexadecimal equivalent of a 14-bit program word where every bit is set.

There's no reason to think that this TK3 update won't cope with every member of the PIC16F87xA family, but testing only included the '876A and '877A. Next time, the 8-pin FLASH programmable 12F family is welcomed.

Editorial Note: The TK3 changes referred in this article have been made by Andrew Jarvis and checked by John Becker, Tk3's author.



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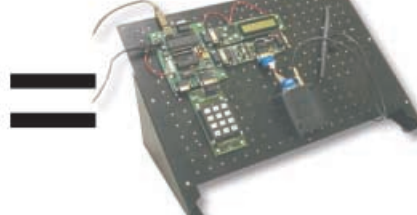
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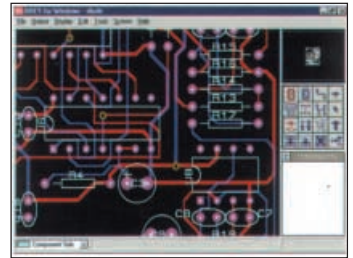


Logic Probe testing

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The projects on the CD-ROM are: Logic Probe; Light, Heat and Moisture Sensor; NE555 Timer; Egg Timer; Dice Machine; Bike Alarm; Stereo Mixer; Power Amplifier; Sound Activated Switch; Reaction Tester. Full parts lists, schematics and p.c.b. layouts are included on the CD-ROM.

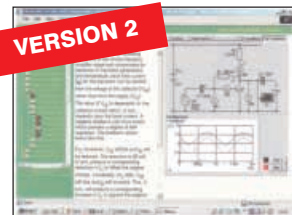
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PCB Layout

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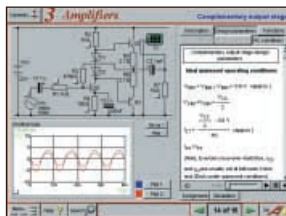
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ANALOGUE ELECTRONICS

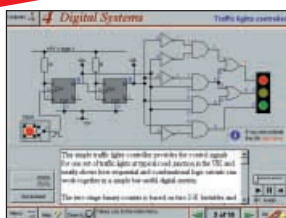


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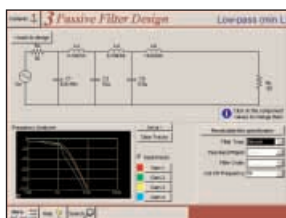


Virtual laboratory – Traffic Lights

Digital Electronics builds on the knowledge of logic gates covered in *Electronic Circuits & Components* (opposite), and takes users through the subject of digital electronics up to the operation and architecture of microprocessors. The virtual laboratories allow users to operate many circuits on screen.

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FILTERS



Filter synthesis

Filters is a complete course in designing active and passive filters that makes use of highly interactive virtual laboratories and simulations to explain how filters are designed. It is split into five chapters: **Revision** which provides underpinning knowledge required for those who need to design filters. **Filter Basics** which is a course in terminology and filter characterization, important classes of filter, filter order, filter impedance and impedance matching, and effects of different filter types. **Advanced Theory** which covers the use of filter tables, mathematics behind filter design, and an explanation of the design of active filters. **Passive Filter Design** which includes an expert system and filter synthesis tool for the design of low-pass, high-pass, band-pass, and band-stop Bessel, Butterworth and Chebyshev ladder filters. **Active Filter Design** which includes an expert system and filter synthesis tool for the design of low-pass, high-pass, band-pass, and band-stop Bessel, Butterworth and Chebyshev op.amp filters.

ROBOTICS & MECHATRONICS



Case study of the Milford Instruments Spider

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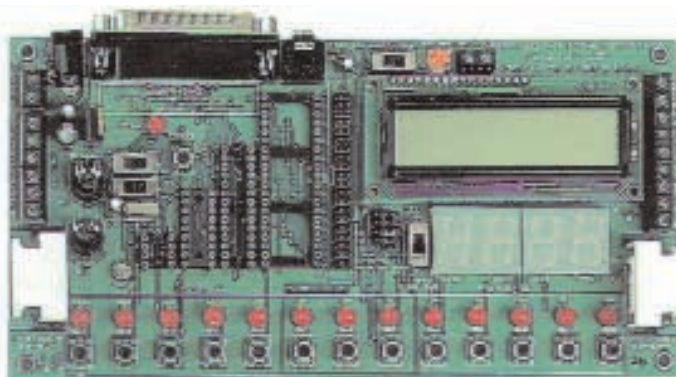
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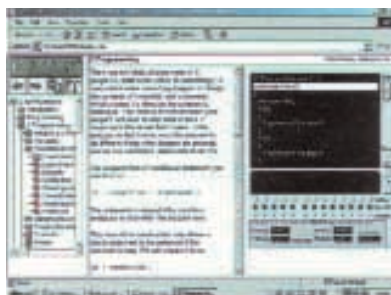
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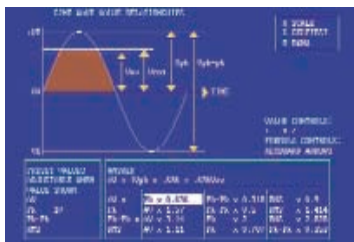
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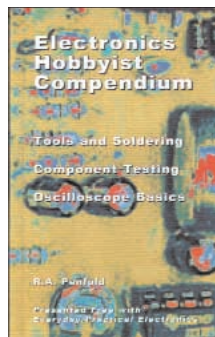
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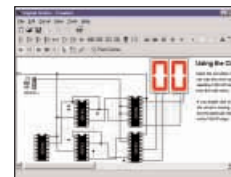


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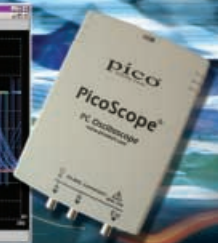
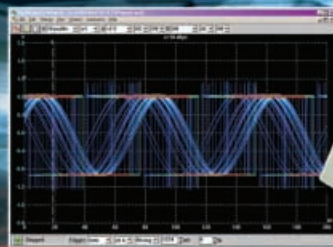
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Floating Point Maths For PICs

Malcolm Wiles

How to use floating point maths with the PIC16F family of microcontrollers

THIS article is an introduction to the use of Microchip's floating point maths routines for the PIC16F series of microcontrollers, and consists of two sections. First, a quick look is taken at the theory of fixed and floating point number representations. The second section consists of descriptions of several files and utility programs which can be downloaded from the *EPE* Downloads site, and which together comprise everything necessary to use the floating point code.

The routines include floating point *add*, *subtract*, *multiply* and *divide*, together with some auxiliary functions, as described below. They are taken from Microchip Application Note AN575 (Reference 1), but the author has restructured them and made some modifications, both to simplify and to remove some unneeded generality in the originals (which are intended for use on a larger range of Microchip products).

It is feasible to run this code on a PIC16F84 (it takes just under half the program memory), but it is probably more useful on the larger members of the PIC16F family, such as the PIC16F628 or PIC16F877.

Number Representations

One of the simplest representations of numbers is *decimal notation*. It is so familiar to us that we just use it every day without ordinarily giving any thought to what we are doing. In decimal notation we can represent both integers and also, by means of the decimal point, non-integer numbers (*real* numbers).

To the left of the decimal point, the number is implicitly the sum of multiples of powers of 10 (so many units, tens, hundreds etc). To the right of the decimal point it is sum of multiples of fractions of 10 (so many tenths, hundredths, thousandths etc). Numbers expressed like this are sometimes called *fixed point* numbers, because once we have placed the decimal point we have to keep it consistently in the same place in order to get the right answers.

One of the chief disadvantages of the fixed point number representation is that, for a given number of digits, it has a relatively limited *dynamic range*. By this we mean the range from the largest to the smallest number that can be expressed.

With one digit it is only possible to represent the integers 0 to 9. With two digits it is possible to represent the integers 0 to 99, and so on.

Scientists and engineers often have to deal with very large (or very small) numbers. For example, one light-year is approximately 5,870,000,000,000 miles. The nearest star to us is some 4.36 light years away, and our Milky Way galaxy is thought to be about 90,000 light years, or 528,000,000,000,000,000 miles across.

Numbers like these soon become unwieldy and hard to understand, so for large and small numbers *scientific notation* is often used. In scientific notation, numbers are expressed as a much smaller number, usually in the range 1 to 10, multiplied by a power of 10. So in scientific notation the light year is 5.87×10^{12} miles, and the galaxy is 5.28×10^{17} miles across.

Note that the same number of digits is used for both these numbers, even though the second is 90,000 times the first number, so that the dynamic range of scientific notation is much larger. For very small numbers, the power of 10 has a negative value, meaning divide by this number of 10s. So, for example, the mass of the electron is 9.11×10^{-31} kg.

From now on in this article we'll use an asterisk (*) to denote multiplication, to avoid possible confusion with *x*, the unknown in algebra.

A bit of technical terminology; in a number k expressed as $k = f * b^e$, f is called the *fraction of mantissa*, e is called the *exponent* or *characteristic* and b is called the *base*.

Binary Arithmetic

In the above we used decimal numbers, but most people will be aware that, because all digital computers are fundamentally built from bistable logic circuits, it is natural to them to use binary arithmetic, where the two bistable states represent a 0 or a 1. In just the same way as with decimals, the bits of a byte or bytes can be used to represent an integer or a binary fraction.

The binary number 01011100 (strictly speaking it should be expressed as 01011100₂, i.e. base 2) is usually taken to represent the integer:

$$(0*2^0)+(0*2^1)+(1*2^2)+(1*2^3)+(1*2^4) + (0*2^5)+(1*2^6)+(0*2^7) = 92$$

in decimal (we can write this as 92₁₀, i.e. base 10).

We could represent any integer from 0 to 255₁₀ like this, or if we want to include negative numbers (in the usual 2's *complement* representation), any integer from -128₁₀ to +127₁₀. With two bytes, or 16 bits, 0 to 65535₁₀ or -32768₁₀ to +32767₁₀ can be represented.

We could also choose to imagine that a binary point divides the number into two halves: 0101.1100₂. This represents the number:

$$(0*1/2^4)+(0*1/2^3)+(1*1/2^2)+(1*1/2^1) + (1*2^0)+(0*2^1)+(1*2^2)+(0*2^3) = 1/4+1/2+1+4 = 5.75_{10}$$

This binary fraction can be added, subtracted, and multiplied (division is a bit trickier, see later) in just the same way as if we regard it as an integer – nothing has changed inside the computer.

So if data memory location **STORE** contains 01011100₂ and **W** contains 00000011₂, and we do an **addwf STORE,W** instruction, **W** will contain the pattern 01011111₂. We can interpret this as adding 3 to 92 to get 95, or as adding 0.0011₂ (0.1875₁₀) to 0101.1100₂ (5.75₁₀) to get 0101.1111₂ (5.9375₁₀). All we have to do is interpret any calculation answers consistently with the interpretations we put onto the inputs. (The binary point can be anywhere, of course, not just half way through.)

But notice two important things about binary fractions. First, by effectively moving the binary point four digits to the left, we have gained precision. Instead of only being able to represent integers, excluding zero we can now represent real numbers as small as 0000.0001₂, or 0.0625₁₀. But in so doing we have lost dynamic range: the largest number that we can represent is now only 1111.1111₂ or 15.9375₁₀.

Second, we cannot represent all numbers exactly. With only four binary digits (bits), the smallest increment we can make to the binary fraction 0.0001₂ is 0.0001₂, to make 0.0010₂. Thus we cannot exactly represent any numbers between 0.0625₁₀ and 0.1250₁₀. The best we can do is take the

nearest approximation. The error can be made arbitrarily small by increasing the number of binary digits in the binary fraction.

We can get more precision and/or more dynamic range by using more than one byte to hold the numbers, and doing 16- or even 32-bit arithmetic. Such routines are available from the *EPE* website (see later). But there are several disadvantages to this approach:

- multi-byte variables take up increasing amounts of comparatively scarce data memory
- the 16- and 32-bit routines get increasingly cumbersome to implement and use
- they take increasingly longer execution times
- it scales only linearly

Division

There's one other problem with fixed point representation, illustrated by the following example. If we divide 4 by 2, the answer is 2; no problem there. But if we divide 4 by 3, the answer is 1.3333 (recurring). This real number needs a binary fraction to represent it accurately. The divisor and dividend were integers, needing no binary fraction at all.

We see that division can change the number of binary fraction digits that we need to represent a number. It thus violates the fixed point rule about keeping the number of binary fraction digits constant. This is why all standard fixed point division routines give as their answer a *quotient* and a *remainder*, rather than a real number, when usually a real number answer would be preferable. It is left to the programmer to sort out the results.

The usual solution is to scale up the numbers involved in the calculation. This is equivalent to moving the point, as we have discussed. For example, if we wanted to calculate a current in amps correct to, say, 0.5 amps, we could choose instead to work in milliamps. Then when a division calculation truncates a result, it is only an insignificant digit that gets lost. The drawback is that we have to be careful that the larger numbers then involved do not overflow the dynamic range of our representation, and with 8- or 16-bit arithmetic that is often a real issue.

Floating the Point

Most of these disadvantages can be overcome if we adopt something like scientific notation to represent numbers. In scientific notation the position of the decimal point and the number itself are held independently, so within much wider limits it is not necessary to trade off precision against dynamic range.

The exponent can change during a calculation as a number grows or shrinks – in this sense the point floats. We don't have to maintain the point in the same place consistently all the time in order to interpret the results. Division can give a real result. Because the dynamic range of a number is represented by an exponent, it scales exponentially. This means that within the same number of digits we can represent a very wide range of numbers; one size fits all, and the same software routines can be used throughout.

The computer implementation of scientific notation is called *floating point*. We are not going into details here (interested readers can find more information in Reference 1 later), but there is an industry standard called IEEE 754 which defines how it is done, and which most computers these days use. IEEE 754 uses a binary fraction, and a base of 2.

The PIC implementation is based on IEEE 754, but due to the PIC architecture it does not, for reasons of efficiency, follow the IEEE 754 standard exactly. Unfortunately, this means that the various IEEE 754 floating point number converters that can be found on the Web cannot be used directly. The author has therefore written his own converters.

Brief Specification

In the PIC floating point implementation described here, three bytes are used to hold each floating point number. The mantissa uses 16 bits and the exponent 7 bits, and is referred to by Microchip as 24-bit floating point format (the remaining bit is a sign bit). The mantissa represents decimal numbers accurately to between 4 and 5 significant figures (some rounding may occur in the fifth digit). The largest and smallest decimal numbers that can be represented are:

Max: $\pm 6.8056 \times 10^{38}$

Min: $\pm 1.1755 \times 10^{-38}$

These precision and dynamic range limits should be sufficient for most PIC projects.

Fix, Float and Normalise

To convert numbers between fixed and floating point representations, most floating point libraries include two functions called *fix* and *float*. *Float* takes a fixed point number – usually assumed to be an integer – and returns the floating point equivalent. *Fix* performs the reverse operation; often the function allows the integer result to be truncated or rounded as an option.

There are, in general, many floating point representations for any given number. For example, 5.87×10^{12} is the same as 58.7×10^{11} , or 0.587×10^{13} . In all floating point schemes one of these representations will be preferred, usually the one in which there are one or zero digits before the point, as in the first and third examples (exactly the same applies in binary). When in the preferred form, the floating point number is said to be *normalised*.

Some floating point routines will only work correctly if normalised numbers are input, but do not necessarily return normalised numbers as results. Floating point libraries usually include a *normalise* function, which takes any floating point number as input and returns the normalised equivalent. However, the PIC library routines always give normalised results, so explicit use of its *normalise* function by the programmer is usually unnecessary.

Disadvantages of Floating Point

There's no such thing as a free meal, and there are some disadvantages to floating point arithmetic. For instance:

- floating point numbers (normally) use three bytes, when in some cases fewer would do
- routines to calculate using floating point representation are complex, and take significant program memory resources
- floating point numbers are very hard to read in their encoded form, and converter routines are needed

Practical Section

On the *EPE* Downloads site (access via www.epemag.co.uk) site there is a zipped archive within the **PICtricks** folder, named **Floating Point**, containing several files for free download. They are:

- **fpdefs.inc** – equates and other definitions used by the floating point library
- **fpcode.inc** – the **.asm** source code for the floating point library
- **fpvars.txt** – variable definitions needed by the floating point library
- **fpdemo.asm** – a demo program illustrating how the floating point library is used
- **tofp.exe** – utility program to convert decimal numbers to floating point
- **todec.exe** – utility program to convert floating point numbers to decimal
- **tofp.cpp** and **todec.cpp** – the C source code for the converter routines

This floating point source code package is written in the MPASM dialect and is intended for assembly by MPLAB/MPASM (Reference 3). It may also be assembled with *EPE Toolkit TK3 V2.0* software onwards (*V2.2 goes up on our site to accompany this article. Ed*). If assembly is attempted with earlier versions of *TK3*, a number of statements may cause assembly errors. Even if these are fixed, some other constructs will not assemble correctly even though no assembly errors will be generated.

File fpdefs.inc

This file contains some equates that are used by the floating point code, and should be put into the directory where your **TK3** or MPASM compiler (**mpasmwin.exe**) is located. It should be included at the beginning of your program, perhaps after the "include" for the processor equates (**p16f84.inc** in the demo program).

The floating point representation of π is also included for convenience.

File fpcode.inc

This file contains the code of the floating point library. It should be put into the directory where your **TK3** or MPASM compiler is located. It is most convenient to include it at the end of your program, but note that the code does not manipulate **PCLATH**, so care will need to be exercised if it overflows a 2K program boundary.

The size of the library is 472 program memory words. If program memory space is at a premium, and not all routines in the library are needed, some routines could be removed, but care is needed when doing this as some routines call others internally.

The code contains seven routines. They are classified as unary routines, which take one argument in locations **AEXP**, **AARGB0**, **AARGB1**, collectively called **AARG** for short, and binary routines

which take two arguments in locations **AEXP**, **AARGB0**, **AARGB1**, and **BEXP**, **BARGB0**, **BARGB1** (the latter together called **BARG**). Results are always returned in **AARG**. This makes it easy to make calls to several routines in sequence to complete a calculation, as the result of the preceding step is usually returned in the correct location for input to the next call.

The unary routines are:

FLOAT
FIX
NRM (Normalise)

The binary routines are:

FPA (Floating Point Add)
FPS (Floating Point Subtract) – **BARG** is subtracted from **AARG**
FPM (Floating Point Multiply)
FPD (Floating Point Divide) – dividend is in **AARG**, divisor in **BARG**

If the called routine succeeded, on return **W** will be zero, else **W** will contain 0xFF and a flag bit indicating the error will be set in location **FPFLAGS**, as in Table 1.

Table 1.

Bit	Exception (error)
DOM	Domain error
NAN	Not a number
FDZ	Divide by zero
FUN	Floating point underflow (number too small)
FOV	Floating point overflow (number too large)
IOV	Integer overflow

If the **RND** bit in **FPFLAGS** is 0, simple truncation is used, which is a little faster. Setting the **RND** bit enables rounding, which may give slightly more accurate results.

File **fpvars.txt**

This file contains data memory variable definitions used by the floating point library; 14 locations are used. It is intended to be “cut and pasted” into your PIC program, so is not set up as an “include” file. This is because most programmers will want to relocate these variables to suit the rest of their program.

As supplied, the variables are located at the “top” of a PIC16F84’s data memory (locations 0x42 to 0x4F). They may be relocated anywhere in Bank 0, but should be allocated a contiguous area of memory and the relative order of the variables should not be changed.

File **fpdemo.asm**

This is a demo program that illustrates how to use the above files. It calculates the volume of a sphere radius $r = 20.3$ units, using the standard formula $4\pi r^3/3$.

Such a calculation would pose several problems in 16-bit fixed point arithmetic. The first problem is how to represent the real numbers π and 20.3 without losing the dynamic range necessary for the rest of the calculation. Second, the calculation has to be done in the “right” order, because the intermediate result $4\pi * (20.3)^3$ is approximately 105123, which would overflow a

16-bit number (even if the question of representing the fraction is ignored). This means that the division by 3 has to be done first. Since this will be integer division there is the third problem of not losing significance before the final answer is obtained.

As can be seen in the demo, none of these is a problem in floating point. The program first floats the integer 4, then multiplies it by the constant π , and then by r three times. Lastly, the intermediate result is divided by 3 and the final result is fixed as an integer, to facilitate output or further processing. Note that this last step causes an **IOV** exception, because the final answer, approximately 35038, overflows the 2’s complement representation of a 16-bit integer. However, the answer is correct if interpreted as an unsigned integer.

It is suggested that readers may like to assemble this program and then run it using a simulator such as that included in Microchip’s MPLAB IDE (see *PIC n’ Mix*, *EPE* August 2004). Some **NOP** instructions are included in the demo code at convenient places to put breakpoints to examine intermediate results.

The floating point values of π , 20.3 and 3, quoted as constants in the demo, were obtained using the utility program **tofp.exe**.

Files **tofp.exe** and **todec.exe**

These utility programs convert decimal numbers to Microchip floating point representation (**tofp.exe**) and back again (**todec.exe**). They have been tested on Windows 98SE, 2000 and XP, and are sufficiently harmless that they should run on any other 32-bit Windows OS.

Load them into any convenient directory, preferably one on the DOS path. To run them, double-click on the filename in Explorer, or type the filename at a DOS box command prompt. Enter the number(s) to be converted at the programs’ prompts.

In the worst traditions of hack utilities, there is little validation of input data. Any syntax errors will cause the programs to exit immediately, with no error messages given. (Note that q is an illegal character in both decimal and floating point numbers, so can be used as an exit character).

File **todec.exe** outputs numbers greater than 10^4 or less than 10^{-4} in the standard C notation for floating point numbers, which avoids awkward superscripts by using the letter E to stand for “times ten to the power”. For example, $5.87 * 10^{12}$ would be output as $5.87E+12$. Decimal numbers may be input to **tofp.exe** in this notation.

The programs are written in C by the author. The zip archive contains the source files **tofp.cpp** and **todec.cpp** if any reader should wish to investigate them further (but be warned that the source code is not commented, and knowledge of the Microchip floating point format is needed).

File **tofp.cpp** is closely based on Appendix A.3 of Reference 1.

If You Want More

The following are beyond the scope of this article, but interested readers may wish to explore further:

1) For simplicity, and to reduce the program and data resources required, the author has described only a 24-bit floating

point implementation. AN575 also includes 32-bit (4-byte) versions for the functions described. 32-bit calculations offer additional accuracy (to 6 or 7 significant figures), but not increased dynamic range.

2) There is an additional Application Note, AN660 (Reference 2), which contains the code for a floating point maths library including the following routines:

- square root function
- exponential function, e^x
- base 10 exponential function
- natural log function, $\ln(x)$
- common log function, $\log_{10}(x)$
- trigonometric sine function
- trigonometric cosine function
- trigonometric sine and cosine functions
- power function, x^y
- floor function, largest integer not greater than x , as float
- floating point logical comparison tests
- integer random number generator

References

1. IEEE 754 Compliant Floating Point Routines, Application Note AN575, **00575.pdf**, available for free download from www.microchip.com and also on Disc 2 of the cover set supplied with *EPE* October 2001.
2. Floating Point Math Functions, AN660, available as above.
3. Microchip MPLAB Integrated Development Environment (IDE), available for free download from www.microchip.com (version 6.60 at the time of writing). MPASM is the assembler included in MPLAB, but it is no longer available as a stand-alone product. However if MPLAB is installed, the MPASM assembler can be used on its own without necessarily running the rest of the MPLAB IDE. More recent versions of *TK3* have an “MPASM” button that can be used to launch MPASM directly from *TK3*, and *TK3* can be used to program PIC chips with the **.HEX** files produced by MPASM.

Acknowledgements

The author wishes to thank:

- Peter Hemsley for reading and commenting on a draft version of this article
- Joe Farr and Ian Stedman for testing the converter programs
- John Becker for his hard work upgrading the *TK3* assembler to cope with this floating point package.

Resources

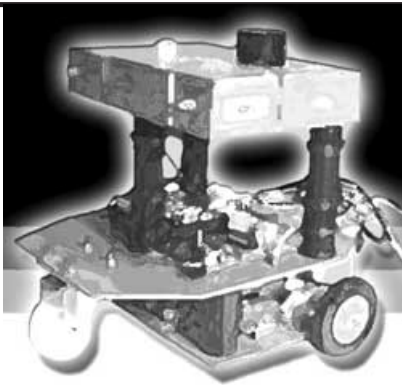
Software for the maths routines referred to in this article is available on 3.5inch disk (“PIC Tricks” disk) from the Editorial office (a small handling charge applies – see the *EPE PCB Service* page). It can also be downloaded free from the *EPE* Downloads site, accessible via the home page at www.epemag.co.uk. It is held in the **PICs/PICtricks** folder.

The *Toolkit TK3* software has been updated (V2) to handle some aspects required by Malcolm’s code and also Andrew’s *Pic n’ Mix* code in this issue, and is also available for free download from our website. □

Smart Karts

Owen Bishop

Part 2 – On manoeuvres and software development Get Smart! - Build a PIC-based mobile buggy that's expandable to meet your needs



LAST month we described the basic construction of the Smart Kart mobile robot. We now put it through its paces using the demonstration program stored in the PIC microcontroller. We then examine the software in a bit more detail, from which discussion we hope you will get ideas about how to write your own software for the Smart Kart.

Smart Kart is a basic mobile robot and there are many manoeuvres that it can be programmed to perform. If you have not programmed a robot before, now is the time to try it. At present there are only two sensors and two motors to think about. You can forget about programming the l.e.d.s and bleeper and tackle these when you are more experienced.

The demonstration software for Smart Kart is available as stated at the end. The program has been written so as to display Smart Kart's talents to the full. It has four modes of behaviour, selected by a pair of switches (S1 and S2) in the upper deck. The settings and the behaviour modes are listed in Table 2.2.

Mode 1 – Line Runner

Mode 1 is called Line Runner. It is selected by switching off both S1 and S2. To demonstrate this function you need a map painted in black on thin white card, as shown in Fig.2.1 for example. A suitable size for trials is 63cm x 102cm, though you may wish to tape together two or more sheets for more elaborate layouts.

For the first test runs it is good enough to paint a short curved line on A4 paper. The standard path width is 20mm to 25mm, but there is no need to be exact. There is a limit to the sharpness of curve that the robot can negotiate. It analyses its position relative to the line at frequent intervals and takes correcting action.

If it travels too far in this time and the line curves too sharply, it runs off the line before it has had a chance to correct its error. It was found with the prototype that curves must have a minimum radius of 7cm. However, this partly depends on the speed and gearing of the motors. If your model has faster motors than in the prototype, or a lower gear ratio, you may need either to alter the program to shorten the time between successive analyses, or draw the path with wider curves.

To run the Smart Kart, turn on both power switches and press the Reset switch to send the PIC back to the beginning of the program. This gives you about 10 seconds to position the robot and wait for it to start.

The robot will not only run along any line on which it is placed (see photographs) but, when placed on a plain white area, it looks for a line, finds it, and then runs along it. The complete range of responses is summarised in Table 2.1, in which 0 indicates black and 1 indicates white.

The first line of Table 2.1 occurs sometimes if the robot is left to find the line for itself. If it approaches the line obliquely, it latches on to it and follows it. However, if it approaches the line at right angles and is

attempting to cross it, it backs up, spins a little and tries a fresh approach. After a few such frenzied trials it approaches obliquely and latches on to the line.

The last line of the table states that the robot runs straight ahead when it is "free", that is, not on a line. The motors usually do not run at exactly equal speeds, so the path is a gentle curve. But it is straight enough over short distances, allowing the robot to negotiate short breaks in the line. This makes it possible for two lines to cross, with their crossed-over sections omitted. The robot finds its way across to the opposite side of the gap. It is also possible for two lines to lead the robot onto a single line, with the actual junction not painted.

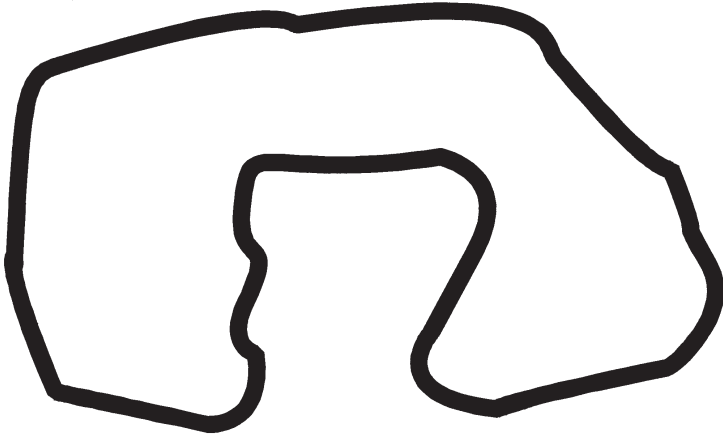


Fig.2.1. A typical map for the Line Runner demo.

Table 2.1: The Action of the Line Runner Mode 1

Input Left Right		Situation	Motor action	L.E.D.s
0	0	Crossing a line	Reverse, Spin a little to the left and try again	Flash headlamp, reversing lamp and sound bleeper
0	1	On line but veering right	Spin a little left	Left indicators
1	0	On line but veering left	Spin a little right	Right indicators
1	1	On the line or running free	Continue forward	Headlamps

There may be reasons for preferring to follow a white line on a black background. There are two solutions to this – the software solution and the hardware solution. The software solution is to go through the assembler listing and alter the lines that respond to the sensor inputs. The hardware solution is easier: replace the 4081 AND gate (IC2) on the processor board with a 4011 NAND gate.

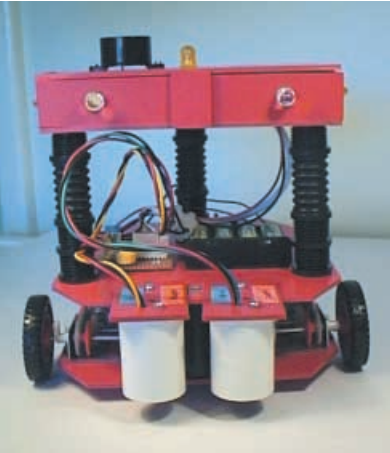
Mode 2 – Line Runner With Stations

Mode 2 can be called Line Runner with Stations, and is selected by switching S1 on and S2 off. The action differs from the simple Line Runner (Mode 1) only in the first line of the table, as listed in Table 2-3.

Maps for this mode are similar to those for Mode 1, but with the addition of “stations”. These are indicated by a black bar about 80mm × 25mm painted across the track. The robot stops and performs its “bells and whistles” act every time it encounters a station.

It has been suggested that, with a small map as the centre-piece of a dinner table, the robot could act as a “Lazy Susan”, carrying the condiments or bread rolls round to each guest in turn. It waits a while for each guest to help themselves.

A vehicle with Mode 2 selected is also able to run on maps of Mode 1, but is not able to find the line for itself.



Mode 3 – Playpen

Mode 3 is called Playpen, and is selected by switching S1 off and S2 on. Table 2-4 shows the responses.

The action is entirely different from that in the other modes. Instead of following a line, the robot is enclosed by a line that it cannot cross. It is in its “playpen”, which might be something like that in Fig.2-2. The floor of the playpen is scattered with “toys” (painted shapes) and the robot interacts with these as it passes by.

Smart Kart operates just as well in the dark and is most spectacular when running in Mode 3. This mode lends itself to a simple game of chance. The playpen can be drawn with two or three gaps in the wall, wide enough for the robot to pass through. The robot is started in the centre of the playpen and players take bets on the gap through which the robot will eventually leave the area. Given the erratic course of the vehicle, it is virtually impossible to predict what will happen – and the outcome can change even at the last moment!

Table 2-2: Switch Settings and Behaviour Modes

Mode	Settings S2	S1	Name	Description
1	Off	Off	Line-Runner	Follows a curving line. Flashes its bright headlamps as it goes; flashes its left or right indicator lamps when turning; flashes its reversing lamp and sounds its bleeper when reversing
2	Off	On	Line-Runner, with stations	Follows a curving line, but stops for about 10 seconds when it comes to a bar painted across the line. Bleeps when it stops and again just before it starts again
3	On	Off	Playpen	Is trapped within a surrounding playpen (enclosed by a line); dashes about, reversing and spinning as it frantically tries to get out; flashing its lamps and sounding its bleeper. Is diverted by its toys on the floor of the playpen. This mode can be made the basis of a game
4	On	On	Maze-Solver	Follows the dividing pathways of a maze, turning randomly to left or right at each fork (Fig.2.3). Stops and beeps when it reaches a terminus. It follows a random path on successive runs, but can be taught to remember the most recent path and repeat it indefinitely. This mode can be the basis of a game

Table 2.3: The At-Station Behaviour in Mode 1

Input Left	Right	Situation	Motor action	L.E.D.s
0	0	At a station	Stop, pause about 8s, then continue forward	Flash headlamp, reversing lamp and sound bleeper on stopping; flash left and right indicators while waiting; flash headlamp and reversing lamp and sound beeper just before continuing

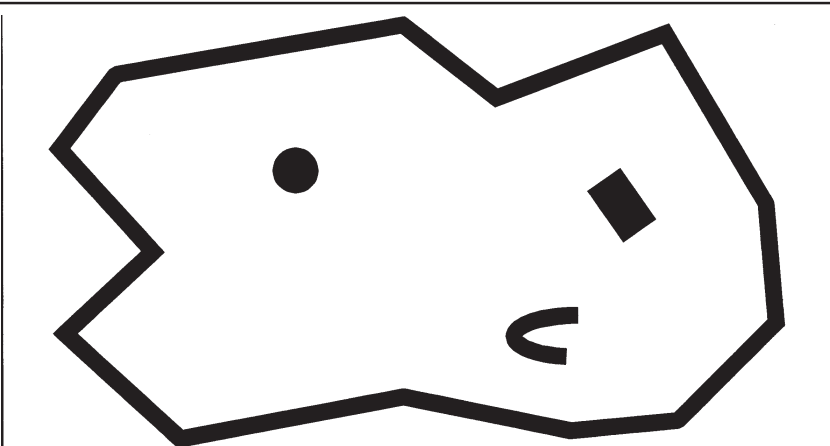


Fig.2.2. A typical map of a Playpen for Mode 3.

Table 2.4: The Action of the Robot in the Playpen

Input Left	Right	Situation	Motor action	L.E.D.s
0	0	Playpen wall close ahead	Reverse a short way, spin about 160° left and run forward to try again	Flash reversing lamp and sound bleeper
0	1	Wall close on right	Spin about 80° left	Flash left indicators
1	0	Wall close on left	Spin about 80° right	Flash right indicators
1	1	Running free	Continue forward	Flash headlamp

Mode 4 – Maze Solver

Mode 4 is named Maze Solver, and is selected with both S1 and S2 switched on. The maze consists of a line that branches repeatedly into two, and there are three levels of branching, giving eight branches, each ending at a terminus (see Fig.2.3). The aim is to teach the robot to find its way to a particular terminus selected beforehand by the operator.

Typically, a maze for robots (and for experimental animals or humans) is set up by building walls (or fences or hedges) to define the paths. The robot needs sensors (perhaps ultrasonic) to detect walls ahead or to its sides. The width of the paths in such a maze needs to be at least as wide as the robot, so building such a maze is no easy task, and can be expensive. It certainly cannot be accommodated on the average dining-room table.

The maze in Fig.2.3 is a system of branching lines which can be detected by Smart Kart's two front-mounted photosensors. This maze is solvable almost instantly by eye. It looks too easy. But Fig.2.4, for example, is the same maze drawn in the more conventional way.

It now looks much harder to solve, but the problem is exactly the same – what sequence of left and right turns should be taken? In this program we are simply making it possible for the robot to use the sensors it already has, rather than our having to build up substantial walls and equip the robot with new types of sensor.

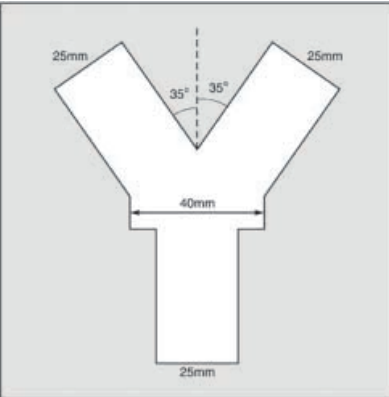


Fig. 2.5. A template for maze branching.

The template used for the junctions in the maze is shown in Fig.2.5. The number of degrees turned depends on the speed of the motors so you may find that your robot turns through greater or lesser angles. If so, you need either to alter the timing in the program or adapt the junction template to alter the angles. It is best for the track to be straight for a short distance before each junction, and for the branches too.

The behaviour differs from other modes in the line as shown in Table 2.5. The robot knows if it is at a branch or a terminus by counting the number of occurrences of "00" from its sensors. The fourth occurrence is a terminus.

The robot is placed at the start of the maze and left to find its way to a terminus. The program includes a pseudo-random number generator which produces a sequence of 127 digits (0 or 1) before repeating. The junction is marked with a

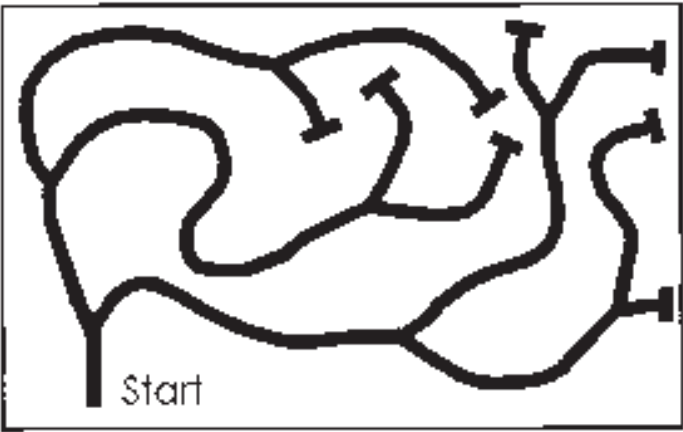


Fig. 2.3 A typical map of a Maze for Mode 4.

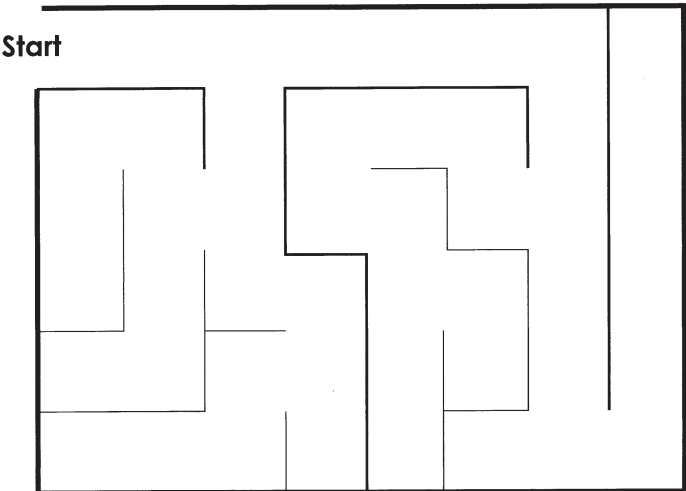
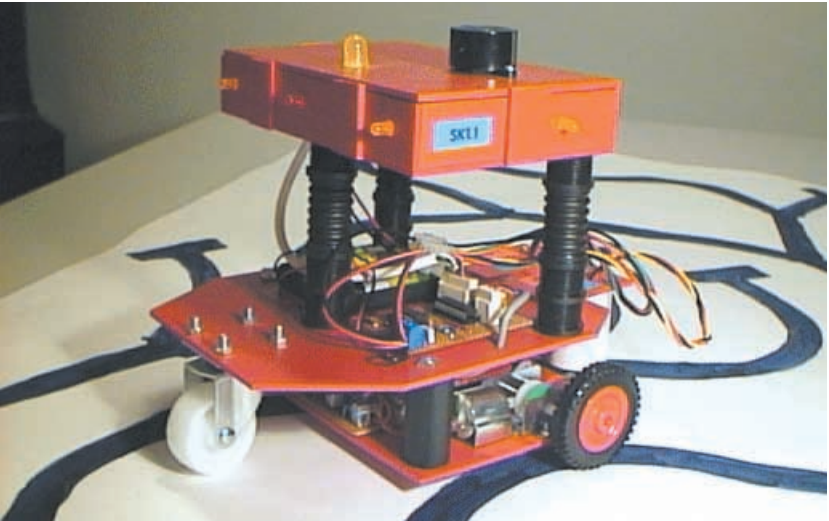


Fig.2.4. One of many equivalents of the map of Fig.2.3 drawn in a more conventional way.

Table 2.5: The Action of the Robot at a Junction or a Terminus in a Maze

Input	Left		Situation	Motor action	L.E.D.s
	Left	Right			
0	0	0	At a branch	Select a random digit and take the left or right branch, accordingly	No action
			At a terminus	Stop and learn the route, if informed that it is at the correct terminus	No action

The robot pauses while deciding whether to turn left or right at a junction in the maze.



bar across it, similar to the stations on Mode 2 maps. As it comes to each junction, the robot draws the next random digit to decide if it will turn left or right. It is equally likely to reach any one of the eight terminuses.

Trial and Error

When it reaches a terminus it stops for about 20 seconds. During this time, the operator must then pick up the robot and transfer it back to the beginning of the maze. DO NOT PRESS the Reset button. After a pause, it starts again and finds its way to a terminus, probably a different one.

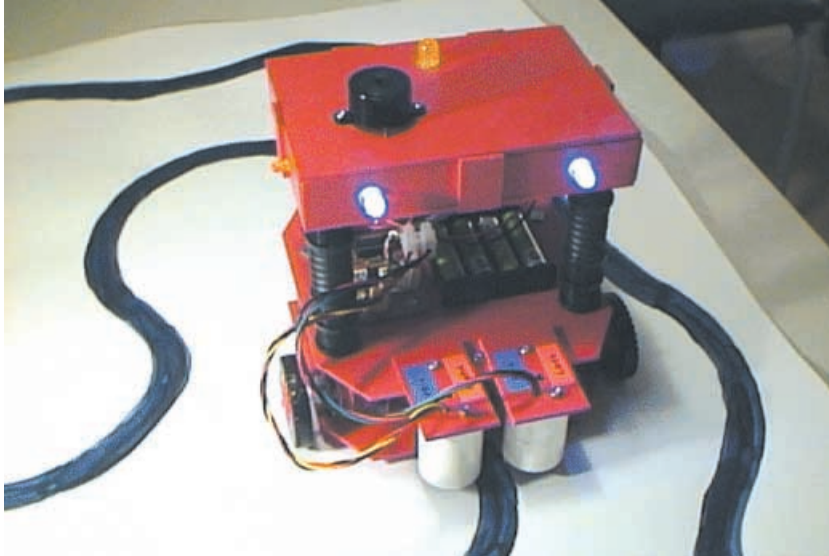
This is the phase in which the robot is finding the selected terminus by trial and error. This is a common learning technique. But the robot must be told when it has done the right thing, otherwise, it can never learn. The operator tells the robot that it has reached the chosen terminus by turning off switch S1. This “rewards” the robot and it “remembers” the route it has just taken.

The operator immediately transfers the robot back to the beginning of the maze and, from now on, it always goes to the selected terminus. It has learnt what to do.

Later, the operator may decide to switch S1 on again. This confuses the robot, which immediately forgets what it has learnt and begins choosing random pathways again. It can then be taught to go to a different terminus.

Although this example is as simple as it can be, it does illustrate the principle of trial and error and the use of reward to reinforce desired behaviour. However, what goes on in the PIC is not the same as what goes on in the human brain.

We now discuss various aspects of how that software has been written. This should help you write your own software (as we



hope you will do) to make the Smart Kart work as you want it to – and there’s a lot of fun in that!

Smart Kart Routines

We will look at segments of the software to illustrate its make-up and show how it works. Table 2-6 shows the “equated variables” and their function in the program. Interrupts are not used in this program.

Selecting Behaviour

On entry to the start of the main program, at label **start**, all five bits of Port A are set as outputs. In Port B, bits RB7 to RB4 are set as inputs, and RB3 to RB0 as outputs. The Watchdog flag is then cleared. The program then goes on to detect what behaviour the Smart Kart is to have, depending on the setting of behaviour (mode) switches S1 and S2.

Listing 2.1.

The flowchart in Fig.2-6 shows the structure of the Listing 2.1 segment of the

program. The first two lines clear the ports, to ensure that the motors do not start running immediately and that the l.e.d.s are off (except for the beacon, which is not under the control of the PIC).

Pause2 is a set of three nested counting loops intended to produce a delay. The processor goes to this subroutine with a value in its working register (**W**) to set the length of delay. In this instance the value is hex F0 (240 decimal), which produces a delay of approximately eight seconds after the power has been switched on, or the Reset switch has been pressed.

This gives the operator time to position the Smart Kart on the track, and stand clear. The table in Fig.2.6 defines the logic and the flowchart explains the way in which the inputs at RB5 and RB4 are read and used to select one of the four behaviour programs of the robot.

Line Runner Routine

By switching off both S1 and S2, the PIC program branches to the routine at

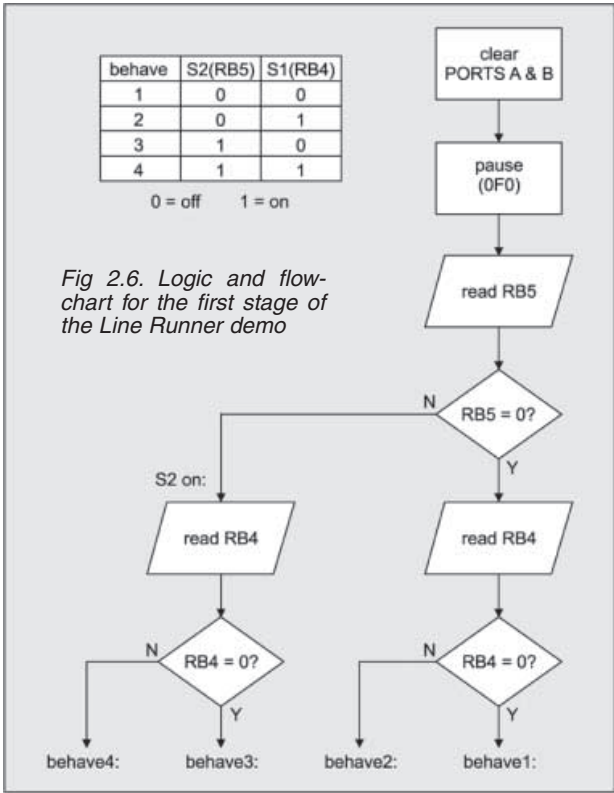
Table 2.6: Smart Kart Variables

Name	Address	Function
Delay0	0Ch	Loop counter (inner)*
Delay1	0Dh	Loop counter (middle)*
Delay2	0Eh	Loop counter (outer)*
Random	0Fh	8-bit random number
Bitn	10h	Bit 5 of Random
Bitm	11h	Bit 6 of Random
xorout	12h	Result of exclusive-or (XOR) of bitn and bitm
branches	13h	Counts number of branches encountered
oldrand	14h	Stores previous value of Random

* used in the Pause2 timing subroutine

Listing 2.1. Mode routing routine

```
clrf porta ; Clear PortA
clrf portb ; Clear PortB
movlw 0F0h ; set value to be used by Pause2
call pause2 ; perform Pause2
btfsc portb,5 ; is RB5 low (switch S2 off)?
goto s2on ; no, S2 is on so go to s2on
btfsc portb,4 ; is RB4 low (switch S1 off)?
goto behave2 ; no, S1 is on so go to Behave2
goto behave1 ; yes, S1 is off, so go to Behave1
S2on: btfsc portb,4 ; S2 is off, so is RB4 low
      (switch S1 off)?
      goto behave4 ; no, S1 is on so go to Behave4
      goto behave3 ; yes, S1 is off so go to Behave3
```



Behave1, which is the one we previously referred to as Mode 1, the Line Runner. This routine is similar in many ways to that of the other Behaviour routines, so let's look at it in detail. Later we describe the ways in which the other Behaviours differ. The first part of **Behave1** is shown in Listing 2.2.

The flowchart in Fig.2.7 shows the input logic for Listing 2.2. The PIC reads the inputs from the two sensors, detects if the robot is deviating from the line and, if so, goes to the appropriate correcting routine. For simplicity we could use the "bit set" mnemonic (**bsf**) to switch on an i.e.d. and "bit clear" (**bcf**) to switch it off.

However, because there are two motors to switch and therefore two bits to set or clear, we use a binary value to control the outputs from Port A. Only the lower four bits are relevant. For example, binary value "1010" runs both motors forward, while "0101" reverses both. If the robot is on the line (or perhaps running free on a blank white surface), the PIC goes back to the beginning, and repeats the forward action.

In a Spin

Now suppose that it is found to be veering to the right of the line (RB6 = 1, RB7

= 0). The flowchart leads to the routine **spinl**, in which the right motor continues running in the forward direction, but the left motor is put into reverse. Consequently, the robot spins a few degrees to the left. Listing 2.3 shows what happens.

The PIC is repeatedly directed back to **spinl** until it is no longer found to be veering right. It may have corrected its error, or the path may have curved to the right. Whatever happens, it is back on the line.

If the robot is veering left, a similar routine (commencing **spinr**: **movlw %0000110**) is used to spin it back on the line. The program puts the right indicators on and off instead.

In Reverse

The **reverse** routine is not likely to be used unless the robot is searching for a line at the beginning of a run. This puts both motors into reverse, sounds the bleeper, and flashes the reversing i.e.d. Then it produces a small spin to the left before sending the PIC to the **tryagain** routine. This cuts out the short forward run, which might take the robot across to the opposite side of the line.

In practice, it usually approaches the line obliquely and then uses **spinl** or **spinr**

to latch on to it and follow it. However, if it approaches the line at right angles then **reverse** makes it back up, spin a little and try a fresh approach. After a few such frenzied trials it is approaching oblique-

ly and latches on to the line.

On Line

When painting the line, remember that there is a limit to the sharpness of curve that the robot can negotiate. It analyses its position relative to the line at frequent intervals and takes correcting action. If it travels too far in this time or the line curves too sharply, it runs off the line before it has had a chance to correct its error.

As said previously, it was found that curves must have a minimum radius of 7cm, although this partly depends on the speed and gearing of the motors. If your model has faster motors than that in the prototype, or a lower gear ratio, you may need either to alter the program to shorten the pause between successive analyses, or draw the path with wider curves.

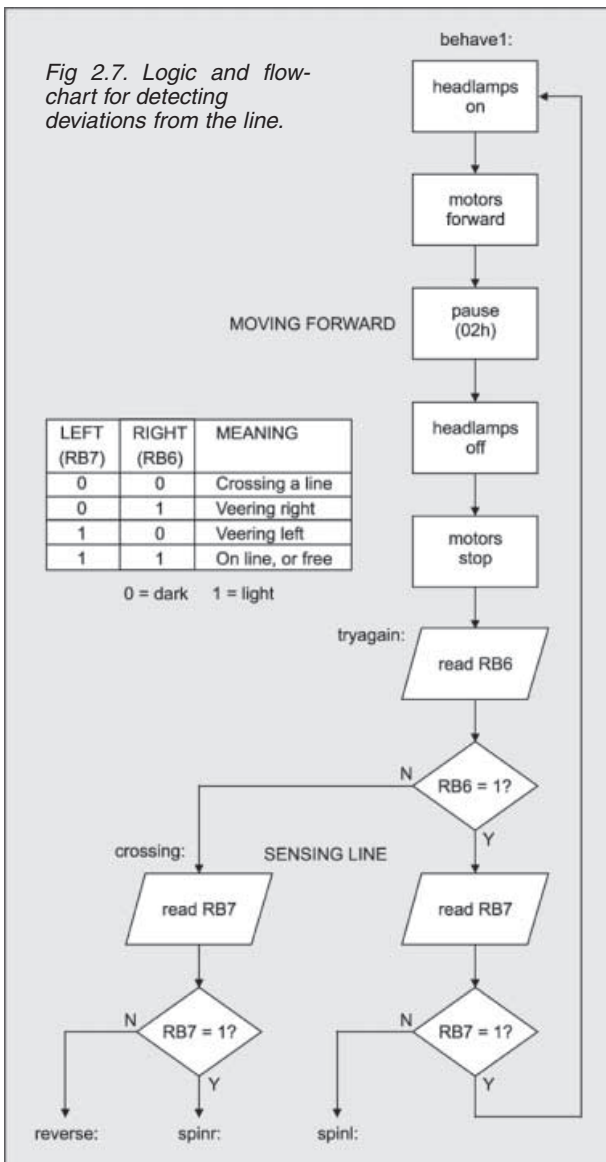
It is also worth repeating that when the robot is "free" (not on the line), it runs more or less straight ahead. The motors usually do not run at exactly equal speeds, so the path is a gentle curve. But it is straight enough over short distances, allowing the robot to negotiate short breaks in the line.

This makes it possible for two lines to cross, with their crossed-over sections omitted. The robot coasts across to the opposite side of the gap. It is also possible for two lines to lead the robot on to a single line, with the actual junction not painted.

Stations Routine

The routine for Mode 2, Line Runner with Stations, is selected by switching S1 on and S2 off. The action differs from that of Mode 1 only when inputs RB6 = 0 and RB7

Fig 2.7. Logic and flow-chart for detecting deviations from the line.



Listing 2.2. Behave1 routine

```
Behave1:  bsf portb,0      ; headlamps on
          movlw %00001010 ; both motors forward
          movwf porta
          movlw 02h        ; short pause (0.067s)
          bcf portb,0      ; headlamps off
          clrf porta        ; stop

Tryagain: btfss portb,6    ; skip if veering right
          goto crossing    ; if veering left or
                          ; crossing line

          btfss portb,7    ; skip if on line
          goto spinl       ; is veering right, so
                          ; correct it

          goto behave1     ; on line (or free), so
                          ; go forward

Crossing: btfss portb,7    ; skip if veering left
          goto reverse     ; is crossing line, so go
                          ; back and try again

          goto spinr       ; is veering left, so
                          ; correct it
```

Listing 2.3. Spin left routine

```
Spinl:  movlw %00001001  ; spin left
          (R forward, L reverse)

          movwf porta
          bsf portb,2      ; left indicators on
          movlw 03h        ; short pause (0.1s)
          call pause2
          bcf portb,2      ; left indicators off
          clrf porta        ; stop
          goto behave1     ; to move forward,
                          ; then repeat tests
```


= 0. In Mode 1, this evokes the line-crossing response described, but in Mode 2 the line that crosses the track is taken to be a "station".

The routines for running forward, veering left and veering right are very similar to those already described. Subroutines could have been used for these actions and called for use in all modes. However, in this application there is plenty of unused program memory space and the routines for each mode are kept entirely separate (except that all use the **Pause2** subroutine). This leaves you free to modify the four Behaviours independently, if you wish.

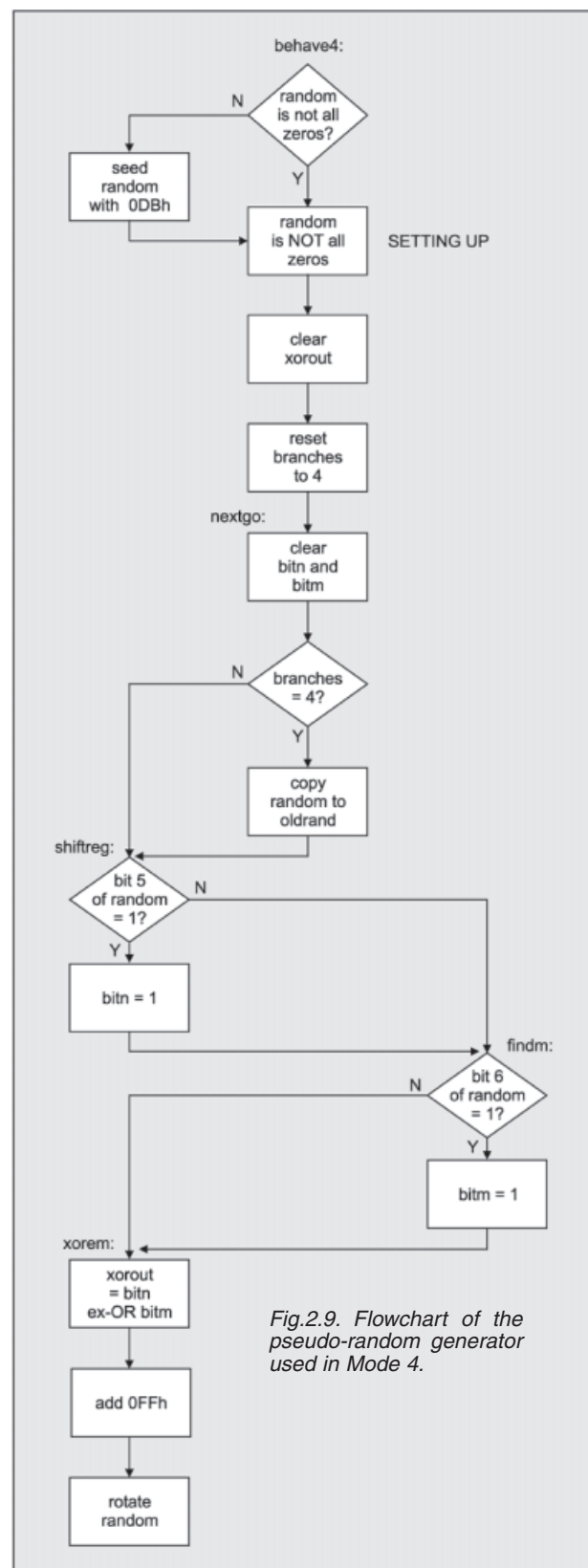


Fig.2.9. Flowchart of the pseudo-random generator used in Mode 4.

At a station the robot stops and runs through a sequence of bleeps and l.e.d. flashing lasting about 10 seconds. The program consists of setting and clearing bits and calls to **Pause2**, so is similar to routines already described. After this, it runs forward for 0.27 seconds so as to get clear of the station before resuming its line running routines.

Playpen and Maze Routines

The Playpen and Maze Solver routines, Mode 3 and Mode 4, are similar to Modes 1 and 2 – setting and clearing bits to operate the motor, l.e.d.s and bleeper. The main difference for Mode 3 is that the action is more dynamic. The pauses are longer so that movements forward and backwards are greater, and the spins take the robot through larger angles.

Random Numbers

The routine for generating the random numbers is the software equivalent of the circuit shown in Fig.2.8. A new number is generated from the previous random number every time the value in the register is shifted left. Shifting is initiated by a pulse from a clock circuit, not shown in the diagram. The gate produces the exclusive-OR of bits 5 and 6 in the shift register and loads the result into bit 0 as the register is shifted.

The effect of this is to produce a sequence of 0s and 1s that is apparently random. In fact, it is not. The sequence actually repeats at regular intervals. For example, if we use bits 5 and 6, it repeats after 127 shifts. This is called a *pseudo-random* number. Because the sequence is so long, we do not notice that it repeats. Random number generators are useful in robotics for producing apparently random action.

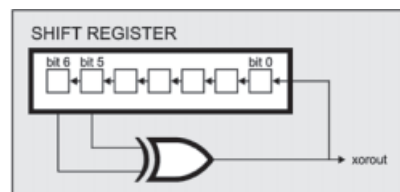
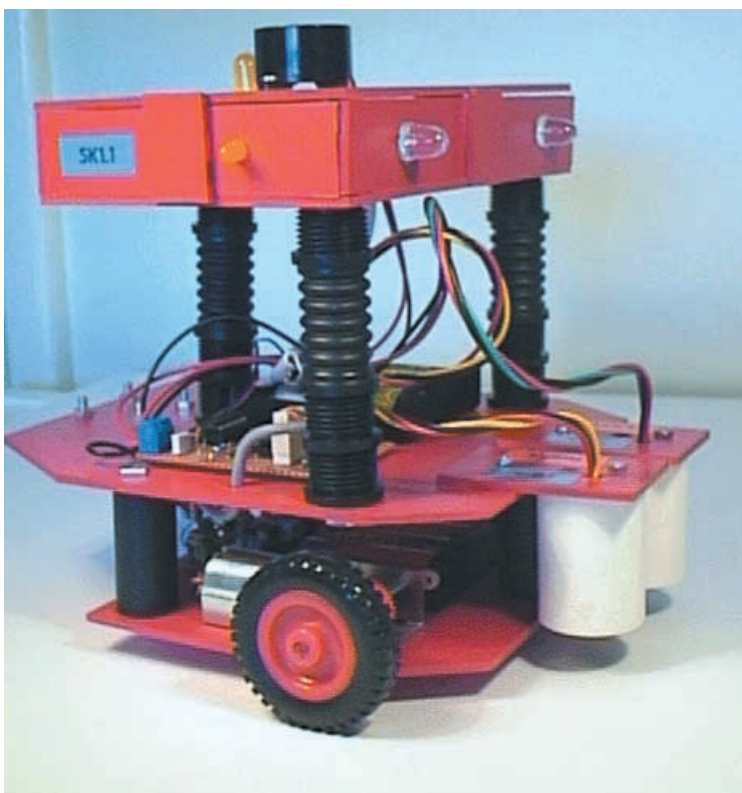


Fig. 2.8. A pseudo-random number generator.

For this circuit to work, of course, the shift register must never contain all zeroes. But, provided that it starts with at least one "1" in its binary value, it will never go to the all-zero state. The flowchart of Fig.2.9 shows how this circuit is translated into software.

The shift register is represented by a PIC memory register called **random**. The Mode 4 routine begins by checking that **random** is not all zeroes (which is highly unlikely, but worth a check). If it is all zeroes, **random** is seeded with the hex value DB (binary 11011011), although any other non-zero value could be used.



Listing 2.4. Section of the randomising routine

```
Xorem:  movf bitn,w      ; load bitn into W
        xorwf bitm,w      ; XOR with bitm,
                        ; result in W
        movwf xorout      ; result to output
        addlw 0FFh        ; set Carry if W = 1
        rlf random,f      ; new random number
                        ; for next go
```

Next **xorout** is cleared and resets **branches** to a value of 4. This part of the routine is run the first time **Behave4** is called, but subsequently the PIC returns to the routine at **nextgo** each time it has negotiated a branch in the track.

At **nextgo** bits **bitn** and **bitm** are cleared. If **branches** equals a value of 4, we know that this is the first time through this routine on this "go". If so, the value in **random** is copied to **oldrand**. This is done in case the robot has reached the correct terminus and needs to "memorise" the initial value of **random**, so as to take the same route on subsequent runs.

The next two segments of the program are concerned with generating the random digit that decides whether the robot turns left or right at a branch. First we need give **bitn** the value held in bit 5 of **random**, and to give **bitm** the value held in bit 6. **bitn** is originally clear, but is set if bit 5 equals 1. Similarly for **bitm**. Next comes the segment of code in Listing 2.4.

In this routine, **bitn** is loaded into the working register (**W**), XORED with **bitm**, leaving the result (0 or 1) in **W**. This is copied into **xorout**, for use when the robot is deciding which way to turn. The PIC's **rlf** (rotate left through carry) command shifts the digits of **random** one place to the left.

It shifts the value of the Carry digit (stored as bit 0 of the Status register) into bit 0 of **random**, then shifts the former bit 7 of **random** into Carry.

To simulate the action of the circuit in Fig.2.8, we need to load the value of **xorout** (which is 0 or 1) into Carry before we rotate **random**. This is done by adding hex FF to **W**, which is still holding **xorout**. If **xorout** is 0, **W** holds hex 00, and adding hex FF gives hex FF. Carry remaining 0. But if **xorout** is 1, **W** holds hex 01. Adding hex FF gives hex 100, which results in hex 00 in **W** and Carry becomes 1.

In this way Carry takes on the same value as **xorout**, and is shifted into bit 0 of **random** at the **rlf** command. The final stage is to rotate left with Carry to produce the next value of **random**, ready for the next junction decision.

Learning

After the last sequence, the PIC runs through a segment called **fwd** that drives the robot forward. Then it checks whether the robot is veering left, veering right or at a branch (or terminus) in the usual way and corrects deviations. If the robot is at a branch or terminus the PIC goes to a routine called **branch**. The first operation is to decrement **branch** and test to see if it is zero. At a branch (**branch** > 0) it spins left if **xorout** equals 0 and right if **xorout** equals 1. It then carries on forward to clear the junction before returning to **nextgo**.

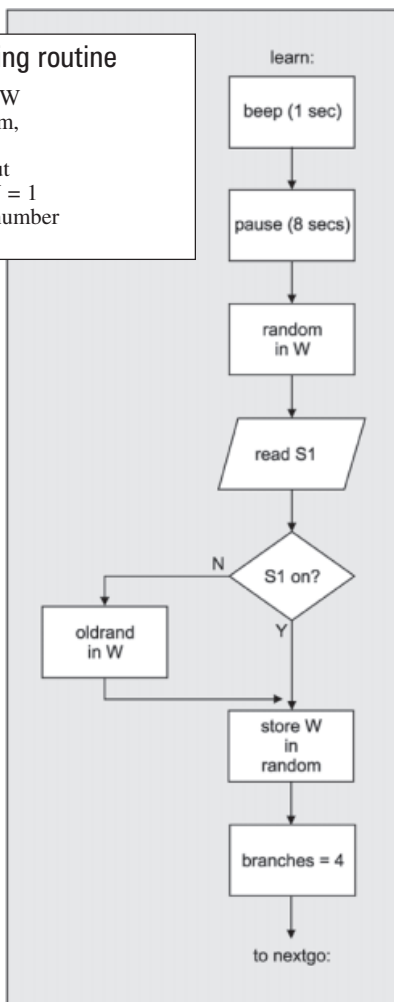


Fig.2.10. Flowchart of the Smart Kart's learning routine.

At a terminus (**branch** = 0), it goes to a routine called **learn**, which is illustrated in Fig.2.10. This starts with a long beep to warn everyone that Smart Kart is waiting at a terminus. Then follows a long pause, during which the operator has to return the robot to the start of the maze. This is when the operator may turn switch S1 off to tell the robot that this terminus is the chosen one.

The PIC already has the current **random** value in its working (**W**) register. If the switch is off, this is replaced by the previous **random**, which has been held in **oldrand**. **Branches** is set to a value of 4 and the PIC goes back to **nextgo** (Fig.2.9).

If **random** has been reset to its previous value, the robot runs through the same sequence of turns as before, and goes to the same terminus. It has learned to solve the maze. Otherwise it takes a new random route.

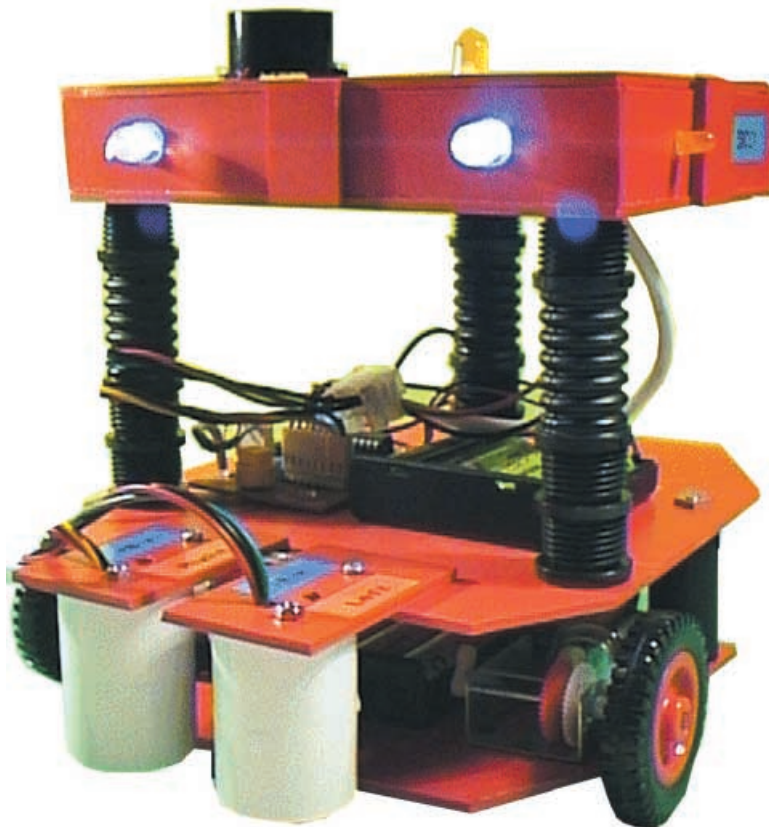
Although this learning routine is simple, it illustrates the principle of trial and error learning and the use of reward to reinforce desired behaviour. However, as said earlier, what goes on in the ALU of a PIC is not the same as what goes on in the human brain.

Resources

Software including source code files, for the Smart Kart is available on 3.5 inch disk from the Editorial office (a small handling charge applies – see the *EPE PCB Service* page). It can also be downloaded *free* from the *EPE* Downloads page, accessible via the home page at:

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Robert Penfold

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Robin Pain

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The fundamental principles of analogue and digital fault finding are described (although, of course, there is no such thing as a "digital fault" – all faults are by nature analogue). This book is written entirely for a fault finder using only the basic fault-finding equipment: a digital multimeter and an oscilloscope. The treatment is non-mathematical (apart from Ohm's law) and all jargon is strictly avoided.

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R. A. Penfold

Getting started with logic circuits can be difficult, since many of the fundamental concepts of digital design tend to seem rather abstract, and remote from obviously useful applications. This book covers the basic theory of digital electronics and the use of CMOS integrated circuits, but does not lose sight of the fact that digital electronics has numerous "real world" applications.

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Second Edition. Morgan Jones

This book allows those with a limited knowledge of the field to understand both the theory and practice of valve audio amplifier design, such that they can analyse and modify circuits, and build or restore an amplifier. Design principles and construction techniques are provided so readers can devise and build from scratch, designs that actually work.

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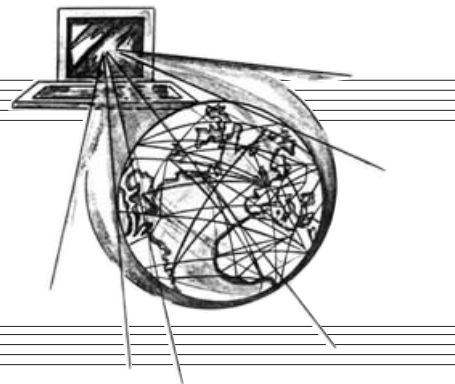
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SURFING THE INTERNET

NET WORK

ALAN WINSTANLEY



IN LAST month's *Net Work*, the simple process of acquiring a domain name was outlined. We suggested the domain supplier Easily as one online source of domains – an Easily banner advert appears on the *Net Work* page of the *EPE* web site where you can search for names and buy online. You can then set them up for email and web forwarding.

When looking for a likely domain name, it is a safe bet that someone, somewhere has already thought of the name that you had set your heart on. It is increasingly difficult to source an original name and there have been many disputes over the registration and ownership of domains in the past.

Domains are generally issued on a first-come first-served basis, but attempts are sometimes made to buy domains possibly with a view to selling them to their "rightful" owners. Buying **marksand-spencer.co.uk** and **bt.org** and more resulted in the celebrated "One in a Million" case in 1997.

A number of distinct domains were purchased by an enterprise called One in a Million and similar agents. Trademark holders alleging passing off and trademark infringement brought a class action against the domain agency. The full case notes are online at: www.nominet.org.uk/ReferenceDocuments/CaseLaw/. It was rather a turning point in the history of domain sales in the UK, which crystallised the perils of infringing well-known corporate trademarks.

Cybersquatting

Sitting on "someone else's" domain name to deprive them of its use is known as "cybersquatting": in 2001 the Dixons retail chain managed to wrest *Dixons-online.co.uk* and others from an irate user who denied he was cybersquatting on the name but was protesting about what he alleged was poor customer service.

Recent history is alive with domain name disputes. A sheep-mad web site enthusiast registered **baa.com**, which incurred the wrath of the British Airports Authority (check the web to see who won). PC World (part of the Dixons Stores group in the UK, a major retail chain of electronics) went gunning for **pcworlddirect.co.uk** which had been registered by the unrelated PC World Direct. As described on the legal web site www.out-law.com, Dixons won the case, their case helped by the fact that the original registrants reportedly offered to sell it to PC World for a measly £300,000.

Typosquatting

Nor does it stop there: the practice known as "typosquatting" involves the registration of a domain name similar to a distinctive company name but with a minor misspelling, e.g. *micorsoft.com* or maybe *waltdinsey.com*. This practise may sometimes be a deliberate attempt to catch misspelled web browser traffic. Abusive or protest names may also be registered such as, possibly, *dioxin-online.co.uk* or *alanwsucks.com*. Corporations often buy such names for themselves as a defensive measure, to prevent them falling into the wrong hands.

The registration of some names, whether for profit or just to make a protest is a gamble that can result in legal action. So before buying a name, certainly for commercial use, it may be worth researching it carefully. Also, consider whether you have the financial muscle to take on the likes of Marks and Spencers, Sainsbury's, Dixons or whoever. You can search for trade marks online at www.patent.gov.uk/tm/dbase/ or employ a trade mark agent or attorney if your needs are more serious.

Pressure Selling

Next, I will highlight a number of methods that are used by sellers of domain names with a view to trying to separate "rightful" owners of a domain name from their money. Over a number of years I have monitored some unsavoury tricks cropping up repeatedly.

An unsuspecting company, let's call it Alantronics International Ltd., receives a unsolicited phone call from a domain "seller". The company is advised by the seller that someone else has "done a search for 'their' domain name let's say *alantronics.co.uk* to try and register it", but the seller has phoned Alantronics as a favour because they may have "more rights" to use it, so they're being given "first refusal".

Alantronics International Ltd is then offered the domain for an inflated sum. And of course, they "have to be quick because the domain name may be snapped up at any time". Thus the company is bounced into buying a domain name, often for an extended period of time at an inflated cost.

What has really happened is that the domain seller has trawled around looking to match available domain names with likely-looking companies. In some cases, a hyphenated domain is offered for sale, so the sales patter is along the lines of "someone tried to buy *alantronics-international.co.uk* but if you're quick, you can beat them to it."

It is blindingly obvious what is going on, but people still fall for it. As *Net Work* readers now know, it costs as little as £9.99 (or less) for two years to register a **.co.uk** domain for yourself.

The writer has personally been involved in a case where an engineering company was telephoned by such a domain seller, who tried to pressurise them into buying a domain name on the spot: it was claimed the domain name was available "as at 11.30 a.m. but may be sold at any minute." The sellers were given very short shrift after the company checked with the writer. In another true case, a client was offered "his" domain name for £600 for ten years.

Other scams, though less prevalent now, involved spying on online searches for domains. A disreputable domain seller's web site might have a "Search for Domains" box but all searches would be logged and followed up. The web company would then race to register the domain name for themselves, with a view to reselling it to a "rightful" owner after doing a bit of follow-up research.

Domain Slamming

Whilst there is only one Registrar in the UK for **.uk** domains (Nominet), the situation in American is different, with a myriad of Registry agencies competing for domain business. A practice known as "slamming" involves trying to bounce unsuspecting domain name owners into switching their domain name Registrars.

This may be done by sending a "Warning" letter to the domain owner, advising that they must renew immediately or risk losing a domain. The trouble is that it's a different Registrar writing to the owner. Tick the box, send some money, and the owner has been frightened into thinking he's renewed the domain; a rival Registrar has in fact slammed him into moving the domain over.

In the UK, owners of *dot-coms* or *dot-net* domains may have received letters purporting to be from "Domain Registry Services" or similar. The writer gleefully seized such a letter when it thudded onto his doormat. It has dire warnings stating that "the domain is due to expire. Please renew it immediately to ensure services continue uninterrupted – If you do not intend to renew it please notify us in writing ... or complete and return this section. £270 for ten years" and so on. The words are chosen extremely carefully. The small print on the reverse is 2/3rd of a page of a solid run-on incomprehensible legal babble that would challenge the finest legal mind.

This practice is not illegal in the UK because it does not infringe the Trade Descriptions Act nor the Consumer Protection Act. The writer's treatment of these letters involves using a rubber stamp specially developed for marking such correspondence with a phrase closely related to animal dung.

I'll continue with the theme of domains next month. You can email feedback, or your suggestions for topics, to alan@epemag.demon.co.uk.

PCB SERVICE

Printed circuit boards for most recent *EPE* constructional projects are available from the PCB Service, see list. These are fabricated in glass fibre, and are fully drilled and roller tinned. All prices include VAT and postage and packing. Add £1 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 408 Wimborne Road East, Ferndown, Dorset BH22 9ND. Tel: 01202 873872; Fax 01202 874562; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.wimborne.co.uk/shopdoor.htm.** Cheques should be crossed and made payable to *Everyday Practical Electronics* (Payment in £ sterling only).

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

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

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