THE No.1 MAGAZINE FOR ELECTRONICS TECHNOLOGY & COMPUTER PROJECTS

MARCH 2001

EVERYDAY PRACTICAL ELECTRONICS

INCORPORATING ELECTRONICS TODAY INTERNATIONAL £2.75

DIY LIGHTNING
Build a Telsa coil

BODY DETECTOR
Capacitance proximity alarm

DOORBELL EXTENDER
Through the mains signalling

Special Feature

INDUCTORS
A practical, understandable exposé

PLUS

Interface • Circuit Surgery
New Technology Update

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12v 18Ah SEALED LEAD ACID BATTERIES, new and boxed, unused pack of 4 £39.95 ref CYC7 or £15 each ref CYC6

AUTOMATIC CHARGER For the above batteries charges 2 at once charge level indicator circuitry, 6 hour charge £10 ref CYC8

A new range of 12v to 240v INVERTERS

IV400S (400 watt) £89

IV800S (800watt)£159

IV1200S (1200 watt) £219

ECG MACHINES?/6v 10AH BATTS/24V 8A TX Ex government ECG machines! Measures 390X320X120mm, on the front are controls for scan speed, scan delay, scan mode, loads of connections on the rear including video out etc. On the front panel are two DIN sockets for connecting the body sensors to. Sensors not included. Inside 2 x 6v 10AH lead acid batts (not in good condition), pcb's and a 8A? 24v torroidal transformer (mains in) sold as seen, may have one or two broken knobs etc due to poor storage £15 99 ref VP2

SODIUM LAMP SYSTEMS £75.70 Complete system with 250w or 400watt SON-T Agro bulb, reflector with bulb holder and remote ballast and starter(uncased) all you need is wire. 250W system ref SLS1, 400W system SLS2.

PC SUPPORT HANDBOOK The ultimate technical guide to building and maintaining PC's. Over 460 A4 pages packed with technical data and diagrams just £10 ref PCBK. If you want 4 copies for £33 ref PCBK2. Also available is a CD packed with diagnostic programmes to use with the book £5 ref PCBK1

D SIZE NICADS Tagged, 1200mA, 1.2v pack of 4 for £6 ref CYC9 or as a pack of 24 for £22 ref CYC10

D SIZE SEALED LEAD ACID BATTERIES 2v 2 5ah rechargeable sealed lead acid battery made by Cyclon 60x45mm (standard D size) supplied as a pack of 12 or 20 giving you options for battery configerations eg 12v at 5ah, 24v at 2 5ah, 6v at 10ah These batteries are particularly useful in that you can arrange them in your project to optimise space etc (eg boat ballast etc) Pack of 12 £10 ref CYC4, pack of 20 £16 ref CYC5

HYDROPONICS DO YOU GROW YOUR OWN? We have a full colour hydroponics catalogue available containing nutrients, pumps, fittings, enviromental control, light fittings, plants, test equipment etc Ring for your free copy.

PC COMBINED UPS AND PSU The unit has a total power of 292 watts, standard mother board connectors and 12 peripheral power leads for drives etc Inside is 3 12v 7 2aH sealed lead acid batteries Backup time is 8 mins at full load or 30 mins at half load Made in the UK by Magnum, 110 or 240vac input, +5v at 35A, -5vat 5A, +12v at 9A, -12v at 5A outputs 170x260x220mm, new and boxed £29 95 Ref PCUPS2

ALTERNATIVE ENERGY CD, PACKED WITH HUNDREDS OF ALTERNATIVE ENERGY RELATED ARTICLES, PLANS AND INFORMATION ETC £14.50 REF CD56

AERIAL PHOTOGRAPHY KIT This rocket comes with a built in camera! it flies up to 500 feet (150 m) turns over, and takes an aerial photograph of the ground below The rocket then returns with its film via its paracute Takes 110 film Supplied complete with everything including a launch pad and 3 motors (no film) £29 98 ref astro

PROJECT BOXES Another bargain for you are these smart ABS project boxes, smart two piece screw together case measuring approx 6"x5"x2" complete with panel mounted LED Inside you will find loads of free bits, tape heads, motors, chips resistors, transistors etc Pack of 20 £19 95 ref MD2

TELEPHONES Just in this week is a huge delivery of telephones, all brand new and boxed Two piece construction - illuminated keypad, tone or pulse (switchable), recall, redial and pause, high/low and off ringer switch and quality construction Off white colour and is supplied with a standard international lead (same as US or modems) if you wish to have a BT lead supplied to convert the phones these are £1 55 each ref BTLX **Phones £4.99 each ref PH2 10 off £30 ref SS2**

3HP MAINS MOTORS Single phase 240v, brand new, 2 pole 340x180mm, 2850 rpm, builtin automatice reset overload protector, keyed shaft (40x16mm)Made by Leeson £99 each ref LEE1

BUILD YOU OWN WINDFARM FROM SCRAP New publication gives step by step guide to building wind generators and propellors Armed with this publication and a good local scrap yard could make you self sufficient in electricity! £12 ref LOT81

CHIEFTAN TANK DOUBLE LASERS 9 WATT+3 WATT+LASER OPTICS Could be adapted for laser listener, long range comms etc Double beam units designed to fit in the barrel of a tank, each unit has 2 semi conductor lasers and motor drive units for alignment 7 mile range, no circuit diagrams due to MOD, new price £50,000? us? £199 Each unit has two gallium Arsenide injection lasers, 1 x 9 watt 1 x 3 watt 900nm wavelength, 28vdc, 600hz pulse freq The units also contain a receiver to detect reflected signals from targets £99 Ref LOT4

MAGNETIC CREDIT CARD READERS AND ENCODING MANUAL £9.95 Cased with flyleads, designed to read standard credit cards! complete with control electronics PCB and manual covering everything you could want to know about whats hidden in that magnetic strip on your card! just £9 95 ref BAR31

SOLAR POWER LAB SPECIAL 2x 6"x6" 6v 130mA cells 4 LED's, wire, buzzer switch + relay or motor **£7.99** REF SA27

SOLAR NICAD CHARGERS 4 x AA size £9 99 ref 6P476, 2 x C size £9 99 ref 6P477

BRAND NEW MILITARY ISSUE DOSE METERS Current NATO issue Standard emergency services unit Used by most of the worlds Military personel New and boxed Normal retail price £400, BULLS bargain price just £99The PDRM 82 M is a portable, lightweight, water resistant gamma radiation survey meter to measure radiological dose rate in the range 0 1to 300 centigrays per hour in air The Geiger Muller (G M) tube detecting unit is energy and polar response corrected The radiation level is displayed on a Liquid Crystal Display The microcomputer corrects for the non-linearity of the G M tube response The instrument is powered by three international C size batteries giving typically 400 hours operation in normal conditions. The dose rate meter PDRM 82M designed and selected for the United Kingdom Government, has been fully evaluated to satisfy a wide range of environmental conditions and is nuclear hard The construction enables the instrument to be easily decontaminated The instrument is designed for radiation surveys for post incident monitoring Used in a mobile role, either carried by troops or in military vehicles for rapid deployment enabling radiation hot spots to be quickly located Range 0 - 300 cGy/h in 0 1 cGy/h increments Over-range to 1500 cGy/h - indicates flashing 300 Accuracy f20% of true dose rate +0 1 cGy/h, 0 - 100 cGy/h f30% of true dose rate, 100 - 300 cGy/h. Energy Response 0 3 MeV to 3 MeV - within f20% (Ra 226) 80 KeV to 300 KeV - within 40% (Ra 226) Detector Energy compensated Halogen quenched Geiger Muller Tube Controls Combined battery access and ON/ OFF switch Batteries 3 International standard C cells Weight 560 grms Operating Temperature Range -30degC to +60 degC Indications High contrast 4 digit LCD Battery low indication Dose rate Rising/Falling £99 ref PDRM

Hydrogen fuel cellsOur new Hydrogen fuel cells are 1v at up tp 1A output, Hydrogen input, easily driven from a small electrolosis assembly or from a hydrogen source, our demo model uses a solar panel with the output leads in a glass of salt water to produce the hydrogen! Each cell is designed to be completely taken apart, put back together and expanded to what ever capacity you like, (up to 10 watts and 12v per assembly. Cells cost £49 ref HFC11

PHILIPS VP406 LASER DISC PLAYERS, SCART OUTPUT, JUST PUT YOUR VIDEO DISK IN AND PRESS PLAY, STANDARD AUDIO AND VIDEO OUTPUTS,. £14.95 REF VP406

SMOKE ALARMS Mains powered, made by the famous Gent company, easy fit next to light fittings ,power point Pack of 5 £15 ref SS23, pack of 12 £24 ref SS24

4AH D SIZE NICADS pack of 4 £10 ref 4AHPK

SENDER KIT Contains all components to build a A/V transmitter complete with case £35 ref VSXX2

10 WATT SOLAR PANEL Amorphous silicon panel fitted in a anodized aluminium frame Panel measures 3' by 1' with screw terminals for easy connection **3' x 1' solar panel £55 ref MAG45**

12V SOLAR POWERED WATER PUMP Perfect for many 12v DC uses, from solar fountains to hydroponics! Small and compact yet powerful works direct from our 10 watt solar panel in bright sun Max hd i7 ft Max flow = 8 Lpm 1 5A Ref AC8 £18 99

SOLAR ENERGY BANK KIT 50x 6"x12" 6v solar panels(amorphous)+50 diodes £99 ref EF112

PINHOLE CAMERA MODULE WITH AUDIO! Superb board camera with on board sound! extra small just 28mm square (including microphone) ideal for covert surveillance Can be hidden inside anything , even a matchbox! Complete with 15 metre cable, psu and tv/vcr connnectors £49 95 ref CC6J

SOLAR MOTORS Tiny motors which run quite happily on voltages from3-12vdc Works on our 6v amorphous 6" panels and you can run them from the sun! 32mm dia 20mm thick £1 50 each

WALKIE TALKIES 1 MILE RANGE £37/PAIR REF MAG30

LIQUID CRYSTAL DISPLAY Bargain prices, 40 character 1 line 154x16mm £6.00 ref SMC4011A

YOUR HOME COULD BE SELF SUFFICENT IN ELECTRICITY Comprehensive plans with loads of info on designing systems, panels, control electronics etc £7 ref PV1

AUTO SUNCHARGER 155x300mm solar panel with diode and 3 metre lead and cigar plug 12v 2w **£12.99** REF AUG10P3

SOLAR POWER LAB SPECIAL 2x 6"x6" 6v 130mA cells, 4 LED's, wire, buzzer switch + relay or motor **£7.99** REF SA27

SOLAR NICAD CHARGERS 4 x AA size £9 99 ref 6P476 2 x C size £9 99 ref 6P477

MINATURE TOGGLE SWITCHES These top quality Japanese panel mount toggle switches measure 35x13x12mm, are 2 pole changeover and will switch 1A at 250vac, or 3 A at 125vac Complete with mounting washers and nuts Supplied as a box of 100 switches for £29 95 ref SWT35 or a bag of 15 for £4 99 ref SWT34

VOICE CHANGERS Hold one of these units over your phone mouth piece an you can adjust your voice using the controls on the unit! Battery operated £15 ref CC3

BULL ELECTRICAL

250 PORTLAND ROAD, HOVE, SUSSEX . BN3 5QT. (ESTABLISHED 50 YEARS).

MAIL ORDER TERMS: CASH, PO OR CHEQUE WITH ORDER PLUS £4.00 P&P PLUS VAT.

24 HOUR SERVICE £6.50 PLUS VAT.

OVERSEAS ORDERS AT COST PLUS £3.50

(ACCESS, VISA, SWITCH, AMERICAN EXPRESS)

'phone orders : 01273 203500

FAX 01273 323077

Sales@bull-electrical.com

30 WATTS OF SOLAR POWER for just £69, 4 panels each one 3'x1' and producing 8w, 13v. PACK OF FOUR £69 ref SOLX

200 WATT INVERTERS plugs straight into your car cigarette lighter socket and is fitted with a 13A socket so you can run your mains operated devices from your car battery £49 95 ref SS66

THE TRUTH MACHINE Tells if someone is lying by micro tremors in their voice, battery operated, works in general conversation and on the 'phone and TV as well! £42 49 ref TD3

INFRA RED FILM 6" square piece of flexible infra red film that will only allow IR light through Perfect for converting ordinary torches, lights, headlights etc to infra red output only using standard light bulbs Easily cut to shape 6" square £15 ref IRF2

33 KILO LIFT MAGNET Neodynium 32mm diameter with a fixing bolt on the back for easy mounting Each magnet will lift 33 kilos, 4 magnets bolted to a plate will lift an incredible 132 kilos! £15 ref MAG33 Pack of 4 just £39 reg MAG33AA

HYDROGEN FUEL CELL PLANS Loads of information on hydrogen storage and production Practical plans to build a Hydrogen fuel cell (good workshop facilities required) £8 set ref FCP1

STIRLING ENGINE PLANS Interesting information pack covering all aspects of Stirling engines, pictures of home made engines made from an aerosol can running on a candle! £12 ref STIR2

ENERGY SAVER PLUGS Saves up to 15% electricity when used with fridges,motors up to 2A,light bulbs,soldering irons etc £9 ea ref LOT71, 10 pack £69 ref LOT72

12V OPERATED SMOKE BOMBS Type 3 is a 12v trigger and 3 smoke cannisters each cannister will fill a room in a very short space of time! £14 99 ref SB3 Type 2 is 20 smaller cannisters (suitable for mock equipment fires etc) and 1 trigger module for £29 ref SB2 Type 1 is a 12v trigger and 20 large cannisters £49 ref SB1

HI POWER ZENON VARIABLE STROBES Useful 12v PCB fitted with hi power strobe tube and control electronics and speed control potentiometer. Perfect for interesting projects etc 70x55mm 12vdc operation £6 ea ref FLS1, pack of 10 £49 ref FLS2

NEW LASER POINTERS 4 5mw, 75 metre range hand held unit runs on two AA batteries (supplied) 670nm £29 ref DEC49J

HOW TO PRODUCE 35 BOTTLES OF WHISKY FROM A SACK OF POTATOES Comprehensive 270 page book covers all aspects of spirit production from everyday materials, Includes construction details of simple stills £12 ref MS3

NEW HIGH POWER MINI BUG With a range of up to 800 metres and a 3 days use from a PP3 this is our top selling bug! less than 1" square and a 10m voice pickup range £28 Ref LOT102

IR LAMP KIT Suitable for cctv cameras, enables the camera to be used in total darkness! £6 rel EF138

INFRA RED POWERBEAM Handheld battery powered lamp, 4 inch reflector, gives out powerful pure infrared light! perfect for CCTV use, nightsights etc £29 ref PB1

SUPER WIDEBAND RADAR DETECTOR Detects both radar and laser X K and KA bands speed cameras and all known speed detection systems 360 degree coverage, front&r earwaveguides, 1 1"x2 7"x4 6" fits on visor or dash £149

LOPTX Made by Samsung for colour TV £3 each ref SS52

LAPTOP LCD SCREENS 240x175mm, £12 ref SS51

WANT TO MAKE SOME MONEY? STUCK FOR AN IDEA? We have collated 140 business manuals that give you information on setting up different businesses, you peruse these at your leisure using the text editor on your PC Also included is the certificate enabling you to reproduce (and sell) the manuals as much as you like! £14 ref EP74

ELECTRONIC SPEED CONTROLLER KIT For the above motor is £19 ref MAG17 Save £5 if you buy them both together, 1 motor plus speed controller rrp is £41, offer price £36 ref MOT5A

INFRA RED REMOTE CONTROLS made for TV's but may have other uses pack of 100 £39 ref IREM

RCB UNITS Inline IEC lead with fitted RC breaker. Installed in seconds. Pack of 3 £9.98 ref LOT5A

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YOUR HOME COULD BE SELF SUFFICENT IN ELECTRICITY Comprehensive plans with loads of info on designing systems, panels, control electronics etc £7 ref PV1

AUTO SUNCHARGER 155x300mm solar panel with diode and 3 metre lead and cigar plug 12v 2w **£12.99** REF AUG10P3

STEPPER MOTORS Brand new stepper motors, 4mm fixing holes with 47 14mm fixing centres, 20mm shaft, 6 35mm diameter, 5v/phase 0 7A/phase, 1 8 deg step (200 step) Body 56x36mm £14.99 ea ref STEP6, pack of 4 for £49 95 PIC based variable speedcontroller kit £15 ref STEP7

ISSN 0262 3617
PROJECTS ... THEORY ... NEWS ...
COMMENTS ... POPULAR FEATURES ...

VOL. 30. No. 3 MARCH 2001
Cover illustration by Jonathan Robertson

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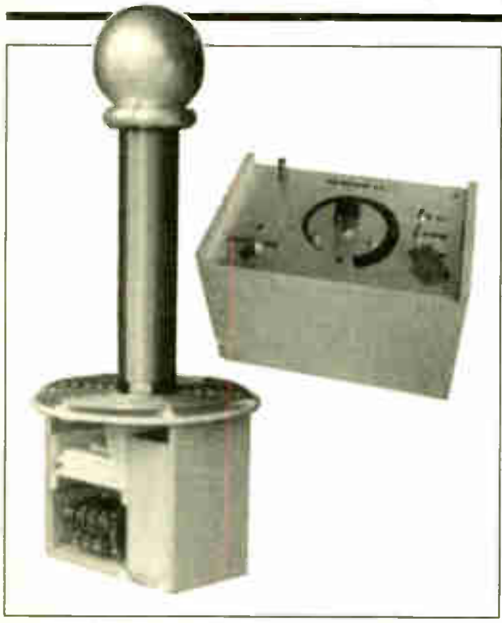

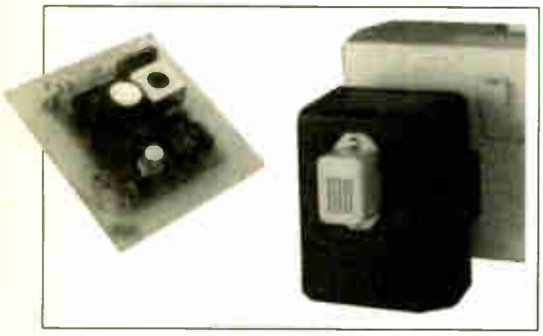

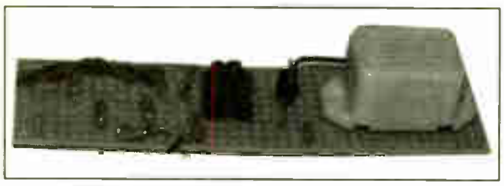

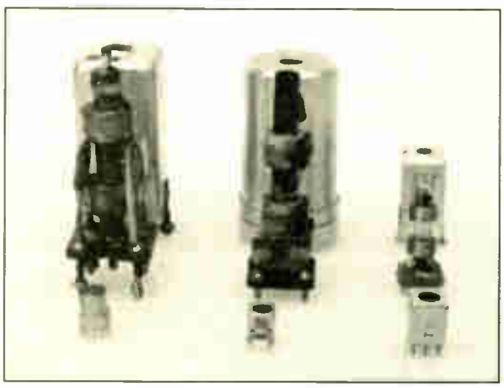

Projects and Circuits

Series and Features

Regulars and Services

Our April 2001 issue will be published on Thursday, 8 March 2001. See page 155 for details

NEXT MONTH

SPECIAL SUPPLEMENT

THE END TO ALL DISEASE

Can disease be cured electronically? A story involving electronics, blackmail, intimidation, government conspiracies, arson, vandalism, theft, bribery and murder! Our Special Supplement looks mainly at the work of R. R. Rife in the '30s and '40s and investigates how diseased cells can be destroyed with magnetic pulses. Did Rife's work surpass the achievements of modern therapies in curing major diseases? Judge for yourself.

SNUG BUG

Keeping tropical pets is a rewarding and popular hobby.. In order that the pets thrive, the temperature of the environment must be maintained to within a few degrees and pet stores supply heating pads and thermostatic controllers for this purpose. If more than one habitat is involved then a separate controller/pad system should be used for each, especially if the habitats are located any distance apart or are in different rooms of the house.

This article describes a four-channel thermostatic controller intended for use with up to four (dry) heat pads. The temperature range in the design is from about 25° to 40° Celsius, though each pad may be individually calibrated to the user's requirements.

WAVE SOUND EFFECT

In a world that seems to be ever noisier, using more noise to improve matters might seem like a strategy that is doomed to failure. However, it is a characteristic of human hearing that one sound tends to mask other sounds, and this can be used to good effect in counteracting otherwise obtrusive sounds.

The wave effects unit is a simple battery powered device that can be used with headphones or used to feed a spare input of a hi-fi system. It does not provide results that are as convincing as units utilising digital recording techniques or sophisticated synthesiser circuits, but it is quite good for a device that uses just a handful of inexpensive components. It is simple to build and is well suited to beginners.

INTRUDER ALARM CONTROL PANEL

This system has been designed to meet British Standards installation specification BS4737 and is based on the Motorola EP520M security microcontroller.

The EP520M is a robust device having its origins at the heart of an automobile engine management system – a hostile environment for any microcontroller to work in. Now masked as an alarm controller, the device operates in high electrical noise and RFI environments, displaying a high degree of immunity to such hazards. The device is used in control panels throughout the UK and Europe, and is reputed to be completely reliable and free from false alarming.

The alarm system's extensive features include four detection zones, with one programmable as an Entry-Exit Delay zone, plus a 24-hour monitor for anti-tamper devices and Panic Attack (PA) use. Normally-closed (NC) and normally-open (NO) detectors can be used on all zones.

Despite the sophistication of the system, the alarm is extremely simple to construct and operate. The EP520M requires only the addition of a simple keypad and a minimum of readily available components.

PLUS ALL THE REGULAR FEATURES

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DON'T MISS AN ISSUE – PLACE YOUR ORDER NOW!

Demand is bound to be high

APRIL 2001 ISSUE ON SALE THURSDAY, MARCH 8

£1 BARGAIN PACKS
Selected Items

CROCODILE CLIPS. Small size, 10 each red and black. Order Ref: 116.

PLASTIC HEADED CABLE CLIPS. Nail in type, several sizes. Pack of 50. Order Ref: 123.

30A PANEL MOUNTING TOGGLE SWITCH. Double pole. Order Ref: 166.

SUB MIN TOGGLE SWITCHES. Pack of 3. Order Ref: 214.

HIGH POWER 3in. SPEAKER (11W 8ohm). Order Ref: 246.

MEDIUM WAVE PERMEABILITY TUNER. It's almost a complete radio with circuit. Order Ref: 247.

HEATING ELEMENT. Mains voltage 100W, brass encased. Order Ref: 8.

MAINS MOTOR with gearbox giving 1 rev per 24 hours. Order Ref: 89.

ROUND POINTER KNOBS for flatted ¼in. spindles. Pack of 10. Order Ref: 295.

CERAMIC WAVE CHANGE SWITCH. 12-pole, 3-way with ¼in. spindle. Order Ref: 303.

REVERSING SWITCH. 20A double pole or 40A single pole. Order Ref: 343.

LUMINOUS PUSH-ON PUSH-OFF SWITCHES. Pack of 3. Order Ref: 373.

SLIDE SWITCHES. Single pole changeover. Pack of 10. Order Ref: 1053.

PAXOLIN PANEL. Approximately 12in. x 12in. Order Ref: 1033.

CLOCKWORK MOTOR. Suitable for up to 6 hours. Order Ref: 1038.

TRANSISTOR DRIVER TRANSFORMER. Maker's ref. no. LT44, impedance ratio 20k ohm to 1k ohm, centre tapped, 50p. Order Ref: 1/23R4.

HIGH CURRENT RELAY. 12V D.C. or 24V A.C., operates changeover contacts. Order Ref: 1026.

2-CORE CURLY LEAD. 5A, 2m. Order Ref: 846.

3 CHANGEOVER RELAY. 6V A.C., 3V D.C. Order Ref: 859.

3 CONTACT MICRO SWITCHES, operated with slightest touch. Pack of 2. Order Ref: 861.

HIVAC NUMICATOR TUBE. Hivac ref XN3. Order Ref: 865.

2IN. ROUND LOUDSPEAKERS. 50Ω coil. Pack of 2. Order Ref: 908.

5K POT, standard size with DP switch, good length ¼in. spindle, pack of 2. Order Ref: 11R24.

13A PLUG, fully legal with insulated legs, pack of 3. Order Ref: GR19.

OPTO SWITCH on p.c.b., size 2in. x 1in., pack of 2. Order Ref: GR21.

1000W FIRE SPIRALS. In addition to repairing fires, these are useful for making high current resistors. Price 4 for £1. Order Ref: 223.

BRASS ENCASED ELEMENT. Mains working, 80W standard replacement in some fridges but very useful for other heating purposes. Price £1 each. Order Ref: 8.

PEA LAMPS, only 4mm but 14V at 0·04A, wire ended, pack of 4. Order Ref: 7RC28.

HIGH AMP THYRISTOR, normal 2 contacts from top, heavy threaded fixing underneath, think amperage to be at least 25A, pack of 2. Order Ref: 7FC43.

BRIDGE RECTIFIER, ideal for 12V to 24V charger at 5A, pack of 2. Order Ref: 1070.

TEST PRODS FOR MULTIMETER with 4mm sockets. Good length very flexible lead. Order Ref: D86.

LUMINOUS ROCKER SWITCH, approximately 30mm square, pack of 2. Order Ref: D64.

MES LAMP HOLDERS, slide onto ¼in. tag pack of 10. Order Ref: 1054.

HALL EFFECT DEVICES, mounted on small heatsink, pack of 2. Order Ref: 1022.

12V POLARISED RELAY, 2 changeover contacts. Order Ref: 1032.

PROJECT CASE, 95mm x 66mm x 23mm with removable lid held by 4 screws, pack of 2. Order Ref: 876.

LARGE MICRO SWITCHES, 20mm x 6mm x 10mm, changeover contacts, pack of 2. Order Ref: 826.

PIEZO ELECTRIC SOUNDER, also operates efficiently as a microphone. Approximately 30mm diameter, easily mountable, 2 for £1. Order Ref: 1084.

LIQUID CRYSTAL DISPLAY on p.c.b. with ICs etc. to drive it to give 2 rows of 8 characters, price £1. Order Ref: 1085.

THIS MONTH'S SPECIAL

IT IS A DIGITAL MULTITESTER, complete with backrest to stand it and hands-free test prod holder. This tester measures d.c. volts up to 1,000 and a.c. volts up to 750; d.c. current up to 10A and resistance up to 2 megs. Also tests transistors and diodes and has an internal buzzer for continuity tests. Comes complete with test prods, battery and instructions. Price £6.99. Order Ref: 7P29.

1mA PANEL METER. Approximately 80mm x 55mm, front engraved 0-100. Price £1.50 each. Order Ref: 1/16R2.

VERY THIN DRILLS. 12 assorted sizes vary between 0·6mm and 1·6mm. Price £1. Order Ref: 128.

EVEN THINNER DRILLS. 12 that vary between 0·1mm and 0·5mm. Price £1. Order Ref:129.

BT PLUG WITH TWIN SOCKET. Enables you to plug 2 telephones into the one socket for all normal BT plugs. Price £1.50. Order Ref: 1.5P50.

D.C. MOTOR WITH GEARBOX. Size 60mm long, 30mm diameter. Very powerful, operates off any voltage between 6V and 24V D.C. Speed at 6V is 200 rpm, speed controller available. Special price £3 each. Order Ref: 3P108.

FLASHING BEACON. Ideal for putting on a van, a tractor or any vehicle that should always be seen. Uses a Xenon tube and has an amber coloured dome. Separate fixing base is included so unit can be put away if desirable. Price £5. Order Ref: 5P267.

MOST USEFUL POWER SUPPLY. Rated at 9V 1A, this plugs into a 13A socket, is really nicely boxed. £2. Order Ref: 2P733.

MOTOR SPEED CONTROLLER. These are suitable for D.C. motors for voltages up to 12V and any power up to 1/6h.p. They reduce the speed by intermittent full voltage pulses so there should be no loss of power. In kit form these are £12. Order Ref: 12P34. Or made up and tested, £20. Order Ref: 20P39.

BT TELEPHONE EXTENSION WIRE. This is proper heavy duty cable for running around the skirting board when you want to make a permanent extension. 4 cores properly colour coded, 25m length. Only £1. Order Ref:1067.

LARGE TYPE MICROSWITCH with 2in. lever, changeover contacts rated at 15A at 250V, 2 for £1. Order Ref: 1/2R7.

BALANCE ASSEMBLY KITS. Japanese made, when assembled ideal for chemical experiments, complete with tweezers and 6 weights 0·5 to 5 grams. Price £2. Order Ref: 2P44

CYCLE LAMP BARGAIN. You can have 100 6V 0·5A MES bulbs for just £2.50 or 1,000 for £20. They are beautifully made, slightly larger than the standard 6·3V pilot bulb so they would be ideal for making displays for night lights and similar applications.

DOORBELL PSU. This has AC voltage output so is ideal for operating most doorbells. The unit is totally enclosed so perfectly safe and it plugs into a 13A socket. Price only £1. Order Ref: 1/30R1.

INSULATION TESTER WITH MULTIMETER. Internally generates voltages which enable you to read insulation directly in megohms. The multimeter has four ranges, AC/DC volts, 3 ranges DC milliamps, 3 ranges resistance and 5 amp range. These instruments are ex-British Telecom but in very good condition, tested and guaranteed OK, probably cost at least £50 each, yours for only £7.50 with leads, carrying case £2 extra. Order Ref: 7.5P4.

REPAIRABLE METERS. We have some of the above testers but slightly faulty, not working on all ranges, should be repairable, we supply diagram, £3. Order Ref: 3P176.

TWO MORE POST OFFICE INSTRUMENTS

Both instruments contain lots of useful parts, including sub-min toggle switch sold by many at £1 each. They are both in extremely nice cases, with battery compartment and flexible carrying handles, so if you don't need the intruments themselves, the case may be just right for a project you have in mind.

The first is **Oscillator 87F**. This has an output, continuous or interrupted, of 1kHz. It is in a plastic box size 115mm wide, 145mm high and 50mm deep. Price only £1. Order Ref: 7R1.

The other is **Amplifier Ref. No. 109G**. This is in a case size 80mm wide, 130mm high and 35mm deep. Price £1. Order Ref: 7R2.

HEAVY DUTY POT

Rated at 25W, this is 20 ohm resistance so it could be just right for speed controlling a d.c. motor or device or to control the output of a high current amplifier. Price £1. Order Ref: 1/33L1.

STEPPER MOTOR

Made by Philips as specified for the wind-up torch in the Oct '00 Practical Electronics is still available, price £2. Order Ref: 2P457.

SOLDERING IRON, super mains powered with long-life ceramic element, heavy duty 40W for the extra special job, complete with plated wire stand and 245mm lead, £3. Order Ref: 3P221.

RELAYS

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240V AC	1-pole changeover	£1.50	FR14
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Prices include base

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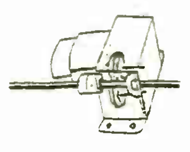

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EVERYDAY PRACTICAL ELECTRONICS

INCORPORATING ELECTRONICS TODAY INTERNATIONAL

THE No.1 MAGAZINE FOR ELECTRONICS TECHNOLOGY & COMPUTER PROJECTS

VOL. 30 No. 3 MARCH 2001

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READOUT

Not so many years ago we struggled to fill a page of *Readout* every month, that has changed dramatically since PICs came along, with many readers querying various methods/software etc. So many PIC-based letters come in that they tend to swamp *Readout* with this one subject – something that we are aware of, but since *Readout* reflects the needs and views of readers it's not something we feel we should take steps to change. Whilst PIC subjects tend to dominate our letters they still only represent a relatively small proportion of published projects, and projects which are not microcontroller based are very popular. I guess the *Readout* response is due to the learning curve many readers are undergoing on microcontroller design and programming.

INGENUITY UNLIMITED

Sadly, presently going in the opposite direction to *Readout* is our *Ingenuity Unlimited* feature. *IU* has been part of *EPE* on and off for over 30 years now. However, just recently we have suffered from a lack of useable material, so this month you will not find *IU*s featured. I wonder if the PIC effect seen in *Readout* is also responsible for the lack of good and ingenious circuit ideas for *IU*?

We have had a few more submissions recently so *IU* should be back next month, but the feature does rely on your input, so if you have any circuit ideas you think we could use please send them in. There is cash waiting for each one we publish, plus the possibility of a Pico PC-based Oscilloscope prize for the best ones published every six months.

Mike Kenward

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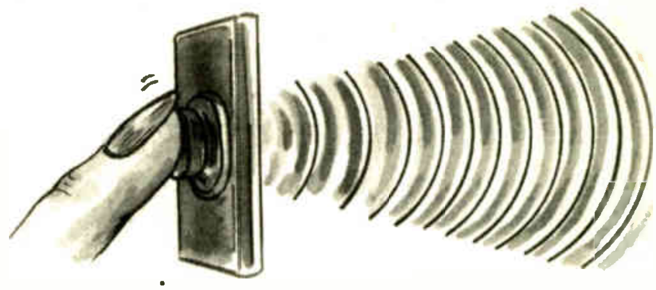
DOORBELL EXTENDER



DAVID PONTING

A "through-the-mains" system that will enable you to hear your doorbell in the garage or workshop. Can be adapted to control remote appliances or as a "help-line" call button.

AFTER months of looking, our Estate Agent said that she had at last found the perfect new home for us. There was a small out-building which would make a great workshop and there was a garage as well. Fortunately we both liked the house, so a few months ago the property became ours.

Now the "shack" is pretty well set up, it is time to think about communications. The wireless telephone means that no calls are missed when at the workbench but the shack is too far away to hear the front doorbell ring. Consequently, having twice missed the arrival of parcels, and had to wait at least another 24 hours before delivery, there was an urgent need for a Doorbell Extender.

IN CONSIDERATION

Obviously there was the relatively simple solution of using an in-house microphone and preamplifier connected by pairs of wires to amplifiers and speakers in the workshop and garage. However, overhead cables would look awful and burying them was well nigh impossible because of the paved back patio. And then there is the cost, of course!

Recently a number of advertisements in an increasing pile of junk mail catalogues did catch the eye: such as one which said, "Hear your doorbell from the bottom of the garden!" But lost interest almost immediately because they all required that you *replace* both your front door bellpush and the internal bell by two special wireless units.

While a third, battery-driven and portable, allowed the doorbell to be heard from wherever you were – provided you had remembered to put it in your pocket. Also, as the "new" Victorian house already sports a really beautiful brass period bellpush the author was not about to replace it with some plastic nasty.

So why not use mains wiring to extend the doorbell? A number of companies sell "wireless" voice communicators and the author was able to borrow a couple to try out. They actually worked pretty well except that not only could you hear the doorbell ring, but also *Radio 4*, the hoover and the howls of a hungry cat!

Even when the house was otherwise empty, the wireless voice communicator not only produced irritating clicks every time neighbours switched anything on or off but also buzzed angrily and irritatingly all the time. That system was not going to allow any peace and quiet when all that was wanted was to be able to hear the doorbell ring. Was this too much to ask?

Even after looking through some books for possible circuits, which nearly always provided some inspiration, it was a "no-go". All the ones found seemed to use obscure and unobtainable inductors and/or were, in the author's view, unacceptably dangerous.

Many needed to derive their d.c. operating voltages by dropping the 230V mains across a large value, 630V capacitor. This will surely serve but circuits like these are dangerous to work on, and they remain so even when switched *off* and *disconnected* from the mains unless the capacitor is shorted by a discharging resistor.

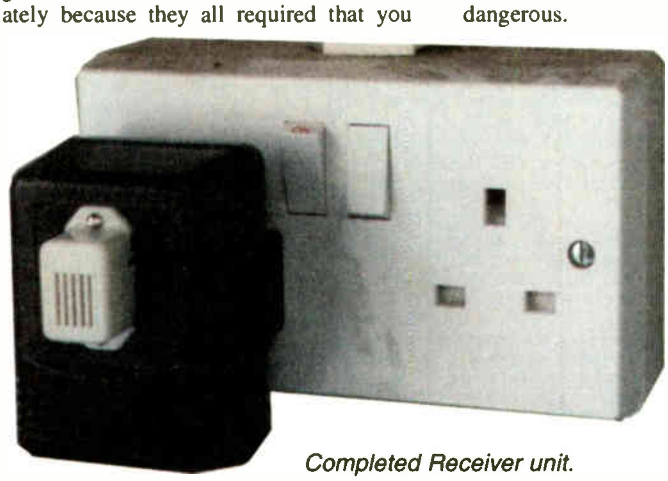
Other ideas seemed safer because they included the use of small mains transformers to produce the necessary working d.c. voltage, but they still coupled high frequency signals into the *Live* line of the mains supply. This type of circuit is probably fine if it works first time but any fault-finding is fraught with danger and the use of an oscilloscope is almost certainly ruled out.

NEUTRAL APPROACH

So it was decided to start from scratch and it was quickly discovered that the solution was surprisingly easy. If using Neutral and *Live* was potentially dangerous, what was wrong with Neutral and Earth as the connecting wires?

Well in theory the simple answer is that this will not work. Since Neutral and Earth are always connected together (at the power station and sometimes also closer to home), any signal being carried on one wire will be shorted to the other.

That's *in theory*. In practice, by the time mains power lines have reached one's house, there is always a small potential difference between Neutral and Earth and this separation is perfectly adequate for our purposes.



Completed Receiver unit.

WARNING

This project should only be undertaken by readers who are competent and familiar with mains operated circuits.
Since these units contain MAINS voltages, great care must be taken in their construction and testing. If in any doubt you should consult a qualified electrician. Mains voltages can be lethal.
Users must ensure that the Neutral and Live connections of the domestic mains supply are not swapped over.

This method largely avoids working with line voltages although proper respect and care ***must always*** be exercised since Live is connected to the transformer primary in the Receiving units; but that is all. Apart from this, the detection of the presence or absence of a signal is much easier and safer using Neutral and Earth, and, of course, oscilloscopes can be used for setting up and fault finding.

TRANSMITTER CIRCUIT

The circuit diagram for the Doorbell Extender Transmitter is shown in Fig.1. The Transmitter could hardly be simpler.

If your house has the usual set up, the components inside the dotted rectangle on the circuit diagram are almost certainly part of your system already. The transformer will be a standard bell-type, in its own case, with its primary winding permanently connected to the mains. The in-house bell is usually a.c. and sounds when the doorbell pushswitch S1 closes the secondary circuit.

Operating voltage is usually about 12V which is perfect for powering the additional Transmitter circuit shown in Fig.1. In fact, any a.c. voltage from 6V to 15V is fine and even if, exceptionally, your bell operates on batteries, voltages up to 24V can be used without modification, except for the omission of bridge rectifier REC1.

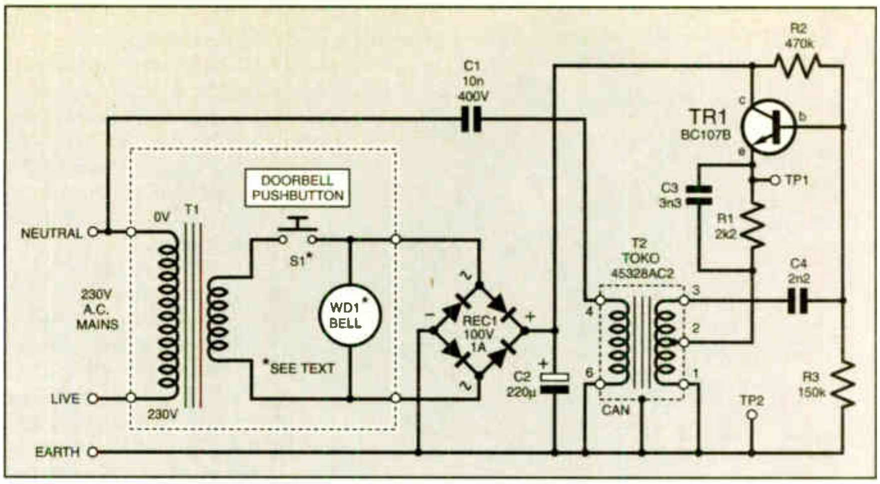


Fig.1. Full circuit diagram for the Doorbell Extender Transmitter. Components within the "dashed" rectangle are existing doorbell parts.

COMPONENTS

TRANSMITTER

Resistors

R1	2k2
R2	470k
R3	150k

All 0·25W 5% carbon film

See SHOP TALK page

Capacitors

C1	10n metallised poly film, 400V minimum
C2	220µ radial elect. 25V
C3	3n3 polyester
C4	2n2 polyester

Semiconductors

TR1	BC107B *npn* transistor or similar
REC1	100V 1A 4-pin d.i.l. bridge rectifier

Miscellaneous

T2	TOKO RHCS-45328AC2 i.f. transformer, or equivalent (475kHz)

Printed circuit board available from the *EPE PCB Service*, code 292; interconnecting cable, between p.c.b. and bell-transformer; solder etc.

Bell pushswitch (S1), bell-transformer (T1) and doorbell (WD1) part of existing system.

TRANSMITTER EXTENSION (Fig.5)

T1	miniature 230V mains transformer, 9V dual secondaries, 1·5VA
S2	pushswitch, press-to-make

Printed circuit board available from the *EPE PCB Service*, code 294.

Approx. Cost Guidance Only **£7**
excl. S1, T1, WD1 and Ext. parts

So assuming that your set-up is similar to the one described above, the Transmitter printed circuit board needs just four connections to your existing system. Besides the two for the low voltage a.c. supply, which is rectified by the diode bridge and smoothed by electrolytic capacitor C2, there is one from Earth and another from Neutral.

The i.f. (intermediate frequency) transformer (T2) with transistor TR1, resistors R1, R2, R3, and the two capacitors, C3 and C4 together form an oscillator. This signal is coupled into the Neutral line via capacitor C1 which provides little impedance to high frequency signals but largely prevents the 50Hz mains frequency from appearing across the output winding of the i.f. transformer. The capacitor *must* be rated at 400V minimum.

Now, when the doorbell pushbutton is pressed, the internal bell, WD1, will sound as normal, capacitor C2 will quickly charge, the oscillator will function and a high frequency signal will be injected into the Neutral line. All that remains is the remote detection of that signal.

RECEIVER CIRCUIT

The circuit diagram for the "remote" Doorbell Extender Receiver is shown in Fig.2. The Receiver is only marginally more complicated than the Transmitter.

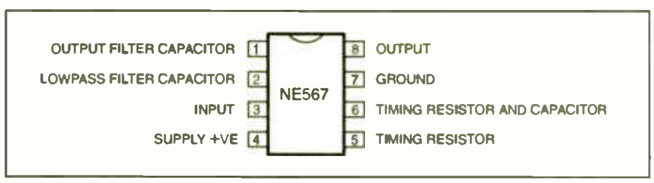
Live and Neutral supply the primary of a miniature 1·5VA mains transformer (T1) which has parallel-wired, 9V dual secondaries. The resulting low voltage a.c. output is rectified by the bridge rectifier, REC1, smoothed by capacitor C2 and reduced to a stable and ripple-free 5V d.c. by voltage regulator IC1, C3 and C6.

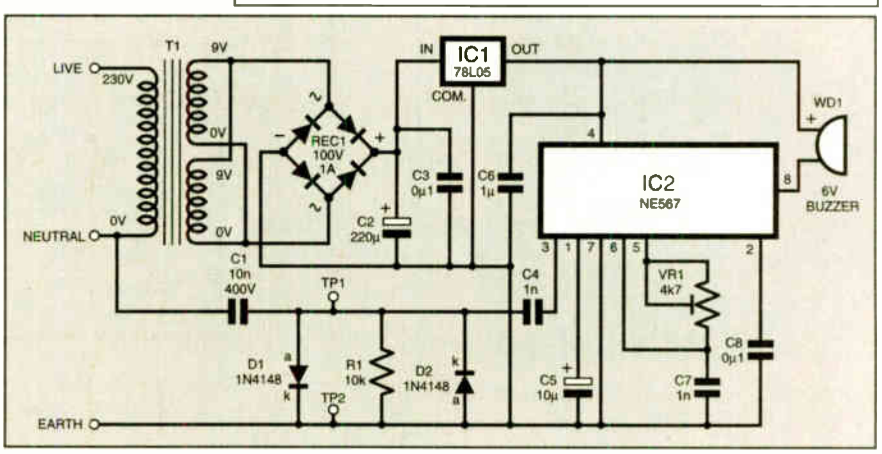
Any high frequency signal arriving on the Neutral line from the Transmitter is coupled to the rest of the receiver circuit by capacitor C1 which together with resistor R1 also forms something of a high-pass filter. Diodes D1 and D2 limit the size of the signal and capacitor C4 couples the resultant signal into the tone decoder, IC2.

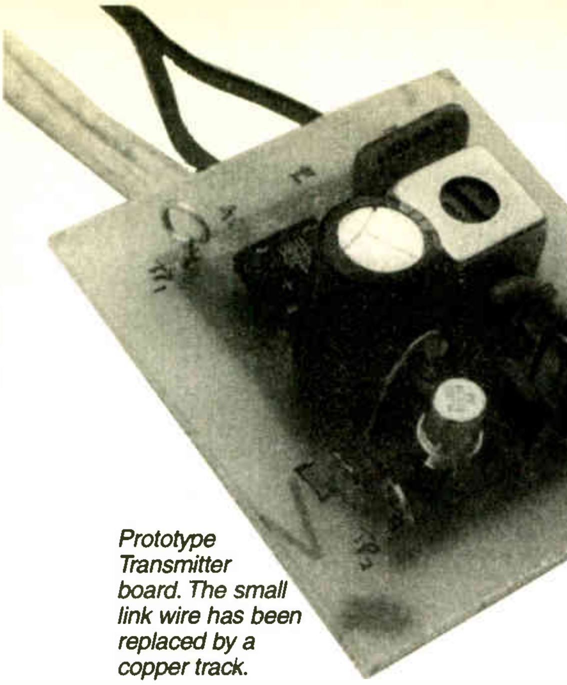
Adjustment of preset VR1 together with capacitor C7 allows the tuning of IC2 to the exact frequency being transmitted. Capacitor C5 provides added filtering and C8 determines the bandwidth within which the wanted signal is detected.

When this occurs, the internal open collector at pin 8 of IC2 is switched to Earth and the buzzer WD1 sounds. In fact, with the component values shown in the diagrams of the Transmitter and Receiver, the buzzer will continue to sound for about four seconds after the bell pushbutton is released! Consequently, no matter how briefly the door pushbutton is pressed it will be difficult to miss the four seconds of the buzzer sounding.

Fig.2. Circuit diagram for the basic Receiver, together with pinout details for IC2.







Prototype Transmitter board. The small link wire has been replaced by a copper track.

CONSTRUCTION – TRANSMITTER

There are few problems in the construction of either unit. Although safety has been the main priority in this project, **it must not be overlooked that both the Transmitter and Receiver need links to the mains supply and all the usual precautions MUST be taken in making up and testing these circuits.**

The Transmitter circuit is built on a small printed circuit board (p.c.b.). The topside component layout and full-size underside copper foil master pattern are shown in Fig.3. This board is available from the *EPE PCB Service*, code 292.

Construction should commence by soldering in position the smaller components working up to the largest. The exceptions being the transistor and i.f. transformer, which should be left until last; do not expose them to any prolonged and unnecessary heat from the soldering iron.

The two "test points" are simply pieces of link wire (off-cuts from surplus resistor leads) twisted into a loop and soldered into the p.c.b. These are clearly seen in the photograph of the prototype board. (The small link wire has been replaced with copper track on the final version.)

You will need to take extra care that you insert the transistor, 4-pin d.i.l. bridge rectifier and i.f. transformer the correct way round on the p.c.b. before soldering in position. The same applies to the polarity of the radial electrolytic capacitor C2.

Important: ***Note that capacitor C1 must have a* minimum *working voltage rating of 400V.***

Perhaps the best way to get the Neutral and Earth connections for the Transmitter are via a standard mains socket, *but wiring the plug with connections to N and E only.*

It is probably best if you use the p.c.b. presented in this article but this does not represent any special layout and any variations you want to incorporate to meet your own requirements should be readily tolerated. In the set-up shown in Fig.3, the completed p.c.b. is so small that it was able to fit it inside the "Avon calling" type of bell housing already installed in the house system.

Many *npn* transistor types may be used in place of the BC107B designated in the circuit diagram. However, do check that the one you want to use has adequate gain (h_{fe} of about 200 or greater) and adequate collector/emitter voltage (say 40 volts).

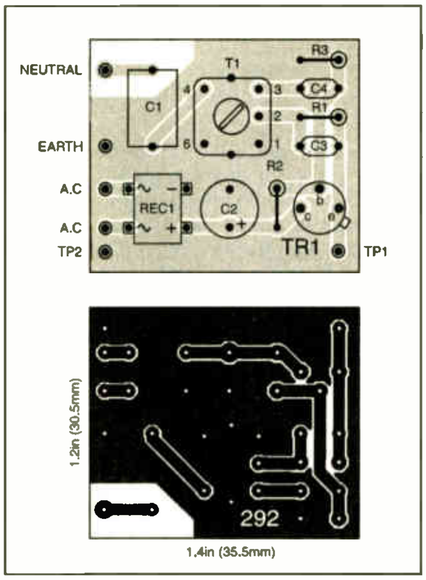


Fig.3. Transmitter p.c.b. component layout and full-size foil master.

RECEIVER

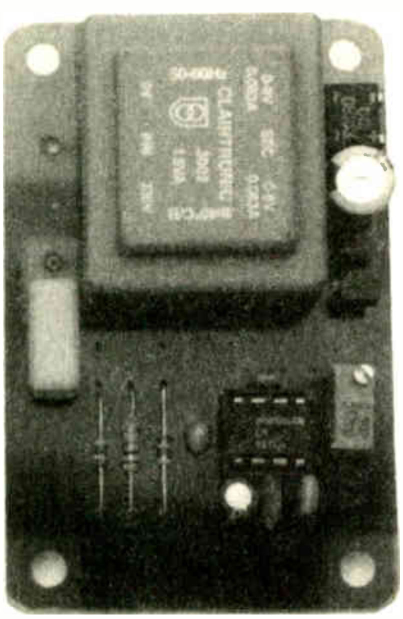
The printed circuit board component layout and full-size foil master for the Receiver is shown in Fig.4. This board is available from the *EPE PCB Service*, code 293.

The receiver needs a few comments and the same method of construction should be followed as that for the Transmitter. It is recommended that an i.c. socket be used for IC2.

The Receiver p.c.b. illustrated in this article is designed to fit into a particular type of mains plug/case (see photographs). The recommended one has the necessary *brass* Earth pin; clearly **a plastic one will not do.**

Inside the case you will find that both the Live and Neutral pins are already wired but the Earth pin is not. So a wire needs to be soldered to the back of this pin. This can be done without loosening it in the plastic case by carefully cleaning the inside surface of the pin and using a very hot iron to "solder tin" the pin's end and complete the soldering of the wire *before* the iron begins to melt the plastic around the pin.

Although the Live and Neutral pins are pre-wired, for some reason these are not conventionally colour-coded. It was found that both wires were blue. *These must not be confused.* So mark as Live the wire which comes from the back of the right-hand pin when looked at as though the plug were already seated in a mains socket. This Live wire ***must only*** connect to the primary winding of the transformer on the p.c.b.



Component layout on the prototype Receiver board ready for wiring into the plug/case.

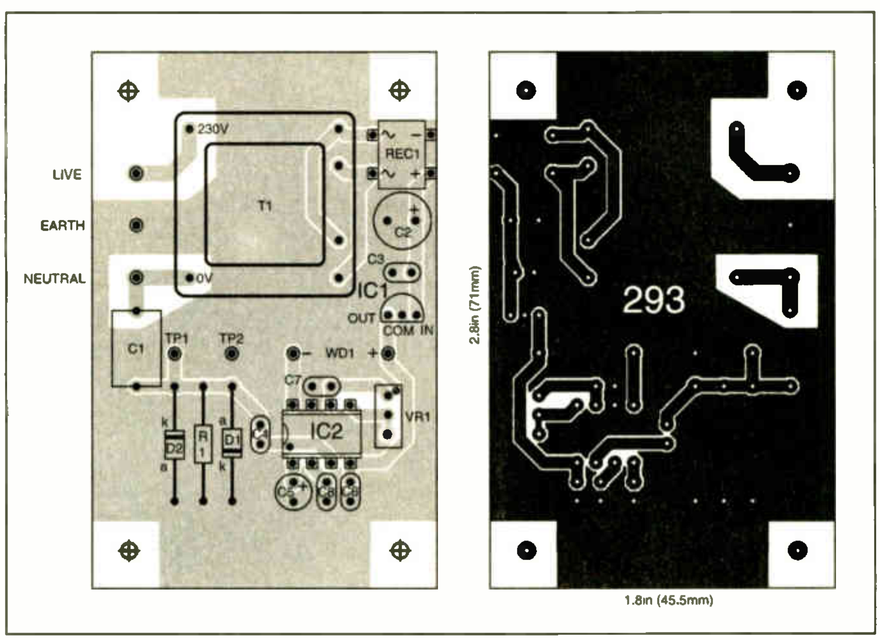


Fig.4. Printed circuit board component layout and full-size copper foil master pattern for the Receiver.

COMPONENTS

RECEIVER

Resistors

R1	10k

0·25W 5% carbon film

Potentiometers

VR1	4k7 multiturn cermet preset, vertical mounting, top adjustment

Capacitors

C1	10n metallised poly. film, 400V minimum
C2	220µ radial elect. 25V
C3, C8	100n disc ceramic (2 off)
C4, C7	1n resin-dipped ceramic (2 off)
C5	10µ radial elect. 16V
C6	1µ polyester

Semiconductors

D1, D2	1N4148 signal diode (2 off)
IC1	78L05 +5V 100mA regulator
IC2	NE567 tone decoder
REC1	100V 1A 4-pin d.i.l. bridge rectifier

Miscellaneous

T1	miniature 230V mains transformer, 9V dual secondaries, 1·5VA
WD1	6V (4V-9V) min. buzzer

Printed circuit board available from the *EPE PCB Service*, code 293; 13A 3-pin plug-in case (size 78mm x 52mm x 52mm approx.), with brass Earth pin; 8-pin d.i.l. socket; interconnecting wire; solder etc.

Approx. Cost Guidance Only **£17**

RECEIVER EXTENSION (Fig.8)

Resistors

R2, R6	10k (2 off)
R3, R7	470Ω (2 off)
R4	4k7
R5	2k7

All 0·25W 5% carbon film

Capacitors

C9	0µ1 polyester
C10	680n polyester
C11	1µ polyester

Semiconductors

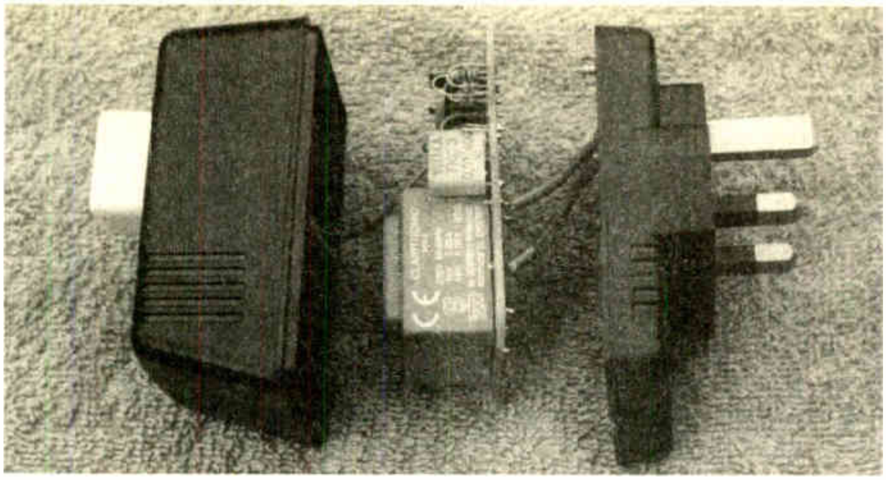
D3, D4	5mm red l.e.d. (2 off)
D5	1N4148 signal diode
TR1, TR2	BC109C *npn* transistor or similar
TR3	BSS295 *n*-type MOSFET or equivalent
IC3	4093 quad 2-input NAND Schmitt trigger

Miscellaneous

RLA	5V single-pole changeover relay with mains rated contacts, coil resistance 114 ohms
S1	pushswitch, press-to-make

Printed circuit board available from the *EPE PCB Service*, code 295; 14-pin d.i.l. socket; multistrand connecting wire; solder etc.

Approx. Cost Guidance Only **£12**



Completed Receiver board wired to the two halves of the plug/case.

Again, it is most important that capacitor C1 must be at least a *400 volt working* type. It was found that a 6V (and even a 12V) buzzer will work perfectly adequately on a 5V supply.

It is good practice to set the multiturn "trim" potentiometer VR1 to half its total resistance before wiring it into the p.c.b. At least then you know where you are when the time comes to adjust it.

When all the components have been soldered into the p.c.b., note which is the positive and which the negative pin of the buzzer. Now fit it to the outside of the "empty" half of the plug case and solder two colour-coded wires, about 10cm long, to connect the buzzer to its corresponding solder pads on the p.c.b. Next, the three wires from the plug-half of the case need to be connected to the appropriate Live, Neutral and Earth pads on the board.

Eventually, the two halves of the case will be screwed together, firmly sandwiching the p.c.b. between them. For the moment they should be left apart.

SETTING UP – TRANSMITTER

Great care must be undertaken when setting up the two units as mains voltages will be present and are highly dangerous.

For testing, an auxiliary transformer should be used to provide a temporary low voltage a.c. supply (say 9V to 15V) to the Transmitter unit. A mains supply for this transformer together with the mains plug wired with just Earth and Neutral should be plugged into a suitable mains socket on one side of the workshop. The Transmitter should now be oscillating continuously.

If you have an oscilloscope, the Transmitter p.c.b. can be checked. Connect the oscilloscope to the Test Points, TP1 and TP2, and verify that the output frequency can be adjusted over quite a wide range by carefully screwing in and out the ferrite slug in the top of the i.f. transformer T2.

Extreme adjustment of the slug screwed out should produce a frequency of about 475kHz but this is really too high for our purposes. Somewhere between maximum and minimum adjustment of the slug should give a fairly clean sinewave, somewhere between 250kHz and 350kHz and around 35V peak-to-peak.

Leave it at this setting. If you have no oscilloscope simply screw the slug in and out a couple of times to get a sense of its total travel and then leave it at an estimated mid-point.

RECEIVER

Now turn to the Receiver. If you are making more than one, it is best to deal with these one at a time. **Remember that mains voltage will also be present on this board.**

Plug a Receiver into a mains outlet on the opposite side of the workshop away from the Transmitter. When it is first plugged in, it should give a brief but reassuring buzz.

However, as the signal into the Receiver is strong with the units so close, the buzzer may sound continuously. If it does not do so, return to the Transmitter and carefully adjust the slug inside the i.f. transformer T2, slowly turning it inwards and outwards until the buzzer sounds.

Unplug the first Receiver and replace it with the second, if there is one. If this does not immediately buzz, adjust preset VR1 on the Receiver until it does. Repeat this with any other Receiver.

Now take a Receiver to its final destination and plug it in. Do not be disappointed if it buzzes but briefly. At this greater distance from the Transmitter, it may not yet be tuned critically enough. Slowly adjust preset VR1 until the buzzer sounds. Repeat this with any other Receiver in the location where it will be used.

FINAL SET-UP

The Transmitter can now be connected to the doorbell circuit and mounted in its final position. Having now moved the Transmitter from its position where the receivers were being tested, you may find that the buzzers still do not operate when the doorbell pushbutton is pressed.

It is here that your handy helper must be co-opted to keep his/her finger on the bell-push while you gently tweak the "trim pots" of all Receivers until each is perfectly in tune with the output of the Transmitter. You may find that at some locations the amount of VR1 adjustment will be extensive; at others it will be highly critical and may need several attempts before the buzzer will sound reliably each time the bellpush is operated.

When all Receivers are functioning correctly, the two halves of each plug-case can be screwed together being careful to see that no wires from the buzzer or the plug pins are trapped.

EXTENDING THE EXTENDER

The Transmitter and Receiver units described allow the front doorbell to be heard at a distance away from the house. The system, although simple, provides very reliable one-way signalling and uses only the mains wiring as the transmitting medium. These are all qualities which can be employed in a number of other applications which reach beyond that of simply extending the range of the doorbell.

For example, a separate, slightly modified, Transmitter unit can be built having its own on-board mains transformer to supply the a.c. voltage, and with its own press-switch button (S2) at the end of a flying lead. The copper foil, full-size, and a guide to the placement of components for adapting the original circuit are shown in the p.c.b. component layout of Fig.5.

This modified Transmitter could, for example, be plugged into a mains socket in the bedroom of a disabled person who could then use the remote pushswitch to summon assistance. Any Receiver set up elsewhere in the property would immediately alert someone to that cry for help.

Beyond the slight confusion of whether the doorbell has been rung or somebody needs support, there would be no problem in having the Transmitter described here set to the same frequency as that of the Doorbell Transmitter. Receivers can then be common to both applications.

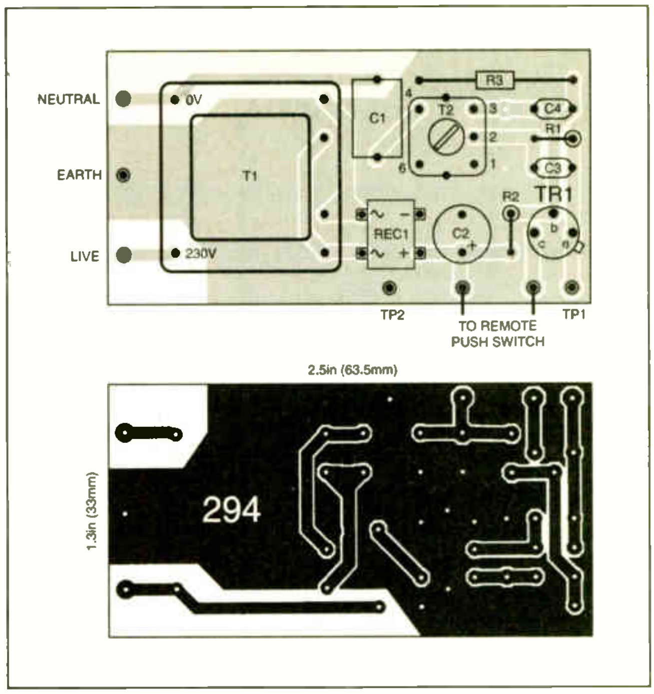


Fig.5. Printed circuit board component layout and full-size foil master for the modified Transmitter unit.

RELAY SWITCHING

Another variation on a similar theme utilises the wide range of frequencies which the Transmitter components can make available. Using a very different frequency from that of the doorbell circuit, it would be possible to power-up mains equipment remotely using a switch-operated (instead of a pushbutton) transmitter.

The buzzer in the Receiver would need to be replaced with a 5V relay. This can be driven directly by pin 8 of IC2, provided that the resistance of the relay's coil is at least 140 ohms (the NE567, IC2, is limited to sinking no more than 35mA).

Sensitive relays like this are fairly rare however. A more universal solution would be to use the sub-circuit shown in Fig.6, where a *p*-type MOSFET switches the relay. Its contacts could then be used to switch an electric blanket, or other appliance, on and off remotely, for example.

The drawback to this use of the Transmitter/Receiver combination is that for the electric blanket to be on, the Transmitter needs to be oscillating continuously.

PRESSING TIME

A much better solution to the problem is to incorporate the "press-on, press-off" circuit diagram of Fig.7. This extension to the original design allows the switching of a remote device by using *consecutive* presses of a Transmitter pushbutton.

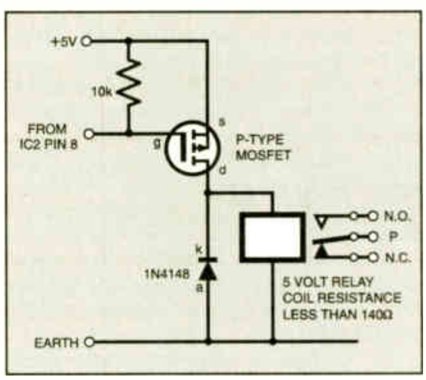


Fig.6. Circuit diagram for driving a 5V relay with a low resistance coil.

Effectively what is needed in the Receiver is a divide-by-two flip-flop so that the first pulse produces a "set" condition and the second a "reset" condition. While there are integrated circuits (such as the CMOS 4013) which are designed with this feature, the flip-flop in this application is required to operate in a very noisy environment, electrically and electronically speaking. If the ultra-sensitive 4013 were used, it would appear to switch randomly as it responded to intermittent mains noise.

Consequently, the design of the divide-by-two circuit shown in Fig.7 needs to be rather special in that it must totally ignore the spurious spikes on both the d.c. and the mains, yet must reliably flip and flop in response to consecutive high-frequency pulses from a Transmitter unit.

The flip-flop, IC3, together with transistors TR1 and TR2 (Fig.7), functions in the following manner. Let us assume that when this section of the Receiver circuit is first powered up, the flip-flop starts with pins 3, 5 and 6 of IC3a and IC3b low. Then, since

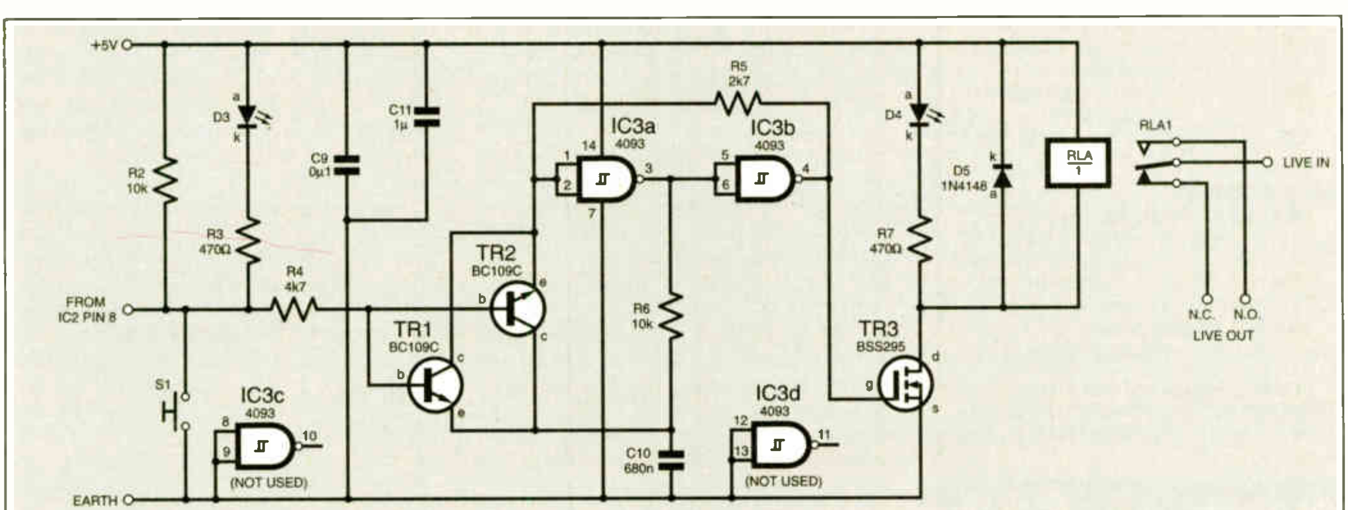


Fig.7. Circuit diagram for adding a "press-on", "press-off" feature, with relay switching, to the basic Receiver.

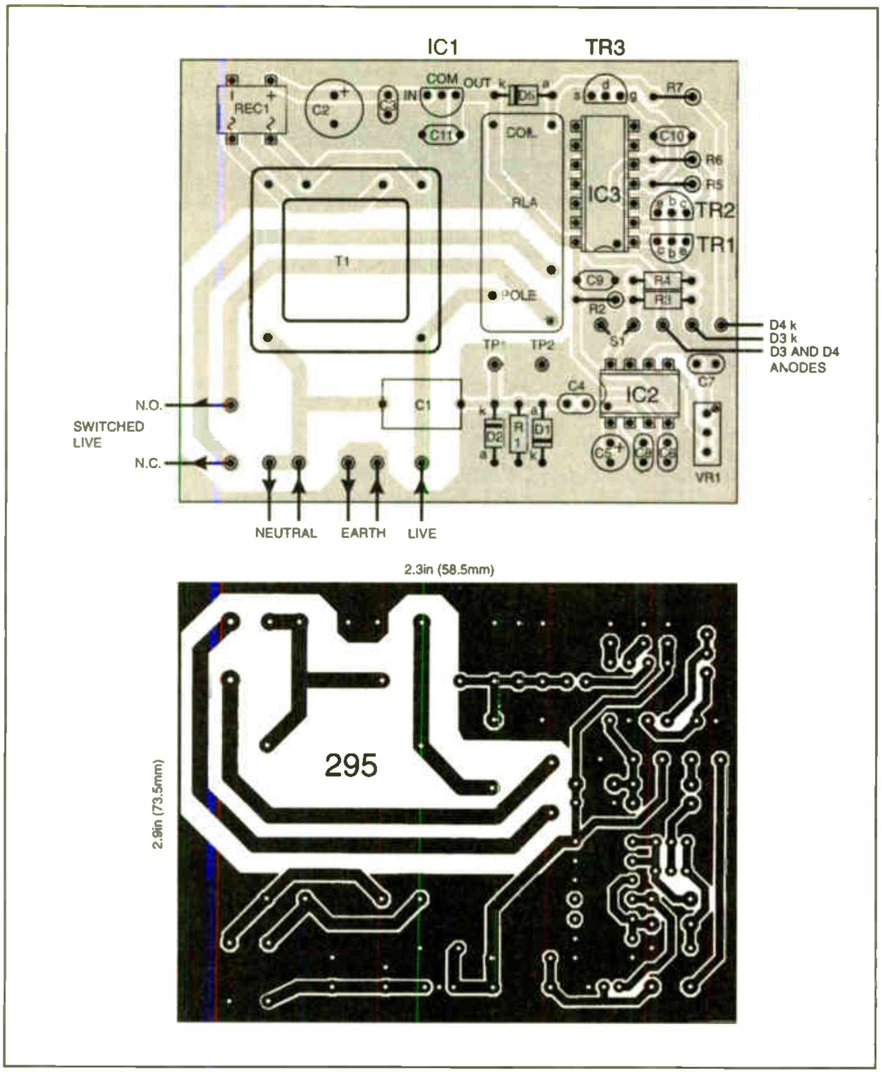


Fig.8. Printed circuit board component layout, wiring and full-size foil master for the modified Receiver unit. This p.c.b. contains its own mains transformer and switching relay.

gate IC3b is wired as an inverter, output pin 4 will go high, switching on MOSFET TR3, and l.e.d. D2 will light indicating that the relay contacts have pulled in (changed over).

At this time the back-to-back pair of high gain transistors, TR1 and TR2, are both potentially conducting because resistors R2 and R4 are biassing positive their bases (b). Consequently, since pins 1 and 2 of IC3a are high (because it is also wired as an inverter and we are supposing that pin 3 is low), capacitor C10 is charged via one of the transistors. The selected value of resistor R6 ensures that pins 3, 5 and 6 are not pulled high however, and hence this state is stable.

When the pushbutton on the Transmitter is being pressed and the signal detected at the Receiver, pin 8 of IC2 is low and both transistors switch off. Capacitor C10 discharges relatively slowly into the low of pins 3, 5 and 6 of IC3, allowing the output at IC3b pin 4 to continue high with the relay pulled in.

However, when the Transmitter's pushswitch S2 is released, transistors TR1 and TR2 switch on again and the discharged capacitor C10 directly pulls pins 1 and 2 low at the input of IC3a. Consequently IC3a's output at pin 3 goes high and so the output of gate IC3b at pin 4 goes low (and is held low by feedback resistor R5), switching off TR3 and the relay RLA.

Now C10 can charge through R6 from the high pins 3, 5 and 6. As the transistors are conducting, pins 1 and 2 will follow the voltage rise on the capacitor but, because of resistor R5, not far enough to change the state of IC3a. This situation too is stable.

The next time the Transmitter pushswitch is pressed, transistors TR1 and TR2 are turned off and capacitor C10 can become fully charged via R6. When the pushswitch is released, TR1 and TR2 switch on, pins 1 and 2 of IC3a are pulled high by the charged C10, and consequently so is pin 4. MOSFET TR3 switches on and so does the relay.

The result of all this is that at one push of the Transmitter button the relay contacts of RLA pulls in, and on the next, it drops out. Note that the relay always changes its state on the *release* of the pushswitch.

POWER-ON

In practice, the initial state of the flip-flop at power-up is indeterminate. This is the reason for l.e.d. D3 and pushbutton switch S1 in Fig.7. Operating this switch will allow the output of the relay to be set to the required state; whichever this is, l.e.d. D4 will provide the illustration.

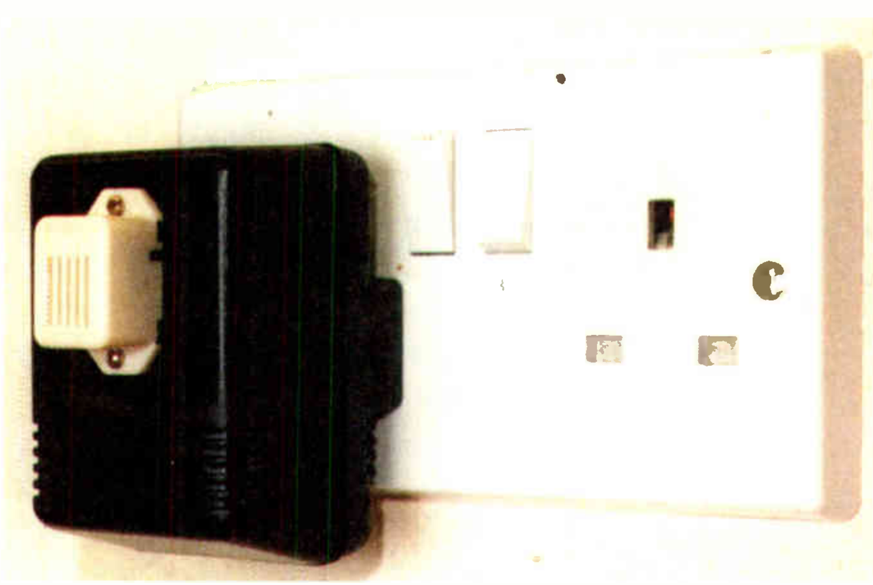
The inclusion of l.e.d D3 is necessary initially in order to be able to tune the receiver to the incoming signal from the Transmitter. After set-up, this l.e.d. will, of course, always light at the start of a transmitted pulse and extinguish at its end, just as the relay and l.e.d. D4 change their state.

CONSTRUCTION

The copper foil (full-size) master and component layout incorporating these modifications to the Receiver is shown in Fig.8. This extended design allows a Receiver to be built which will switch mains Live on consecutive pushes of the button of a modified Transmitter. The circuit diagram for this p.c.b. is a combination of the original Receiver (Fig.2) and the "press-on, press-off" circuit (Fig.7). One additional decoupling capacitor is needed (C11, 1μf) which is shown in the circuit diagram Fig.7 and on the component layout diagram Fig.8.

To complete this modified Receiver construction (Fig.8), one of the switched Live outputs from either the Normally-open or Normally-closed relay contacts, together with Neutral and Earth, need to be connected to a standard mains socket. **All this wiring-up involves 230 volts a.c., so all the usual precautions and care MUST be taken in making and testing this board and socket.**

Both of the modified Extender p.c.b.s are available from the *EPE PCB Service*, codes 294 and 295. □



News . . .

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

AAC, THE NEW MUSICAL TERM TO USE

Audio compression system AAC offers faster web transfer rates than MP3. Barry Fox reports.

ON the can't-beat-them-so-join-them principle, the music industry is coming to terms with electronic music delivery over the Internet. The Bertlesmann Music Group has done a deal with Napster, to try and earn money from music file sharing.

Along with the Universal Music Group, BMG has also signed to use the new Advanced Audio Coding (AAC) system which is at least 30 per cent more efficient than MP3 at compressing music. So music can now stream at around half the data rate needed for MP3, and so download in half the time or twice the audio quality (**www.aac-audio.com**).

AAC DEVELOPED TO REPLACE MP3

The Fraunhofer Institute in Germany, which developed the MPEG-1 Layer 3 audio compression system popularly known as MP3, is now offering AAC as a replacement (**www.iis.fhg.de/amm**). Although there is no compatibility between MP3 and AAC, PC users do not even need to know they are using AAC instead of MP3, because music sites prompt an automatic download of the new player software.

Heavy-hitters AT&T Corp (**www.att.com**), Sony Corporation (**www.sony.com**) and Dolby Laboratories (**www.dolby.com**) are helping Fraunhofer develop, promote and licence the technology. The International Organisation for Standards, ISO, has now included AAC in the MPEG standard. Hardware manufacturers Compaq, Diamond Rio, Panasonic, Sanyo and Toshiba have developed AAC-ready portable players. ARM has designed key component chips (**www.arm.com**) and Integrated Services Digital Broadcasting. Interactive Objects (**www.iobjects.com**) has written the Dadio operating system for AAC devices.

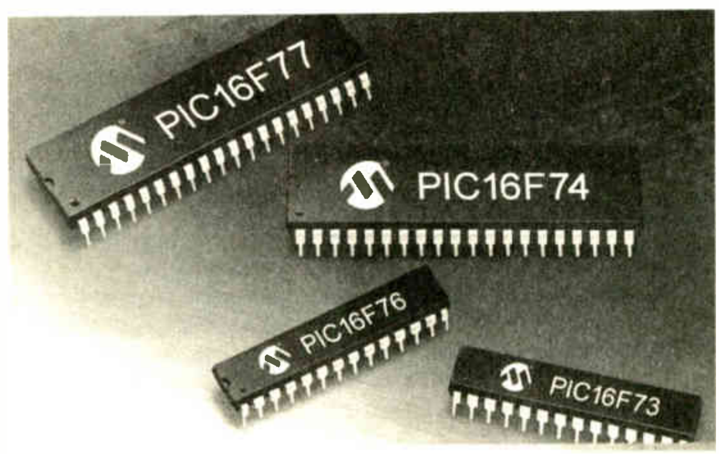
UMG (A&M, Decca, Deutsche Grammophon, MCA, Philips, Island and Verve) and BMG (Arista, RCA and Ariola) have now started to deliver music for sale over the Internet, using AAC. The new Version 6 of MusicMatch Jukebox player software is AAC-capable and includes InterTrust's digital rights management (DRM) technology which stops people getting music for free (**www.musicmatch.com/plug-ins**).

MUSIC DELIVERY

Commercial music delivery services Liquid Music Network and UMG's Bluematter now carry AAC content. They tell the purchaser what player software they need to play a selected title and prompt with a click for free download. (**www.bluematter.com/purchase/default.php3** and **www.liquidaudio.com/music/lmn/**)

AAC is being used on the Internet at data rates down to 64Kbps, but the system is scaleable to deliver broadcast quality surround sound. Japan has chosen AAC for its new digital radio and TV system. AAC can sample sound at up to 96kHz (the hi-fi standard used for DVD-Audio) and code 5·1 multi-channel surround at 320Kbps.

NEW PICS



MICROCHIP has introduced six new PIC microcontrollers. The PIC16F73, 'F74, 'F76 and 'F77 "flash" (reprogrammable) devices have the same facilities as their near relatives, the 'F873/4/6/7, but use Microchip's new 0·5 micron process technology and benefit from a power consumption of typically 20μA operating at 32kHz at 3V.

The other two chips are the PIC16C745 and PIC16C765 which feature 8k x 14 words of OTP (one-time programmable) memory and 256 bytes of user RAM. These devices include support for the Universal Serial Bus (USB) 1·1 low-speed interface. Additional features include 33 I/O ports, eight channels of 8-bit ADC.

The USB provides a fast and flexible method of connecting a computer to wide range of peripheral hardware. It is set to become the *de-facto* standard for interconnecting PCs to devices such as printers, scanners, digital cameras and sound systems.

For more PIC microcontroller information contact either of the following:

Arizona Microchip Technology, Dept EPE, 505 Eskdale Road, Winnersh Triangle, Wokingham, Berks RG41 5TU. Tel: 0118 921 5800. Fax: 0118 921 5820. Web: www.microchip.com.

Unique Memec, Dept EPE, 64/65 Rabans Close, Aylesbury, Bucks HP19 8TW. Tel: 01296 397396. Fax: 01296 397439. E-mail: info@unique.uk.memec.com. Web: unique.memec.com.

OOPIC

TOTAL Robots Ltd have become the sole UK distributor of OOPic, the first Object-Oriented Programmable Integrated Circuit. The OOPic microcontroller can be programmed directly from a PC, in Visual Basic, C and Java syntax.

OOPic is more than a programmable microcontroller, it is also a programmable *virtual circuit* in which OOpic objects can be linked together to emulate a discrete electronic circuit. Note, though, that it has nothing to do with PIC microcontrollers!

Software to program OOPic, plus a comprehensive manual, is available free when downloaded from the company's web site. A starter kit, which contains an OOPic module, programming cable and battery clip is available at £49.95 including delivery.

For more information browse web site **www.totalrobots.co.uk** or phone 01372 741954.

Crowning PIC Basic

CROWNHILL Associates have told us proudly that they have published *Experimenting with the PicBasic Pro Compiler*, a book written by Les Johnson.

They say that Les has produced an informative and thought provoking book that takes over from the PicBasic Pro manual to demonstrate how this language can be implemented in real life applications.

The book is accompanied by a CD-ROM and between them they illustrate how to control readily available devices such as ADCs, DACs and sensors etc. Tips and techniques are discussed and each experiment suggested has an illustrative program that shows exactly what is happening.

Also released by Crownhill is *PIC Basic – An Introduction*, jointly authored by Eric Edwards and Neil (Jasper) Roberts. Eric says that the book has been written to describe the nature of PICs, what they can do and why you should want to use them in the first place!

He explains matters in simple plain language, often explaining them in several different ways so that "one of my explanations will hit the right spot". Jasper's program codes look easy to understand, and there are a lot of examples of different applications to entertain and inform you, not only through the book pages but also through the accompanying CD ROM.

For more information on both books contact Crownhill Associates Ltd, Dept EPE, 32 Broad Street, Ely, Cambs CB7 4AH. Tel: 01353 666709. Fax: 01353 666710. E-mail: sales@crownhill.co.uk. Web: www.picbasic.co.uk.

GPS ADD-ON FOR COMPUTERS

A CLIP-ON satellite navigation receiver designed specifically for the Palm V hand-held computer and IBM Workpad has been launched by Magellan, one of the world's leading manufacturers of GPS (Global Positioning System) receivers.

The Magellan GPS Companion is a small lightweight attachment that fits neatly without connecting cables. It provides instant positioning information that can be viewed in conjunction with a series of UK and European road maps. Features include speed, direction and ETA.

For more information contact Sowester Simpson-Lawrence Ltd., Dept EPE, Stinsford Road, Nuffield Industrial Estate, Poole, Dorset BH17 0SW. Tel: 01202 667700. Fax: 01202 668585.
E-mail: sow@sowester.co.uk.
Web: www.sowester.com.

KELLYSEARCH.COM

RENOWNED for in-depth commercial product directories, Kelly's has launched its website **www.kellysearch.com** to provide the manufacturing industry with its own specialist search engine. It will be of significant interest to many *EPE* readers as well, providing answers to questions about sources for products of all manner of types.

It will give users access to a new Kelly's database of more than 100,000 manufacturers distributing over 1.5 million products. Users will be able to locate suppliers of the precise product they need and find out more by linking through to the supplier's website.

John Irlam, group publishing director, industrial and commercial, at Reed Business Information said that "kellysearch.com will give users an industrial search engine they have been hunting for since dial-up first started".

New Technology Update

Transistor dimensions continue to shrink and Intel processors having 400 million transistors and running at 10GHz will soon be reality. Ian Poole reports.

ON 11 December 2000, Intel announced that its researchers had achieved a significant breakthrough by building the world's smallest and fastest CMOS transistor. With dimensions measured in single nanometers and speeds well in excess of those currently available in integrated circuits this development promises to have a major impact on the whole field of electronics.

Recently, people have been heralding the end of current electronics technology, saying that it cannot meet the needs for speed and size reduction for the future. This new development will revolutionise current technology enabling field effect transistors to be used for many years to come.

The new transistors act as switches. Intel anticipates that in the next ten years it will be able to build microprocessors containing more that 400 million transistors, with the processors running at speeds of 10GHz, and using supplies of less than a volt.

With current processors running at speeds of around 1GHz, this new development represents a significant improvement in terms of speed and the level of integration that can be achieved. Intel say that while the transistors feature capabilities that are generations beyond the most advanced technologies used in manufacturing today, they were built using the same physical structure as in today's computer chips.

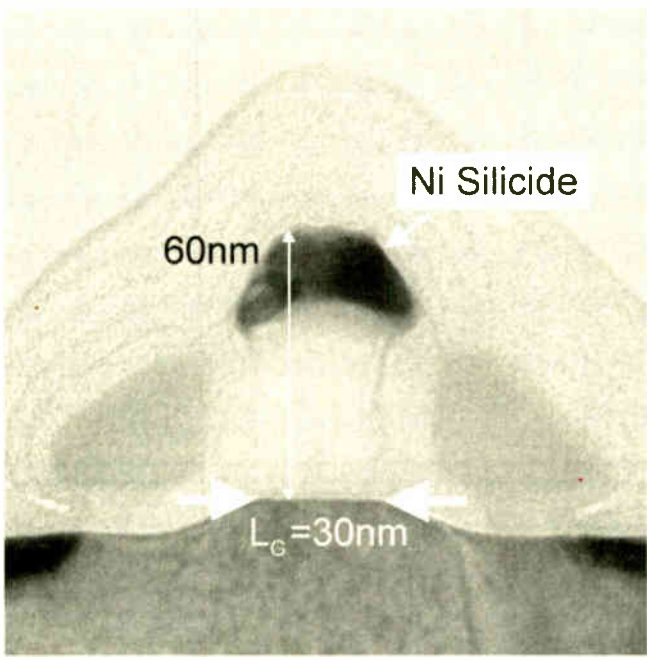
Dr Gerald Marcyk noted: "Many experts thought it impossible to build CMOS transistors this small because of leakage problems. Our research proves that these smaller transistors behave in the same way as today's devices and shows there are no fundamental barriers to producing these devices in high volume in the future.

Structures

The difficulties associated with the size reductions required to continue the current rate of progress in the semiconductor industry have received a great amount of attention in the electronics press. The Intel research team have looked at the options and devised their new devices using a conventional planar CMOS process flow.

The first stage in the production process is the lithography. This is the process in which circuits are printed on silicon wafers. Here a two-mask phase shift approach was used enabling the fabrication of 30nm lines using 248nm lithography with over exposure.

The 0·07 micron (70 nanometer) technology relies on Extreme Ultra Violet (EUV) lithography, for printing the narrowest lines. This is combined with 157nm lithography to enable manufacturers to continue producing smaller and faster processors.



Micro photograph of Intel's smallest and fastest transistor. Courtesy Intel.

EUV allows semiconductor manufacturers to print ever-smaller features on a wafer. The difference between features drawn by EUV and Deep Ultra-Violet (DUV) lithography, today's most advanced method, is similar to drawing two lines of equal width and quality on a piece of paper, but using a fat-tipped marker to draw one line and a fine-tipped marker for the other.

Deposition of the oxides and polysilicon was equally key to the success of the project. The physical gate oxide was scaled to below 1·0nm and the polysilicon gate electrode thickness was brought down to below 100nm. This was required in order to achieve the high drive currents and controllable short channel effects needed for the devices.

Further developments were required to achieve the required "on" resistance and overlap capacitance.

Additionally, it was also necessary to ensure that the silicide resistances did not rise too high in view of the very narrow polysilicon line widths of less than 50nm.

Performance

The performance of the new devices has been very encouraging. The figures for gain and current capability are all within the requirements. The gate delay for the *n*-MOS device that was fabricated showed a figure of only 0·94ps – the fastest value ever recorded for a silicon CMOS device. Furthermore, this result combined with the "on" and "off" currents that were measured suggests that the technology is consistent with the use of conventional coplanar CMOS transistor design and processes.

Reality

These transistors will be built into Intel processors that are nearly 10 times more complex than the Intel Pentium 4 processor, today's most advanced processor. For example, the future processors will have 400 million or more transistors, will run at 10GHz and operate at less than one volt. The Pentium 4 processor has 42 million transistors, runs at of 1·5GHz and operates at 1·7 volts.

Apart from their speed and the increased level of integration there are other advantages to using the new devices. Running at 1V or less, these future processors will consume significantly less power than today's processors, making them ideal for use in battery-operated devices such as laptop computers.

Applications

With the greatly increased processing power that will be brought about by the use of these processors, Intel are already seeing many new applications. One they mention is in shattering the language barrier. A 10GHz processor could power a universal translator – similar to a device used on *Star Trek* they explain.

This may seem futuristic, but with the ever-increasing levels of processing power many of the ideas previously only available in science fiction stories are now becoming reality. After all, ideas like calculators, and electronic watches were once only contained in science fiction stories, and today they are established parts of everyday life.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Constructional Project

BODY DETECTOR

THOMAS SCARBOROUGH

Create your own "invisible" protective shield and let the force be with you!

CAPACITANCE is an extraordinary phenomemon, in that it is able to work through empty space. This is a quality that is normally taken for granted. The accumulation of charge on a metal plate gives rise to an electric field, which will affect another plate in direct proportion to the inverse of its distance.

Capacitance is also one of a vast range of physical phenomena that may be translated into electrical oscillations.

The Body Detector featured in this article relies on the fact that the human body itself possesses a fairly large order of capacitance to the ground ("earth"), and that if such a body approaches the positive plate of a given capacitor, its value will rise. If, then, one could find a means to detect such an increase in capacitance, one would have an effective means of detecting the presence of a human body.

In the present application, a metal sensor is attached to the positive plate of the small timing capacitor of an *RC* oscillator, so that when a human body approaches, the value of *C* increases, and the frequency of the *RC* oscillator decreases. This drop in frequency is detected digitally, and is used to switch a relay.

CIRCUIT APPLICATION

Due to its high sensitivity and good stability, the Body Detector may be attached to a wide variety of metal objects – in the process sensitising the entire object concerned.

Although in theory the Body Detector is dependent on the electric field which surrounds the human body, in *effect* it acts as though an invisible field were created around the object concerned – similar to the "invisible" defence shields seen in the latest *Star Wars* movie.

From a practical point of view, the sensor may include any object from the size of a pin to about 70kg in weight (e.g. a lightweight motor-scooter). However, the greater the weight of the metal sensor, the less the sensitivity of the circuit, the more critical the tuning, and the more it becomes susceptible to temperature variations especially.

If attached to lighter metal objects (e.g. a sheet of tin-foil), the Body Detector may be tuned to detect a person's presence up to 80cm away. At several centimetres' distance, the circuit is sufficiently stable to avoid spurious triggering over a wide temperature range.

In one test, a bicycle was moved from shade to full sun and back into the shade during the course of a day, maintaining reliable triggering. In another test, a 300mm square sheet of tin-foil was tested successfully without the need for readjustment between 10°C and 50°C – and would, in fact, have exceeded this. This compares very favourably with variations in room temperature, which typically amount to no more than 10°C.

It will work satisfactorily over a wide range of conditions – however, it is designed to perform to its best potential under the following circumstances:

- Over a modest temperature range, e.g. 10°C to 25°C.
- Using relatively lightweight sensors – up to a kilogram or so would be ideal.
- Over longer periods, e.g. days at a time rather than minutes or hours.
- In a single application which does not require the unit or sensor to be moved about.

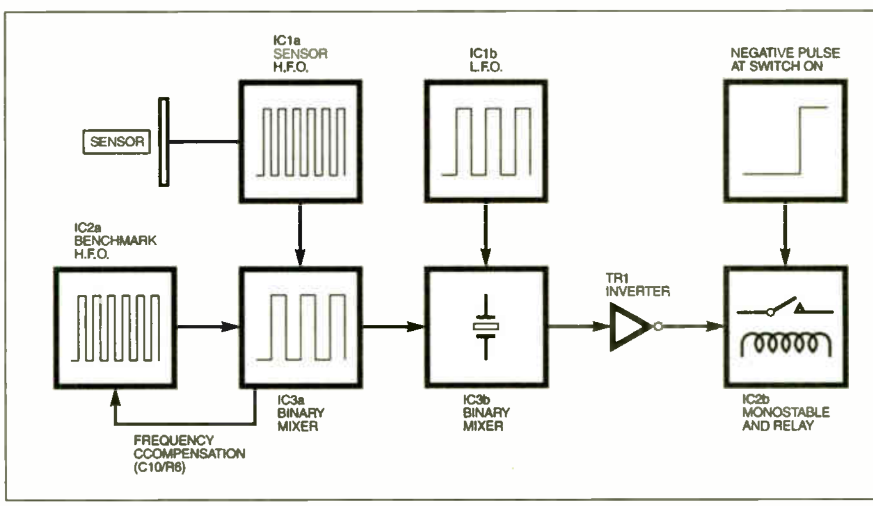


Fig.1. Block schematic diagram of the Body Detector.

POTENTIALLY VANDAL PROOF

One of the advantages of the Body Detector is that the "sensor" is potentially completely vandal-proof and tamper-proof – you cannot come near it with a pair of clippers or a similar instrument, let alone fingers. It is immune to a.c. fields and it will also detect body presence on the *other side* of a variety of materials, including insulators such as glass.

HOW IT WORKS

At the heart of the Body Detector is a versatile mixer (see block diagram Fig.1 and circuit diagram Fig.5), which will detect frequency variations to within a small fraction of one per cent. While the mixer is deceptively simple, it has a high degree of accuracy as well as flexibility. It could have a wide range of possible applications – among them to tune instruments, detect treasure, or act as a thermostat. However, in this article, just one such application is pursued here, namely the detection of body capacitance.

Two binary mixers, IC3a and IC3b (see Fig.1), are each based on one half of a CMOS 4520 dual binary counter. These mix a signal from high frequency oscillator IC1a (we shall call it the "sensor h.f.o.", as it incorporates the sensor) with a benchmark frequency produced by IC2a (the "benchmark h.f.o."). Both oscillators are based on the 7556 dual timer i.c., and both are tuned roughly to the same frequency of around 100kHz.

Sensor h.f.o. IC1a is an *RC* oscillator, so that when its metal sensor is approached, *C* increases and frequency drops, creating a frequency difference (we shall call this the "difference frequency") between the two h.f.o. oscillators. The point at which this difference frequency drops to zero we shall call "the null point".

The difference frequency is further mixed with the output of low frequency oscillator ("l.f.o.") IC1b – also based on the 7556 i.c. – so that the smallest difference frequencies *only* are detected. These are indicated audibly by a piezoelectric sounder (WD1), in the form of "crackles", or a beep.

To improve the circuit's stability, the difference frequency is fed back to the Benchmark h.f.o. IC2a through resistor R6 (see Fig.5), so that the unit has "*intelligent*" frequency compensation (as opposed to *temperature* compensation, which merely reacts to environmental conditions).

An important feature of the circuit is that the frequency of IC2a, the benchmark h.f.o., is "fuzzed" with the assistance of IC1b, the low frequency oscillator (l.f.o.). The effect of such "fuzzing" is illustrated in Fig.2.

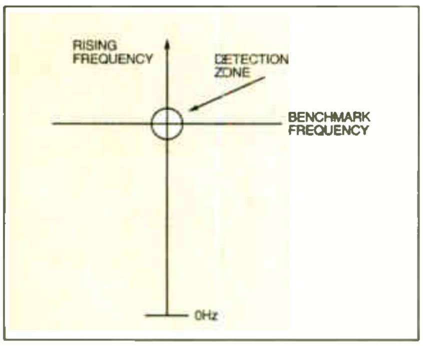


Fig.2. "Fuzzing" the benchmark frequency.

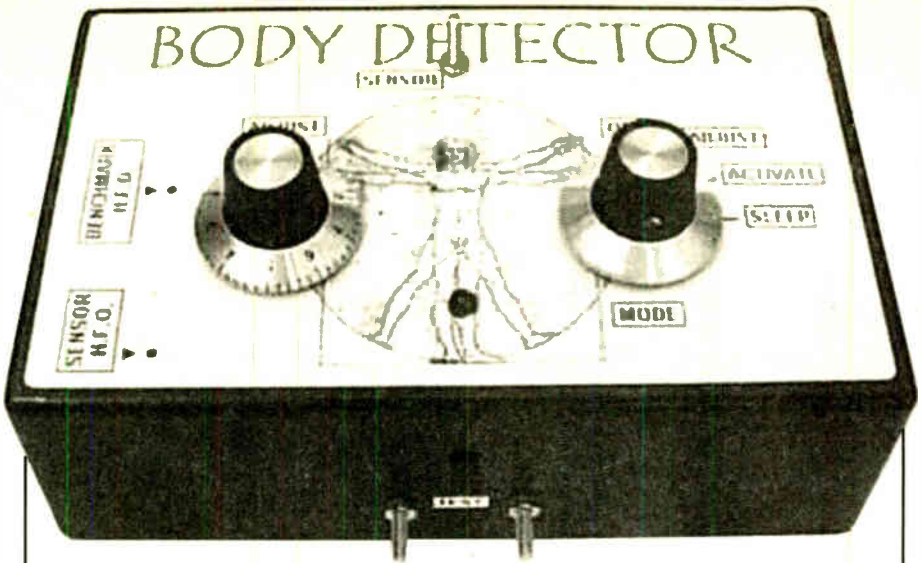
The low frequency oscillator IC1b creates a "detection zone" around the benchmark frequency, so that the fluctuating frequency of IC1a is detected as soon as it strays into the detection zone. This overcomes the possibility of the two h.f.o.'s "locking on" to each other near the null point (see below), and also assists with adjustment of the circuit (it is easier to tune in to a detection *zone* than a spot frequency).

Finally, a short delay is provided at switch-on, through capacitor C11 and resistor R9, so that the user has time to step out of range before monostable IC2b and the relay are activated.

STABILITY

Stability is a challenge with any circuit of this order of sensitivity. This is essentially because the quantity that the circuit measures – in this case body capacitance – is so extremely small that minute variations within the circuit itself may swamp the quantity being measured.

The chief hazards in the present application are threefold: Variations in external temperature, which cause variations within the circuit. Variations in temperature which originate within the circuit itself – such as minute warming within voltage regulator IC4 or other components. Finally, fluctuations in the supply voltage.



Possible Applications

- A **Pressureless Pressure-Mat** – which would detect the presence of a person passing over it, or past it. It could thus serve as an alarm, or as a "turnstile counter".
- An **Invisible Switch** – set for example into a concrete wall. Among other things, this could serve as an invisible "panic button".
- A **Safety Switch** – which would render an entire area a safety zone. This could shut down dangerous machinery, or child-proof certain areas.
- A **Defence Shield** – if a thin length of wire were used for the sensor, and run down a passageway or across a room, a "defence shield" could be created to cover a considerable walking area.
- A **Safe Area** – a detector wire could be circled around a tent or sleeping-bag when camping, to detect footprints (but unfortunately not spiders or hyenas)!
- A **Touch Sensor** – the Body Detector could be attached to metal items of value, such as a computer system-unit or a bicycle, to trigger an alarm merely when the paintwork is touched.
- A **Tamper Alarm** – it may be used to prevent tampering with, for instance, burglar bars or a Yale lock.
- A sensor could also be placed *behind* items of value, or *in front* of them, such as paintings or antique items of furniture, to protect them from theft or abuse.

Because of the importance of achieving a high order of stability, the author dedicates a fair deal of attention to this subject in this article. This does not mean, however, that stability remains a significant problem at the end of the day – the final circuit exhibits a high degree of stability.

FLUCTUATIONS

When a small sensor plate is touched (e.g. a 300mm square sheet of tin-foil), the frequency of IC1a typically drops more than 10kHz. In more demanding applications (when attached to a small scooter, for instance), the frequency drop will be far less – perhaps as little as 500Hz. On the other hand, temperature fluctuations could cause changes of a few tens of Hertz per degree C in a circuit of this kind.

Assuming that the day-night temperature variation is 15°C, this could cause frequency fluctuations in IC1a of 500Hz or more. In addition to this, fluctuations in supply voltage would cause further fluctuations in frequency. Therefore, if no special effort is made to overcome such temperature and supply voltage fluctuations, spurious triggering could occur. It is thus of crucial importance that the Body Detector circuit should be relatively immune to such variations.

The author's core approach to the problem was to balance any temperature changes in IC1a and IC2a by constructing them of identical components. Thus each would be equally affected (more or less) by any rise or fall in temperature.

This provided reasonably good stability to the extent that over a 30°C temperature variation, using the 300mm square tin-foil sensor-plate above, the Body Detector wandered across about a third of its useable range. (An even higher degree of balance would probably be achieved by separating IC1 and IC2 into discrete 7555 timers – however, this would have come at the expense of simplicity and compactness).

COMPENSATION

A further improvement was possible through "intelligent" frequency compensation. This was developed with the help of just two components – namely capacitor C4 and resistor R6. As the frequency of

IC1a rises in relation to the frequency of the benchmark h.f.o. IC2a, so the difference frequency increases, which feeds back to capacitor C4 via resistor R6, and causes the frequency of IC2a to rise. In short, as the difference frequency tries to rise, so it is pulled down, and vice versa, over a limited range.

With this small but crucial modification, the stability of the Body Detector is increased a few times – typically wandering over just 10 per cent of its useable range over a 30°C temperature variation. (During testing, the author destroyed a thermometer and melted part of the case – yet the unit stayed within range . . . !)

The effects of temperature on the Body Detector in one fairly representative test are shown in Fig.3. The sensor itself, whether big or small, was not found to have any significant effect on the temperature stability of the circuit. It may be seen from Fig.3 that, over a 40°C range, with suitable adjustment, the circuit stays far below the point of complete insensitivity, while remaining safely above the trigger threshold.

On the other hand, Fig.4 translates the voltage measurements shown in Fig.3 into the distance at which the circuit triggers when a hand is brought towards a 300mm square sheet of tin-foil. We shall return to these diagrams under Calibration later.

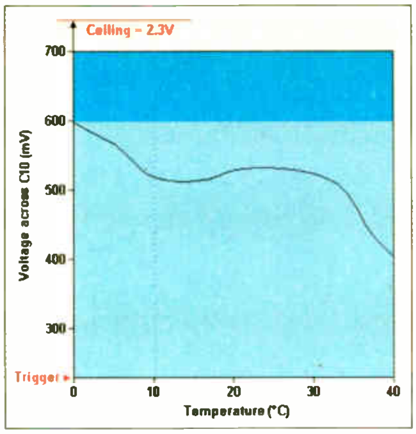


Figure 7. Temperature stability/drift

Fig.3. Graph showing the effects of temperature stability/drift.

HOT SPOT

The main source of *internal* temperature variation is (as would be expected) the voltage regulator IC4. Although this generates very little warmth, it is nonetheless sufficient in such a circuit to cause a measurable frequency drift.

This cannot be cured merely with a heatsink, since warmth runs down the leads, and through the circuit. The solution in this case is to temperature-isolate (relatively speaking) the regulator i.c., as well as other "power" components such as the transistors, by placing them on a separate component board. This was found to measurably improve stability as the connecting wires dissipated the small amount of warmth present.

Further than this, stability is enhanced by the use of high grade components. Also the h.f.o.s themselves are based on the 7556 dual timer i.c., which is a highly stable device.

SUPPLY RIPPLES

One further problem was found at first to significantly affect the stability of the circuit – namely "ripples" in the supply voltage. As IC1a and IC2a timing capacitors C1 and C4 charge and discharge, this may cause minute ripples in the supply, which can have a significant effect on an adjacent oscillator. When two oscillators are running so close together at high frequency, this could cause them to "lock-on" to each other, and in some cases can be seriously compromised.

To overcome this, oscillators IC1a and IC2a are kept separate. Each employs separate supply decoupling (C3 and C6), as

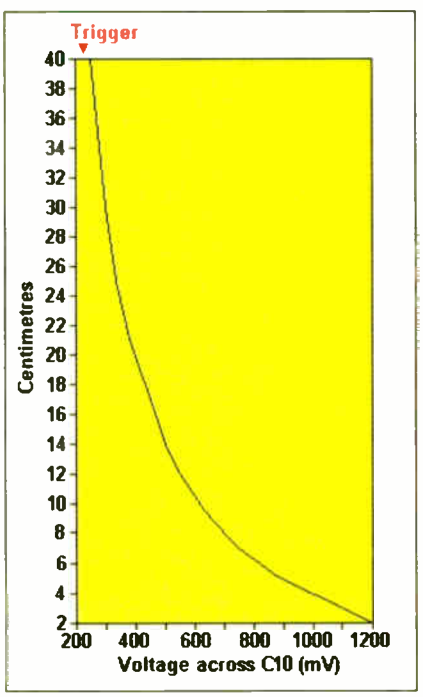


Fig.4. Graph translating the voltage/distance of detection, sensor being a 300mm square of tin-foil.

COMPONENTS

Approx. Cost Guidance Only £20 excluding case & potentiometer.

Resistors

See SHOP TALK page

R1, R2, R4, R5 R7, R10	10k (6 off)
R3	470Ω
R6	3M3
R8	270k
R9	150k
R11	100k
R12	2k2
R13	220k
R14	15k
R15	68Ω

All metal film 0·6W 1% (50ppm/°C temp. coefficient)

Potentiometers

VR1	200Ω to 500Ω 10- (or multi-) turn wirewound potentiometer
VR2, VR3	50k 18- (or multi-) turn horizontal cermet preset (2 off)
VR4	470k vertical sub-miniature carbon preset, linear

Cermet presets 100ppm/°C temp. coefficient

Capacitors

C1, C4	100p metallised ceramic plate, zero temp. coefficient (2 off)
C2, C5, C9, C13	100n multilayer metallised polyester film (4 off)
C3, C6, C7, C11, C12	100µ sub-miniature radial electrolytic, 10V (5 off)
C8	4n7 multilayer metallised polyester film
C10	150p metallised ceramic plate, zero temp. coefficient
C14	100n metallised polyester film
C15	1000µ miniature radial electrolytic, 10V
C16	10µ sub-miniature radial electrolytic, 35V
Cx	A variety of metallised ceramic plate from 1p to 100p. See text

All metallised ceramic plate capacitors have zero temp. coefficient

Semiconductors

D1	5mm red l.e.d.
D2, D3	1N4001 50V 1A rect. diode(2 off)
TR1	2N3904 *npn* low power transistor
TR2	BC337 *npn* medium power transistor
IC1, IC2	ICM7556IPA low power dual timer (2 off)
IC3	HCF4520BEY dual binary counter
IC4	LM2940CT 1A low dropout regulator. See text

Miscellaneous

RLA	5V p.c.b. mounting miniature relay 200mW nom. operating power (2-pole changeover). See text
S1	3-pole 4-way rotary switch, break-before-make
SK1	2·5mm power socket, single hole fixing with break contact
SK2	3·5mm open mono jack socket
WD1	low profile wire-ended piezo electric sounder

Stripboard 0·1in. matrix, size 18 holes by 34 strips (2 off); ABS plastic box, with slotted walls, 152mm by 89mm by 47mm internal; calibrated and pointer pair knobs with fixing nuts; 14-pin dual-in-line socket (2-off); 16-pin dual-in-line socket; M3 16mm panel head steel bolts with nuts and solder tags (see diagrams); eight colour-coded wires 15cm long (or multicore cable); optional 9V d.c. power adapter; PP3 type battery clip, optional PP3 alkaline battery; 2mm nylon cable ties; solder pins, solder, etc.

well as control voltage decoupling (C2 and C5). Also, the circuit does not detect the difference frequency at the null point, where "lock-on" is potentially most serious, but about 500Hz away – namely at the edge of the detection zone.

While some of these measures may make little difference in an undemanding application, altogether they result in a very stable circuit that should not wander more than a few tens of Hertz over 24 hours. Instability will typically amount to no more than a few per cent of the frequency change which is caused by the presence of a human body.

CIRCUIT DESCRIPTION

The full circuit diagram for the Body Detector is shown in Fig.5. IC3 is a CMOS 4520 dual binary counter, which is wired as a dual binary mixer.

Many mixers in similar applications employ a charge pump to detect a difference frequency – however, this tends to be an art as much as it is science. The 4520 dual binary counter enables precise digital detection, potentially to an accuracy of about 1Hz at frequencies up to 5MHz.

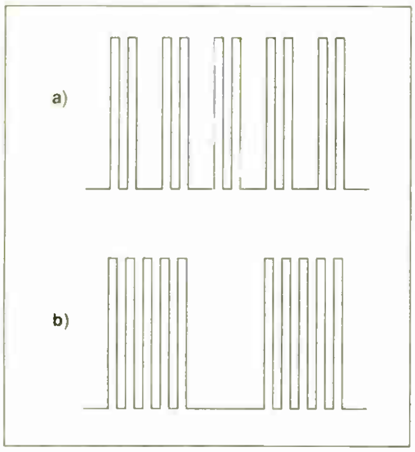


Fig.6. Simplified representation of waveforms at pin 3 of IC2.

Benchmark high frequency oscillator (h.f.o.) IC2a clocks binary counter IC3a, while Sensor-h.f.o. IC1a resets the counter at around the same frequency. These two inputs, far from simply cancelling each other out, produce a waveform as in Fig.6a when a larger difference frequency is present, and as in Fig. 6b when the difference frequency is close to the null point. It then remains merely to detect the troughs in the waveform which exceed a specific duration (e.g. 50ms). This is accomplished through binary mixer IC3b.

The mixed signal (the difference frequency) from IC3a is fed to the reset pin (15) of binary mixer IC3b. The low frequency oscillator (l.f.o.) IC1b feeds the clock input of binary mixer IC3b.

The clock input is completely cancelled out by the reset pulses, unless the duration of the troughs at the reset pin falls below the frequency of the clock input. In this case the clock pulses break through. With the component values shown, the frequency of the l.f.o. is fixed at around 500Hz – that is, 500Hz away from the null point.

TIME DELAY

At this stage, the output of binary mixer IC3b, at pin 12, is not particularly useful,

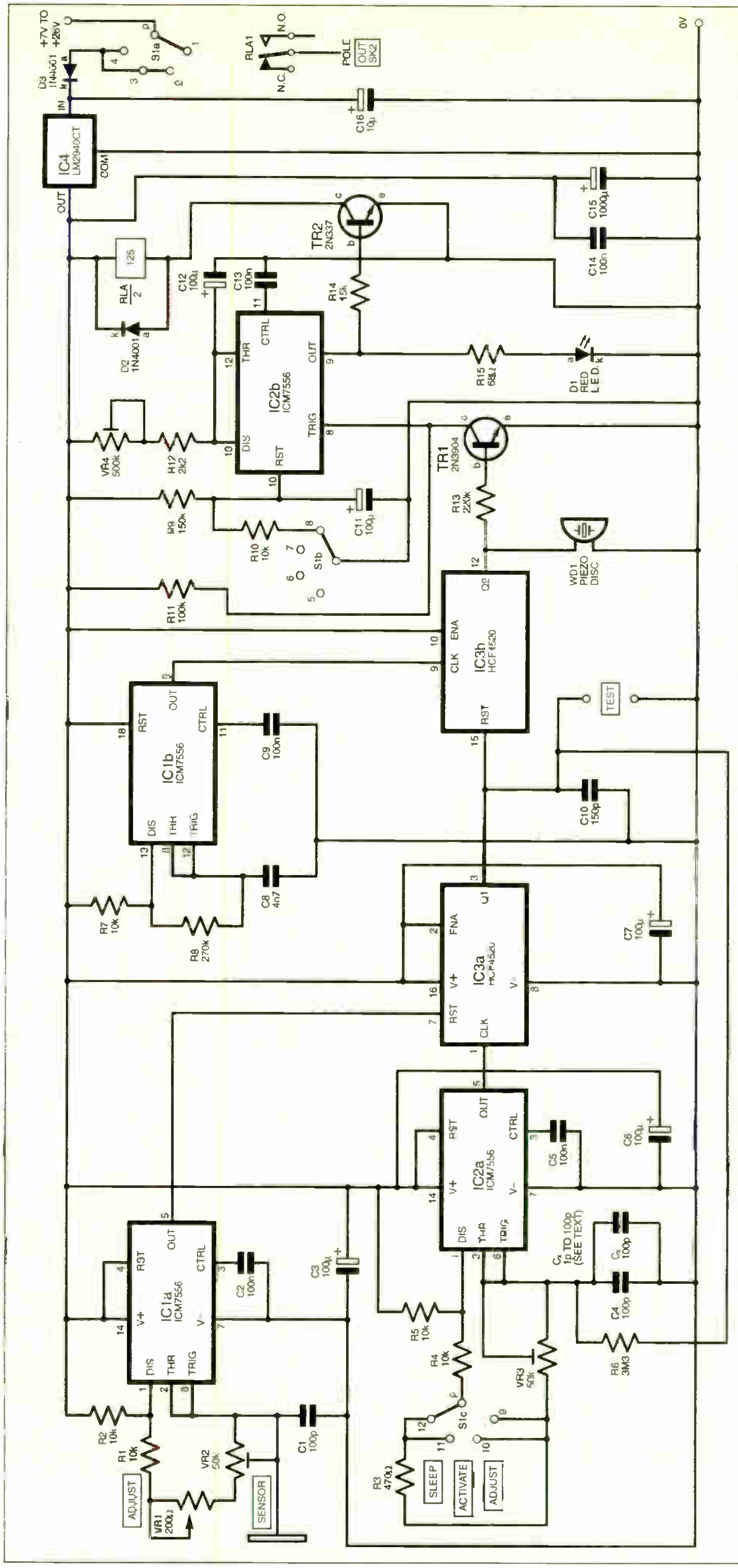


Fig.5. Complete circuit diagram for the Body Detector.

and first needs to be inverted before triggering monostable timer IC2b. This is accomplished with the help of transistor TR1.

With the component values shown, monostable IC2b may be adjusted over a useful 150ms to more than 30 seconds by means of preset VR4. If different timing periods are required, capacitor C12 may be altered accordingly.

The output of monostable IC2b, at pin 9, provides current for switching transistor TR2, which in turn controls relay RLA. A variety of miniature relays would be suitable here, provided that the nominal operating power does not exceed 500mW. Diode D2 suppresses back-e.m.f. when the circuit is broken.

A delay is provided at *switch-on* in the form of capacitor C11 and resistor R9. This arrangement produces a negative pulse for a few seconds at IC2b's reset pin, so that the user has sufficient time to step out of range before the Body Detector is activated. The delay is reactivated in the Sleep position setting of rotary switch S1 (see Calibration section later).

Low dropout regulator IC4 is used to ensure a steady supply voltage. Any similar regulator may be used, on condition that it is rated 150mA or higher. With the specified low dropout regulator, the unit's power consumption is typically 13mA on standby, and up to 100mA when triggered.

An alkaline PP3 battery should thus give two days' continuous service – the battery option is provided mainly for freeing up the unit during testing, and for demonstration purposes. The option of an external d.c. power supply (7V to 26V) is included.

The circuit is reverse-polarity protected through diode D3 – although the regulator itself is virtually indestructible.

CONSTRUCTION

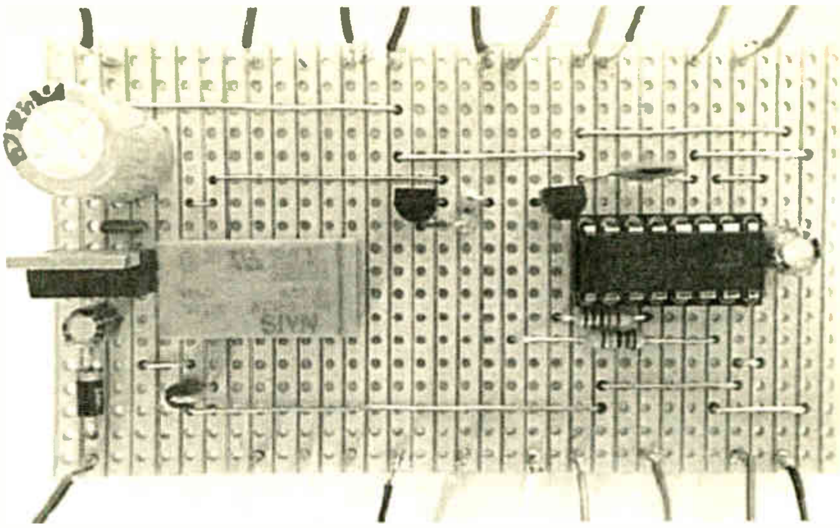
The Body Detector is built up on two pieces of stripboard each having 18 holes by 34 copper strips. We start construction with Board A. This holds the regulated power supply, the digital mixers (IC3), the inverter, and the relay.

Details of the topside component layout, together with the underside details, are shown in Fig.7. All the components should fit into place without difficulty, provided that miniature radial capacitors are used (other types can however be coaxed into position).

Commence construction by cutting a standard piece of stripboard down to size using a hacksaw. Create the breaks in the underside of the stripboard with a handheld drill bit or other appropriate tool.

Solder in position the wire links and solder pins, then the dual-in-line socket, then the resistors, the relay, and the diodes, continuing with the capacitors, transistors, and voltage regulator IC4. The polarity of the piezoelectric sounder WD1 is unimportant – if it has black and red leads, red may be taken to position *R26* on the stripboard, and black to position *R32*.

Be careful to observe the correct polarity of the electrolytic capacitors, and the correct orientation of the regulator, the transistors, diodes, l.e.d., relay and IC3. Pin 1 of IC3 lies close to a small indentation on one end of the encapsulation. The cathode (k) of l.e.d. D1 has the shortest



Component layout on the completed Board A. Note the relay orientation stripe.

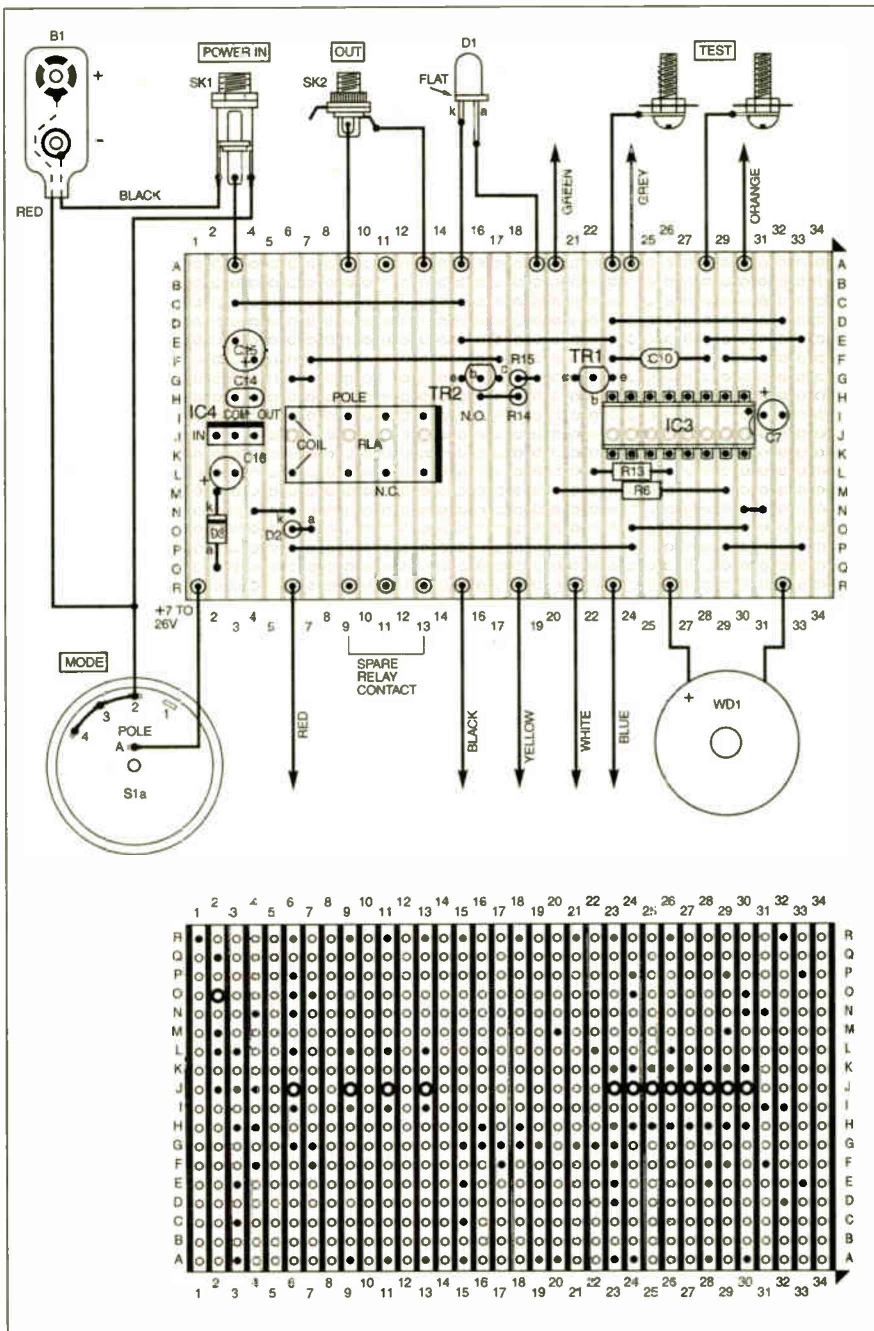


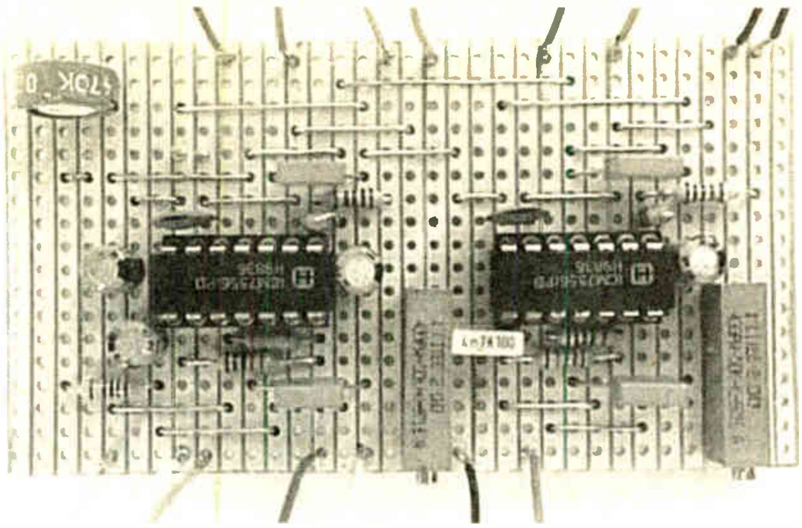
Fig.7. Mixer/relay (Board A) component layout, interwiring and details of breaks required in the copper tracks. The coloured lead-off wires go to corresponding points on Board B (Oscillator).

lead, and the cathodes (k) of diodes D2 and D3 are banded.

Prepare seventeen sheathed wires 15cm long – eight of which are colour-coded as shown in Fig.7. The colour-coded wires attach to the Oscillator Board (Board B) later. Solder wires to Mode Switch S1, power socket SK1 (Power In), jack socket SK2 (Out), l.e.d. D1, and two solder tags which each attach to a Test bolt as shown.

Finally, attach the leads from S1, SK1, SK2, D1 and the test bolts to the topside of the stripboard, and connect the colour-coded wires to the solder pins as indicated in Fig.7.

Check that all the wire links and components are correctly in place. Check that the track breaks are all there, and in the correct positions, and that there are no solder bridges on the board. The author routinely runs a thin, sharp screwdriver down between all the stripboard tracks.



Prototype Oscillator board (B) component layout.The author's stripboard has "phantom" strips printed on the topside to aid construction. The copper tracks run along the underside as usual.

PRELIMINARY TESTS

Meaningful testing can only be carried out once the Oscillator board has also been completed and connected up. For the time being, you may establish that regulator IC4 is supplying the correct voltage.

Attach a 9V PP3 battery to the battery clip, switch S1 to any position other than Off, and measure the voltage across capacitor C15. This should be close to 5V. The regulator i.c. should remain fairly cool, and supply current should not rise above 15mA.

If any specified components for the Body Detector cannot be sourced at this stage, it is important that equivalents should have *low* temperature coefficients – particularly capacitors C1 and C4 which should if possible have a *zero* temperature coefficient.

The multiturn potentiometer VR1 may be pricy. However, these devices may sometimes be obtained cheaply as surplus goods. Alternatively, use a cheap 470 ohms or 1 kilohms potentiometer, although this will not offer the same high degree of precision when it comes to calibration.

OSCILLATOR BOARD

Having completed the preliminary checks, we can now tackle the construction of Board B, which includes the h.f.o.s, the l.f.o., and monostable. We shall also be casing the unit, and calibrating it.

Taking the second piece of stripboard, again having 18 holes by 34 copper strips, create the breaks in the underside copper tracks with a drill bit or other appropriate tool. Details of the topside component layout, together with the underside details, are shown in Fig.8.

Solder in position the wire links and solder pins, then the dual-in-line sockets, then the resistors and multiturn presets, continuing with the capacitors. Be careful to observe the correct polarity of the electrolytic capacitors, and the correct orientation of IC1 and IC2, when inserting them into their holders. Pin 1 of IC1 and IC2 lies close to the small indentation on one end of their encapsulation.

Next, prepare seven sheathed wires 15cm long, and solder them to potentiometer VR1, the Sensor solder tag, and sections S1b and S1c of the Mode switch. Finally, attach the leads from VR1 to the solder pins on the topside of the stripboard, the wire from the Sensor solder tag, and then

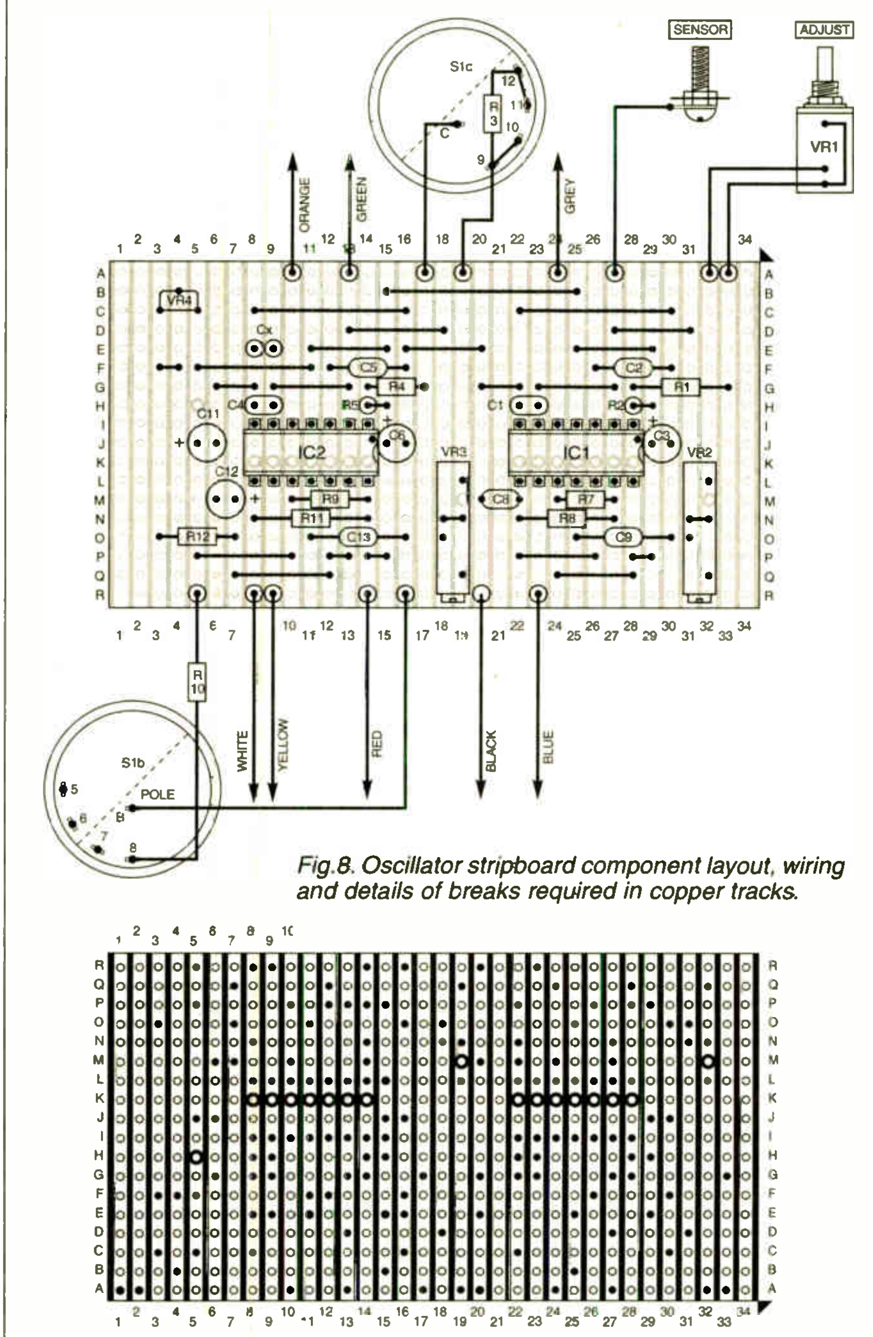


Fig.8. Oscillator stripboard component layout, wiring and details of breaks required in copper tracks.

the eight colour-coded wires from Board A, as indicated in Fig.8.

Jack socket SK2 is included for switching small external loads – a second jack socket may easily be added. Solder pins have been provided for this purpose at the opposite side of relay RLA, at board positions *R9* and *R13* on Board A. The specified relay is rated at 60W 250V a.c., and would therefore also be capable of switching small a.c. *resitive* loads.

WARNING: If the Body Detector is used to switch mains voltages, wiring should be carried out by an experienced constructor, or under expert supervision. Mains voltages are lethal.

SWITCHING ON

Since the Body Detector is intended to detect any and all body presence, an on/off switch that is mounted close to the circuit could in some instances present a problem. At the same time, to include any delays in triggering might be self-defeating, since some applications will require instant triggering (such as a "turnstile counter" or an anti-tamper alarm).

A key switch was thought to be the most obvious solution for switching off, and may be located some distance from the circuit. This may be inserted in place of (or in series with) S1a. Best of all, any delays in triggering should be included in the external circuit. The author mounted the on/off switch on the case for the purposes of neatness and easy setting up. In most applications, this did not cause the circuit to trigger when switching off.

However, solder pins have been provided for compensation capacitors (Cx) at positions *E8* and *E9* on the oscillator board (see Calibration below). Their insertion may be left until the circuit is complete, and is found to be working satisfactorily.

CASING UP

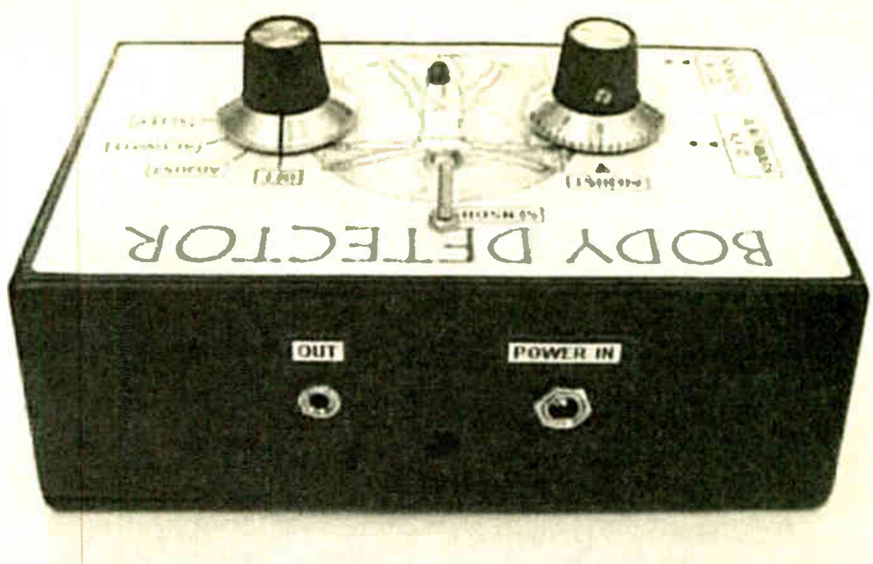
The Body Detector is built into a plastic case with slotted walls, size 158mm × 95mm × 54mm approx. Holes are prepared on top of the case for VR1, S1, l.e.d. D1, and the Sensor bolt. Two small holes are also carefully positioned on top of the case to expose multi-turn presets VR2 and VR3, so that these may easily be adjusted from outside the case.

It is suggested that the holes for the presets be clearly labelled, so that their purpose is not forgotten with the passing of time. The author has more than once returned to a past project, only to puzzle over what the various adjustments might once have been for!

Power socket SK1 and jack socket SK2 are mounted on the back of the case. (The author also drilled a hole there for the insertion of a thermometer).

The Test bolts and piezo disc WD1 are mounted on the front of the case. The piezo disc may be mounted behind a small hole on the front wall of the case.

Board B is slotted into the case with the multiturn cermet presets VR2 and VR3 face downwards. Cable ties may be used to tidy up the connecting wires. Make sure that the battery is secure, since a change in its position inside the case could slightly affect the unit's calibration.



Rear view of the completed Body Detector showing the power input socket and output socket. The author also drilled a hole between the sockets for the insertion of a thermometer. Note the sensor bolt on the top of the case.

CALIBRATION

To undertake initial setting-up, use a test lead terminated at each end with a crocodile clip. Attach one end to the Sensor bolt, and the other to a piece of tin-foil about 300mm square. Due to the sensitivity of the circuit, it is important that both ends of the test lead should have a sure connection.

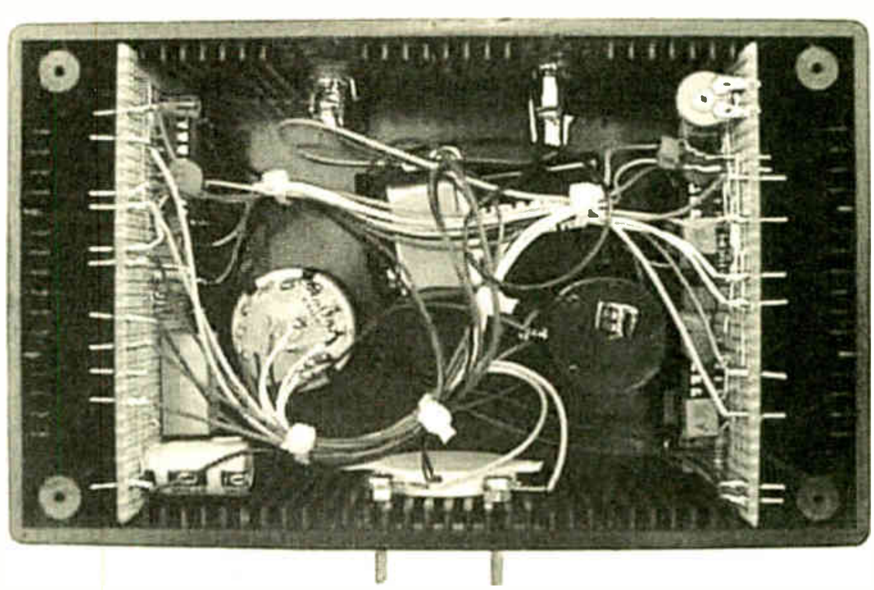
Turn carbon preset VR4 back completely. Turn multiturn preset VR3 to 40 kilohms (40k), and multiturn preset VR2 to its maximum setting (50k). Turn the multiturn potentiometer VR1 to its mid-point (usually five complete turns). Set switch S1 to Adjust position. If at any time the circuit does not behave as described, switch off immediately, and check the wiring carefully.

Now carefully turn back preset VR2 (it may need to be turned through several complete revolutions), until piezo sounder WD1 sounds and relay RLA triggers. Continue to turn back very carefully until WD1 merely crackles.

Be aware that the presence of your body may affect the tuning. Use a plastic or insulated screwdriver to turn VR2, and stand back from the circuit to see whether the crackling stops. If not, continue to back-off VR2 very carefully, until the crackle *just* stops (or *very nearly* stops) when you stand back.

Now set switch S1 to Activate. The unit should now react when your hand approaches the sensor plate, from a distance of few centimetres. Experiment a little to discover the best settings for preset VR2 and potentiometer VR1. A single "crackle" triggers monostable IC2b.

Note that the Activate position of S1 is optimised both for small sensors such as the 300mm square tin-foil sensor used in testing, and a moderate temperature range (10°C or 15°C variation). Other applications may require calibration in the Activate setting, monitoring the voltage across capacitor C10 by means of the Test bolts provided.



Internal layout inside the prototype model. The Oscillator board should be slotted into the case so that the side adjustment screws of the cermet presets align with the holes on the front panel (see photographs). Also shown are the two "test" bolts.

SENSITIVITY

Bear in mind that body capacitance varies from body to body. If you are of more impressive proportions, it may be worth setting up with the help of a smaller person, so that the alarm will detect such persons also – particularly in more demanding applications.

All in all, it is sensible to calibrate the Body Detector so that it is sensitive enough to safely trigger, yet not so that it comes too close to its trigger threshold. With lighter sensors, this can be achieved with ease.

A useful guide to calibrating the unit is provided by Fig.3 and Fig.4. It will be seen from Fig.4 that, with a lightweight sensor, a setting of about 300mV to 400mV above the trigger point should provide both good sensitivity and good stability.

After calibration, allow half an hour for initial "settling in" of the circuit – then re-calibrate. Check the calibration again after 24 hours. From a practical point of view such additional calibration may well not be necessary, however, this ensures optimal setting up as the components settle down.

Note that the value of the feedback resistor R6 was chosen carefully to optimise the circuit's performance between 10°C and 30°C. The value of this resistor is crucial to the stability of the circuit, and if the Body Detector is used under different circumstances, some experimentation with the value of R6 may significantly improve circuit stability (which is monitored, again, by the voltage across capacitor C10).

The value of resistor R6 was also selected deliberately so that the unit would be more likely to trigger at *higher* temperatures (it is easier to simulate higher temperatures than lower). This means that calibration under the warmest conditions anticipated should ensure no spurious triggering.

Mode switch S1 also provides a Sleep position. This is because it is better to put the unit "to sleep" than to switch it off when not in use, which obviates the need for a "settling in" period at switch-on.

Finally, adjust carbon preset VR4 to set the duration of the on-period of the relay on triggering.

OPTIMISATION

The Body Detector should work well under a wide variety of conditions without further modification. Ideally, however, it should be optimised for use with a specific metal sensor. Such optimisation is recommended.

The need for such modification arises because the attachment of a Sensor plate increases the value of sensor h.f.o. IC1a's timing capacitor C1. This means that multiturn preset VR2 needs to be turned back, which exposes "benchmark" oscillator IC2a to a little more frequency drift than IC1a (VR2 and VR3 are now unequal).

The solution is fairly simple. The type of timing capacitor selected (metallised ceramic plate) has a *zero* temperature coefficient up to 220pF. Therefore, by increasing the value of the benchmark-h.f.o.'s timing capacitor C4 (by adding Cx in parallel with C4), preset VR2 can again be increased to match VR3.

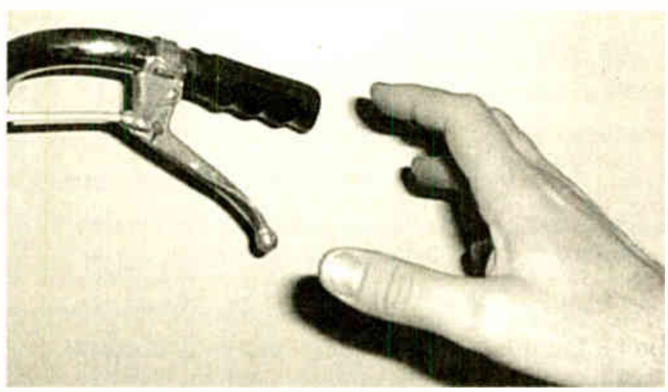
At first a formula was tried for calculating the value needed for Cx, however, this was not found to be dependable in practice. Therefore Cx is selected through trial and error – increasing its value until preset VR2 can be turned up again to roughly 40k (the same as VR3). With the 300mm square tin-foil sensor, the value of Cx will likely be in the region of 15pF.

Such final optimisation may be left until one has had the opportunity for experimentation, and has settled on a final application.

IN USE

Be sure to locate the unit itself in a place where it is relatively immune to body presence. Once initial setting-up has been completed, and if the unit and its sensor are not moved about, they should require no more than a little adjustment of the front panel dials for long-term, reliable service.

A wide variety of metal sensors may be tried. Note, however, that each time the sensor is exchanged, this is likely to require quick re-calibration of the unit. Always be sure to make a secure connection between the Sensor bolt and the sensor – this is important.



Try different shapes and sizes of tin-foil, also a *grid* made of tin-foil. Try zig-zagging or spiralling thin wire over a space (do not coil it), e.g. across the floor of a room. The centre-point of a wire spiral was found to be particularly sensitive. Such a spiral may be wound, for instance, under a carpet or around a door frame.

You may also experiment with larger objects such as a bicycle or a fridge door, which should serve quite well as sensors. Note that in the case of heavy metal items, a lighter sensor (insulated wire included) may usually be mounted on their surface, without any physical connection to the metal object, to far better effect.

Remember that the unit's sensor is also capable of picking up body presence through various materials – even through insulators such as glass.

When the Body Detector is attached to a metal object, whether to a pin or a motor-scooter, the *entire* object to which it is attached is sensitised.

For instance, if it is attached to the handlebars of a bicycle, it will reliably pick up fingers touching a rear-wheel nut. Only those parts of the bicycle which are *insulated* from the whole (through rubber washers, for instance, or even rust or loose bolts) will not be sensitised.

Having said this, an object need not always have physical contact with the Body Detector's sensor to become an *extension* of the sensor. As an example, a sensor plate may be placed under a table, and a tin placed on top of the table. With correct adjustment, the tin will become an extension of the sensor, as though it were directly attached to it.

Finally, with the proper adjustment and installation, nobody (no body!) should be able to slip undetected past the Body Detector! ☐

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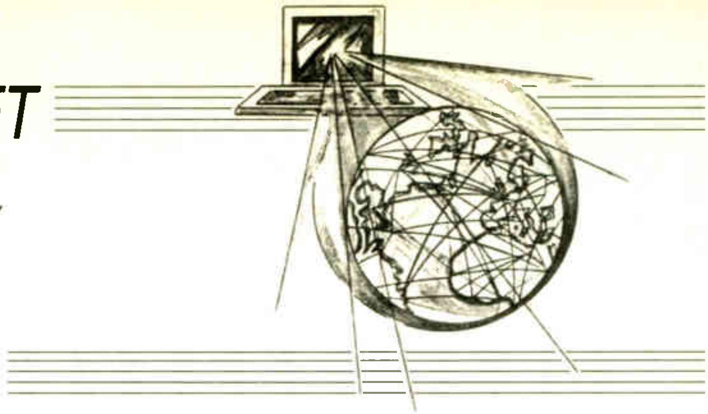


SURFING THE INTERNET

NET WORK

ALAN WINSTANLEY

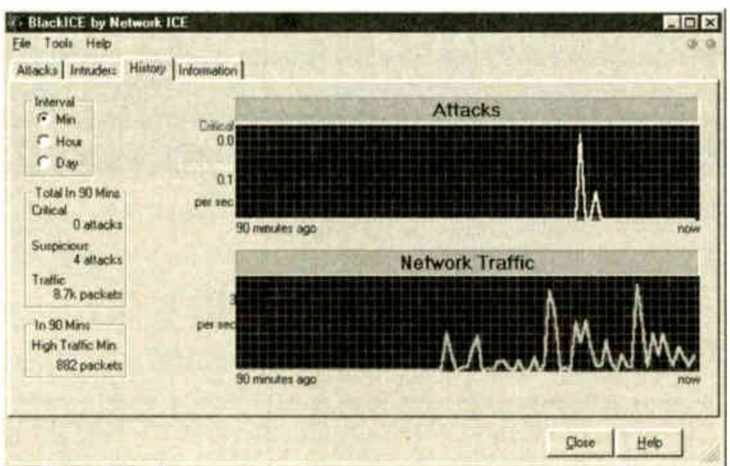
Firewall Software

ONE major concern of having fast "always on" Internet access (perhaps via a cable modem or DSL service) is that it exposes your system to outside attacks from hackers. This month's *Net Work* offers a background to firewall protection, and suggests some practical solutions that are readily available to help combat unauthorised intrusion.

A firewall system has been a necessity for savvy Internet users for years. They help to block unauthorised access to systems, and they are fast becoming as essential as anti-virus software. Some desktop software products such as Norton Internet Security (**www.symantec.com**) combine an anti-virus feature with an Internet firewall to offer good all-round system protection. Other firewalls are free and are worth checking.

For many inexperienced users, setting up such a firewall will probably be a daunting task: a badly configured one is about as much use as a smoke alarm with a flat battery. Norton Internet Security hides the trickier aspects as an advanced option which many users will be happy to leave at their default settings. The product also includes parental controls, ad. blocking filters and more.

More advanced Internet users may want to delve into the settings and configure the firewall for themselves. This process boils down to deciding what sort of traffic should be allowed to pass through your system in either direction. The firewall will block any traffic falling outside of these parameters, but deciding what should pass or not could become an involved process, especially when confronted by the baffling jargon of Internet protocols.



Any Port in a Storm

One particular function of firewall packages is to block access to unused "ports" that may be accessible on your system when it's online. Without delving deeply into the complexities of TCP/IP, a port is effectively a numbered gateway or address in a system which handles a specific flavour of Internet application traffic: these "applications" include common Internet services such as web (**http**) and file transfer protocol (**ftp**). Probably the best known TCP ports are Port 80 (**http**) and Ports 20 and 21 (**ftp**). However, there are some 65,000 such ports covering many more esoteric Internet applications, since one of the functions of TCP/IP is to send a multitude of different application data over a network simultaneously. A number of common ports are listed on the Nukenabber freeware Firewall web site (**www.dynamsol.com/puppet/nukenabber.html**).

Anyone trying to access a system from the outside will attempt to find a port that's been left wide open. The system owner may want to close the port if it's never needed. In fact some *EPE* readers occasionally report problems downloading files from our FTP site, which we think arises because they are working from behind a corporate system which has its firewall set to block FTP access. The problems disappear when they try again from home.

Some firewalls offer very good degrees of security without you needing to be an expert to set them up. One product I favour is BlackICE Defender by Network ICE which is based on a commercial network firewall product. It can be purchased from **www.networkice.com**, and it needs hardly any initial configuration at all. Just as anti-virus packages are updated for new virus information, BlackICE also allows for updates of the latest Trojan horse and port probes. As with some other firewalls, a modest annual subscription is required for this update service. Other firewall products are available for free. A few are listed later.

BlackICE is a sophisticated tool which they claim analyses the structures of packets of data rather than simply try to match patterns of events. It has a useful logging and graphical analysis of "attacks". Not all attacks are actually hostile – BlackICE will initially sound an alarm for, say, innocent UDP (User Datagram Protocol) port probes emanating from, say, an AOL or ICQ server. You can decide to "trust" these servers thereafter to prevent such alarms recurring. BlackICE does, however, recognise serious hostile attacks and blocks them accordingly. It also reports on the hacker's IP address.

I have used BlackICE for several months and I like the product: it has a good reporting system and is easy to use, and doesn't constantly "nag" you when operating. Without question the most regular forms of hostile "attack" BlackICE detects are the SubSeven and UDP Trojan Horse probes. What's happening is that thousands (or millions) of IP addresses – including ours – are constantly being scanned by hackers in search of a particular Trojan horse hidden on the target system. A Trojan horse can open a back door and reveal your system to hackers. A firewall blocks and reports such attacks as they occur. Other more sinister forms of probe, such as a Back Orifice port scan, are logged and stamped on immediately by BlackICE Defender.

Don't be frightened by all this activity, though. Port scanning or Trojan horse probes are quite commonplace and the chances are that you have probably never known they've happened to you. By using an extra module with BlackICE the attack details (including the time and their IP address) could be mailed to the hacker's ISP. However, BT Internet, for example, states that port scanning is not an illegal activity in itself although it may break the service's terms and conditions. If data theft is suspected, then the Police ought to become involved, says BT. So there's not much point complaining about port scans.

Freeware Firewall

Other popular firewall products include the highly popular ZoneAlarm (**www.zonealarm.com**) which unlike BlackICE Defender is free for non-commercial use. This may well satisfy the needs of many home users, though perhaps the paid-for BlackICE Defender may suit the more serious surfers looking for a hassle-free firewall system. Also consider Lockdown 2000 (**www.lockdown2000.com**), for more advanced users; they have a very informative web site as well. Some readers may recall Signal 9 Solutions (**www.signal9.com**) which produced Conseal Private Desktop, now sold by McAfee. Corporate Windows network users can visit **www.consealfirewall.com** though, where prices for multi-user network protection systems run into several hundred thousand dollars.

You can E-mail me at **alan@epemag.demon.co.uk**.

READOUT

E-mail: editorial@epemag.wimborne.co.uk

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

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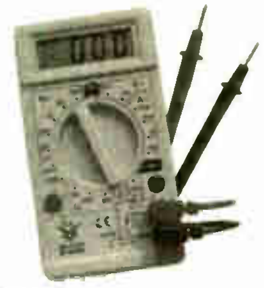


★ LETTER OF THE MONTH ★

WEBBED THANKS

Dear EPE,

Having recently discovered your web site, I wish to thank you for providing such an informative and thought-provoking *Illustrated History of EPE*. Having started in electronics, as a young teenager in about 1972, I was a regular purchaser of *EE*, which as you rightly state contained projects more suitable for the beginner.

Having mastered the resistor colour-code I surprised myself (and my family) in creating many a project involving infra-red beams, buzzers and sound generators! In those days, a 2N2926 (green) was the 741 of its day and, most importantly, within the pocket money range of a 14 year old. I must have bought dozens! Eventually I graduated to the lofty heights of *PE*, in about 1985, even having been paid £40 for a digital model railway train warning circuit in *Ingenuity Unlimited*.

My interest in electronics continued well into my University life, and despite reading a languages degree, was one of two people in the languages department who were given a computer account (back in 1976) for the college's Prime 300 computer.

During my last year of college, during which the Sinclair ZX80 came about, I realised that languages were not my forte, but computer programming was. A career ever since in computers was the reward for being interested in *EE* as a young lad! I even built my first computer in 1980, it being a UK101. The kit came with umpteen chips, resistors etc and had to be built from scratch – but it worked first time, thanks, I believe, to the soldering experience given to me by creating projects in *EE*.

Since then I have built a number of Intel-based PCs but my real love was discreet component electronics. Recently I have "returned to the fold", and my daughter now solders simple projects with me. Your recent fridge alarm project has been a wonderful success, if only in proving to my wife just how quickly the temperature in the fridge can rise if the door is left open too long!

At the age of 43, I have only recently discovered PIC chips, where electronics and computer programming truly meet, I am feverishly reading books from R. A. Penfold that describe their function and recently ordered the back issue for PIC Toolkit Mk2!

Thanks for a great magazine; the amalgamation of *EE* and *PE* has, to my mind, given the electronics community a magazine that covers all aspects of electronics, from beginner to expert. Long may you prosper and I look forward to the next issue!

Ralph S. Bacon, via the Net

It's heart warming to read such stories as you relate Ralph. There are many professional electronics and computing engineers who owe their choice of career through having read EE/PE/EPE, *including myself, giving up professional film making in about 1972 to further pursue what had just been a hobby, dominated by the influence of electronics mags.*

HARD GRAFT!

Dear EPE,

As a contributor to various magazines, including of course *EPE*, I get a lot of brainpick enquiries like those mentioned in the Jan '01 *Editorial*. I get them from students, often clearly at the suggestion of a class teacher, I get them from PR people, market analysts and TV researchers. All are looking for a short cut round research and reading. They would rather do lunch or play footie or video games than hard graft.

I was an idle student myself, who copied other people's essays, and I later wished they hadn't let me. That's why I have settled on a standard reply. If someone has clearly done a lot of their own research and run up against a brick wall on one or two key issues, I'll try to help. But I am not going to help them fool their teacher, examiner or boss. It seems far better for others who have done the hard graft to get the rewards and credit.

Barry Fox, via the Net

Well said, Barry. To which I would add that those things learned hardest are those that remain learned longest!

James Foo, whose letters are below, shows a good example of learning through perseverance.

PIC TUTOR

Dear EPE,

Can anyone tell me where I can find answers to the programming challenges presented in the *PICtutor* CD-ROM? I have become stuck on some them.

James Foo,
via the Chat Zone

I advised James that, quite deliberately, I did not include answers to the PICtutor *challenges. There are many ways of achieving the desired effect with any program and it is to get people thinking about the various options that these challenges were set.*

The intention is that you should keep thinking about what you might need to do, and try experimenting until you achieve what you want. It's the best way to learn. I originally taught myself PIC programming in this way without help. It's really very simple once you get your mind into gear! James later replied:

Thanks John, you are right, I have finally got my first tutorial challenges completed, two more to go.

A question about the *PICtutor* development board (which I have not yet bought): after I switch off the computer and the board power supply, will the data inside the chip stay intact? If yes, can I use the PIC chip for an actual purpose, running without the computer connected?

Glad to know you are getting on OK. Yes, the program stays in the PIC when the power is turned off, and the programmed PIC can be transferred to control another circuit without the computer being connected. That's the whole nature of PIC microcontrollers and their programmers (which is what the PICtutor *board is).*

MORE FLIGHT LOGGING (1)

Dear EPE,

The *Flight Logger* letter (Jan '01) raised a few concerns, due to the possible safety aspects concerned with modifying any aircraft, of which microlights are included. I am an aircraft electrician working with light aircraft and there are rules in place for everybody's safety.

Please do not get the impression that I am out to spoil Mike Woodmansey's fun, just the opposite, everything he requires can be obtained as a ready-made unit off the shelf at a reasonable cost (I will gladly give him names and addresses of suppliers). If Mike wants the satisfaction of making the unit himself I am happy to help in any way I can. It is also worth mentioning that, in general, people in aviation are willing to help others. There are also many organisations and clubs who are happy to help.

Please feel free to pass on my E-mail address to Mike: **mcqriffin@btinternet.com**

Mark Griffin, via the Net

A very generous offer, Mark. Thanks.

MORE FLIGHT LOGGING (2)

Dear EPE,

Referring to the request you had from Mike Woodmansey regarding the device for his microlight (Jan '01), I have details for a device similar to what he wants, designed by an Australian, available on the net (instructions and hex files). If you pass my E-mail on to Mike he can ask me to forward the details.

Thanks for a good mag. I've been reading it since I was 10 and it probably helped me get my degree as well!

David J. Owen Bsc, via the Net

Thanks, and congrats, David. If other readers ask us for the details, I hope you won't mind if we contact you. Mike Woodmansey, let us know how you are getting on.

PIC ECHO

Dear EPE,

I have been trying for a year now to find Bucket Brigade Device (BBD) i.c.s, to no avail.

How about designing a PIC digital echo project and allow all those past BBD projects to be resurrected?

Mike MacLeod,
Mossel Bay, South Africa

In fact, Mike, my Maplin CD-ROM says that the MN3004 BBD and its family are still available, so PIC equivalents seem unnecessary – yet! (I still lament the demise of the TDA1024 and TDA4096 around the late '80s!)

PIC FAILURES

The following paragraphs are a part of a "thread" topic that was recently woven on the EPE Chat Zone *(they are not necessarily in strict order owing to the nature of* Chat Zone *threads).* ***John Waller*** *started the weaving:*

Having previously thought how wonderful the PIC16F84 is, I have had two unexpected failures. Both failures occurred sometime during the re-programming process, not while in service.

One PIC has gone completely dead; won't do nuffin. The other PIC runs the main program loop, but some of the logical operations are incorrect, possibly consistent with one or more port failures. It is not a programming error, as several other PICs run the same program correctly.

It is probably coincidence, but the PIC running, albeit incorrectly, is the only one in the batch with 10MHz speed capability, and which was formerly configured for a crystal clock of less than 4MHz, and was changed to RC clock. All the other PICs running the program use RC clock, but were never configured for any other clock type.

Although not mentioned anywhere that I have seen, I always take anti-static precautions when handling a PIC. I am careful about plugging a PIC in the right way round, of course, but may have slipped up on the PIC which has died completely. Can anyone comment please? **John Waller**

As a frequent user of PICs I have reprogrammed individual ones well in excess of the data sheet life time quoted. The only time one has died on me was when I powered it incorrectly at 9V. They have been otherwise utterly reliable. Could it be that your code has become corrupted within the PIC, this seems to be a possibility in some circumstances of static electricity exposure. **John Becker**

I had considered the possibility of the code being corrupted, and have tried several times to reprogram, with the same result. Since almost everyone is saying how reliable and robust the PIC is, it behoves me to do further investigation. Interesting to read your comments about exceeding the flash memory re-programming limit. I am nowhere near that yet. What are the symptoms of flash memory failure, I wonder? **John Waller**

I don't know what an expired PIC might look like, maybe it just splays its legs out sideways! Who knows, anyone? **John Becker**

I have had mixed responses to whether backwards plugging a PIC wrecks it; some say yes, others say no. I suspect it is an over-current/heating problem, thus depends on how much current the regulator can provide and/or how long it is left in the condition. Thus, to extend your metaphor a little further, it may have splayed out some of its internal connections sideways! **John Waller**

Could be that you've been unlucky enough to get hold of PICs with programming threshold levels/timing at the extreme of the manufacturer's tolerance range. Microchip specify program verification at both $V_{dd} = 4{\cdot}5V$ and $V_{dd} = 5{\cdot}5V$ to ensure a good "erase margin" and a good "program margin". To me, this suggests that programming may be unreliable for chips near/outside the tolerance range. You did verify at both voltages, didn't you? **Geoff**

No Geoff, I did not (slap, slap). Does anyone do such verification? **John Waller**

I don't either; and I can't imagine anyone doing it for home-brew projects, but presumably it's done commercially. **Geoff**

Most commercial programmers should do it, but most home-brew ones (and a few cheap commercial ones) just do the whole lot at 5V. Microchip classes these as "experimental" programmers, the implication being that it should work, but we can't blame them if it doesn't. **Graham Bartlett**

And I've no wish to add dual-level verification to *Toolkit*! In fact I frequently work with *Toolkit*'s verification facility disabled (especially with the new *Toolkit TK3 for Windows* that I'm still developing). Also there are some programming readers whose computers are incapable of reading data back from a PIC. So unless you all besiege me with bribery, I'm not adding dual-level V! **John Becker**

I have plugged them in the wrong way round, more than once. All that happens is the 7805 gets hot and the PICs worked OK after being re-inserted correctly so I don't think that is your cause. I have found PICs to be very robust when abused. **Peter**.

I have worked on the errant PIC again. I re-re-configured the clock, just for the heck, RC to RC to RC. Before I did so, the old program was running, albeit with strange behaviour. After re-configuration the program would not run at all! Then I loaded a slightly revised version of my program, and it appears to run correctly, as far as I can tell from the *PICTutor* board setting. Both versions of this particular program run happily on other PICs.

It is not the first time I have had to redo configuring and programming to get a PIC running, but never to the extent as I have had to do with this particular PIC. The configuration was done thrice, and the program at least five times. To the best of my ability, I never expose a PIC to static electricity. But I don't monitor the programming lines from the PC; with Windows 95, since it is a Microsoft product, I suppose anything is possible. I'm kind of glad the *PICTutor* will not work with NT. **John Waller**

Anyone care to add to the discussion directly through Readout*?*

TOOLKIT HEX AND RC5 FIX

Dear EPE,

Using *Toolkit* V2.3 and V2.4, I tried to program a PIC with RC5.HEX from the *Remote control IR decoder* (Sep '00). I got "DOS error 14" and "String Error" part way into processing.

After some fiddling I discovered that if I deleted the config H'3FF9' line 5 of RC5.ASM and reassembled, the resultant hex file loaded into *Toolkit* OK without error.

I'm not sure what this directive does, and having looked in the MPASM manual I'm not much the wiser. But there's clearly an error in both *TK* V2.3 and 2.4, because it's legal MPASM syntax and therefore *TK* shouldn't barf at it.

Malcolm Wiles, via the Net

Several of you have reported Toolkit *Mk2 V2.3 and V2.4 giving problems when handling some HEX files. Examining the RC5.HEX file that Malcolm and some others referred to, I found that an address value in a line at the end (:02400E00F93F78) is far too high to be acceptable by* Toolkit*. The value is given by the 400E (hex 400E) section of the line, which is in excess of 16383.*

It is not known why such a high value should exist, but appears to be something to do with the MPASM configuration value embedded in the hex code. To fix the hex file directly, try setting the value to the next one up from that in the previous line, i.e. change the 400E to 01D0, resave and try Toolkit *again.* Toolkit *worked OK for me when I did it (having previously crashed as Malcolm found). I sent the code to a PIC16F84 and then dissembled the program. Examining the original RC5.ASM and decoded files seemed to show that nothing had been lost.*

Amended software (V2.4a) is available via the EPE *web site and on disk from the Editorial office. It intercepts values greater than 8191 (the maximum capacity of a PIC16F877), telling you if they exist, but still completing the process being done. Thanks to those who sent me files.*

Regarding "barfs", Toolkit *does not claim to be fully compatible with MPASM. In this context it is simply a platform which converts between the commonly found differences of MPASM and TASM. However, when significant differences such as this come to light, I shall be pleased to be told and will try to correct* Toolkit *to handle them.*

Since Malcolm first communicated, he has re-written the SIRC program for the IR Decoder*, adding several enhancements and text notes. The files, SIRCV2.ASM and SIRCV2.TXT, are available on* EPE Disk 3 *and our web site, with the original files, although we have not tested the amendments. Our thanks to Malcolm.*

Malcolm did comment however, that he felt such changes as he made should not have been necessary. He went on to say:

You have and maintain good standards for hardware design, p.c.b. layouts, etc, and rightly so – don't you have similar standards for the PIC source code that you publish? If not, you should have, because learners are going to use these programs as model answers and be unable to tell good practice from bad.

What Malcolm overlooks is that nearly all projects and software published in EPE *are designed by hobbyist readers. Hardware aspects we can and do vet for design "solidity". Software is another matter. There is no way that we can spend time analysing and re-writing readers' code. If the designs perform the function that they are intended to do, that is our only requirement regarding software.*

We do not expect the code to be written in the most efficient or professional manner. Even software written by beginners is acceptable if it achieves its purpose. Most readers will soon get to know whose software they can rely on for guidance on how to do things. But even experienced software writers may take short cuts and not fully optimise their code's efficiency – such matters can significantly add to development time.

I am reminded of the 18th century writer (name forgotten) who apologised for her letter being too long as she had not had time to shorten it! (A bit like with the subject being covered now!)

EXTENDING TOOLKIT

Dear EPE,

Five years ago after designing a project to help me with another hobby, I fancied re-creating it using a PIC microcontroller, not only to simplify the construction, but also as a challenge in itself.

I started by building a PIC programmer from *ETI* June '95 and followed it up with various exercises, e.g. alarm clock. But it was only with the arrival of your excellent *PIC Tutorial* board/articles that I eventually arrived at my destination, namely my MK2 project up and working (first time!), after nine months of construction.

A stumbling block I had to overcome was that the programmer used MPASM assembler, and I didn't fancy having to keep taking the chip in and out of the Tutorial board to place it in the programmer. Consequently I converted all the tutorials to MPASM using the utility from *Toolkit*'s software. Then I made a small p.c.b. to use as an "interface" adaptor between the *Tutorial* board and my programmer.

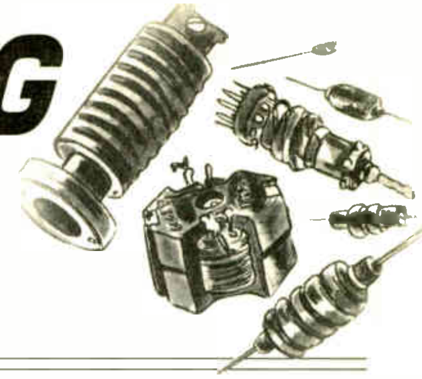
My local stockist says there are not so many enthusiasts actually building projects today as there were, say, ten years ago. Such a pity! Don't they know what satisfaction they're missing? I've been reading *(E)PE* since the mid sixties. Keep up the good work. The only problem I have is that I don't have enough time to build all the projects.

J.A. Houston, Sheffield, via the Net

A full round of applause from us for your ingenuity! Whilst the electronic d.i.y. hey-day peaked in the seventies, there are still many who do realise the sense of achievement that can be gained through our hobby. More power to us all!

Special Feature

UNDERSTANDING INDUCTORS



RAYMOND HAIGH

Chokes, coils and transformers all rely on the phenomenon known as inductance. This article takes a very practical look at these important components.

AT THEIR simplest, inductors are no more than coils of wire. They function in the way that they do because of electro-magnetism. What they do can best be illustrated by comparing them with resistors and capacitors.

IN COMPARISON

Resistors oppose the flow of current in a circuit. They affect alternating (a.c.) and direct currents (d.c.) in the same way.

Capacitors block direct current and oppose alternating current. For a given value of capacitance, opposition reduces as frequency increases: e.g. a 1μF capacitor presents a resistance of 1590 ohms at a frequency of 100Hz, and this reduces to 159 ohms when the frequency is 1000Hz.

Inductors allow direct current to flow but oppose alternating currents. For a given value of inductance, opposition increases with rising frequency: e.g. a 1H (henry) inductor presents a resistance of 628 ohms at 100Hz, and this increases to 6280 ohms at 1000Hz.

Inductors are, therefore, the electrical opposites of capacitors. Their frequency-dependant opposition to the flow of current is known as ***reactance*** to distinguish it from pure resistance.

INDUCTOR TYPES

Inductors are given specific names related to the circuit action they perform. When used simply to impede the flow of alternating current they are known as *chokes*. Teamed with capacitors to produce tuned circuits (more about this later) they are often referred to as *coils*. When they are tapped or have multiple windings in order to change voltages or match impedances they are called *transformers*.

Although transformer windings exhibit inductive reactance they function in the way that they do because of a related phenomenon known as ***mutual inductance***.

UNITS

The unit of inductance is the *henry* (symbol *H*). The amount of inductance used in a circuit depends on the frequencies being processed. Inductors operating at mains and low audio frequencies are usually measured in henries (H).

At high audio and low radio frequencies, values are usually expressed in milli-henries (*mH*). At medium and high radio frequencies, the micro-henry (μH) is a more convenient unit.

CORES

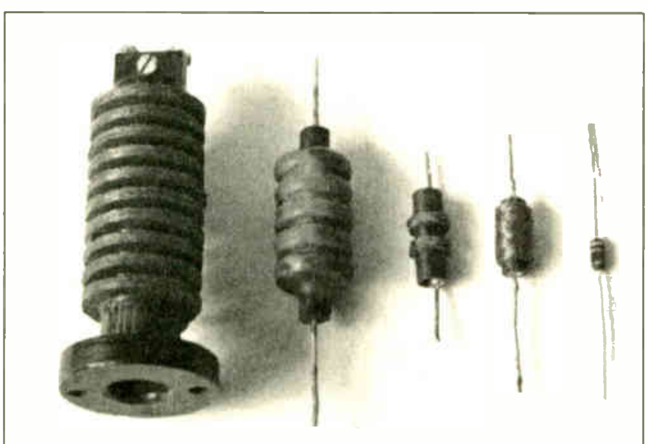
The high values of inductance used at mains and audio frequencies cannot be obtained by coils of wire alone. At these frequencies the coils are wound around cores of iron and its alloys (ferro-magnetic materials). This dramatically increases the magnetic flux and enables high values of inductance to be realised with components of manageable size.

GREAT NAMES

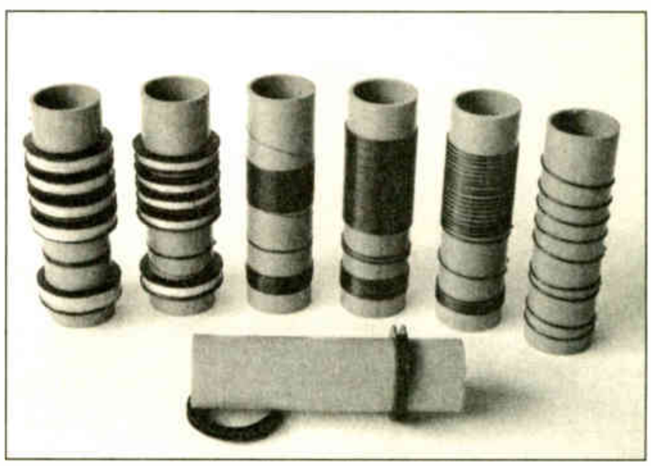
Three nineteenth century scientists worked independently on electromagnetism and induction. Michael Faraday (1791-1867) in England, Joseph Henry (1797-1878) in America, and Heinrich Friedrich Emil Lenz (1804-1865) in Russia.

Henry announced his discovery of self-induction, or inductance, in 1832, just ahead of Faraday. The unit of inductance, the henry, is so named in his honour.

About this time, Lenz defined the phenomenon. His definition has come to be known as Lenz's law.



Radio frequency chokes: The air-cored, pie-wound component on the left has an inductance of 8·5mH. The ferrite cored choke on the right is the same size as an 0·25W resistor. It has an inductance of 4·8mH.



Tuning coils for radio receivers: These hand-wound coils are illustrated in Fig.1, and details of the windings are given in Table 1 and Table 3. The card bobbins for the pie-windings have been dipped in black cellulose to stiffen them.

EDDY CURRENTS

Currents are induced in conductors placed in a changing magnetic field, and the iron core of a transformer is no exception. If cores were iron bars these eddy currents, as they are called, would flow freely and energy would be wasted as heat. This is why iron cores are built up from thin (0·3mm to 0·6mm) laminations, insulated from one another by a varnish or other coating.

At radio frequencies, laminations are not enough to prevent these losses. Sometimes the problem is avoided by not using a core (i.e. the coils are air-cored). Usually, however, the iron is reduced to powder and the bonding agent insulates the particles from one another. This measure enables cores to be used up to 300MHz.

The high inherent resistance of ferrites (ferro-nickel or ferro-zinc compounds) results in very low eddy current losses, making cores of this material suitable for use at radio frequencies.

CHOKES

Inductors which do no more than oppose the flow of alternating current are known as chokes. They are used to keep signal voltages out of power supply rails and to prevent fluctuations on power rails reaching signal circuits. Sometimes they block radio frequencies but allow lower, audio frequencies to pass (e.g., an r.f. choke placed in series with the output of a radio detector).

CHOKES AT R.F.

Radio frequency chokes were originally pie-wound on formers of insulating material (some transmitter chokes still are). Modern ferrite cored components are much smaller and range in value from 4·7mH down to 1μH. They are identical in appearance to resistors and are colour-coded in the same way to give the value in μH (micro-henries).

The choke winding is tuned by its own capacitance, and manufacturers usually quote the resonant frequency. Above this frequency, the self-capacitance will have an increasing shunt effect, passing the radio frequencies which are supposed to be blocked. The problem is greater with miniature chokes, which are layer-wound, than with pie-wound components.

If it is necessary for the choke to be effective over a particularly wide range of frequencies, try connecting two or more in series, placing the component of lowest inductance closest to the signal source.

LOW FREQUENCY CHOKES

During the valve era, high inductance chokes with cores of soft-iron or mild steel laminations were a standard feature in power supply smoothing circuits. In the early days of radio they were also used as valve anode loads. Smoothing chokes had values of around 10H or more, whilst those used as valve anode loads ranged up to 50H in order to maintain amplification at low audio frequencies.

Low frequency chokes are now seldom encountered. Power supplies rely on high values of reservoir capacitance and/or electronic regulators to eliminate supply line ripple.

Table 1: Hand-wound coils on 22mm diameter formers
Tuned with a 10pF to 200pF variable capacitor.
(Total stray capacitance 25pF)

Range	No.of turns	Wire S.W.G.	Wire A.W.G.	Inductance μH	Coverage MHz	Winding details
1	500	36	32	3650	0·18 - 0·43	4 pies of 125 turns
2	220	36	32	740	0·4 - 0·9	4 pies of 55 turns
3	95	36	32	145	0·9 - 2·3	Close wound
4	52	24	22	20	2·0 - 5·4	Close wound
5	21	24	22	5	4·8 - 15	Spaced over 40mm
6	7	24	22	1	11 - 30	Spaced over 40mm

See Fig.1. for details of construction. "Pie-wound" is the traditional term for a pile-wound coil.

PIE-WOUND
Pie-wound is the traditional way of describing a coil where the turns of wire form a number of piles, spaced apart to reduce the self-capacitance of the winding.

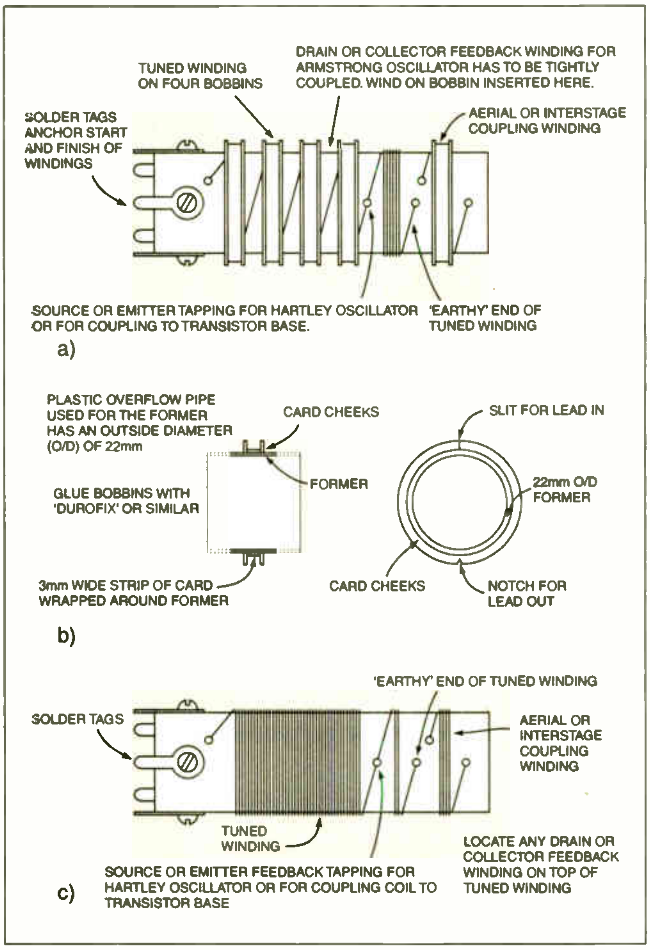


Fig.1. Constructional details for air-cored, hand wound, radio frequency coils. (a) long and medium wave pie-wound coils, (b) details of card bobbins and (c) single layer shortwave coil. See Table 1 and Table 4 for winding details.

COILS

Inductors used in the tuning circuits of radio receivers are commonly referred to as coils. When they are connected in series or parallel with a capacitor they resonate, electrically, at the frequency at which the inductive and capacitive reactances are equal. At resonance, the coil/capacitor combination magnifies signal voltages.

This property of tuned circuits makes radio transmission and reception a practical possibility.

'Q' FACTOR

The amount of magnification depends almost entirely on the "Q" factor of the coil.

Being made of wire, coils inevitably have resistance. The Q factor is the ratio of the coil's inductive reactance at a particular frequency to the pure resistance of its windings. The lower the winding resistance, the higher the Q.

Loading the coil with amplifying devices (valves or transistors) reduces the effective, in-circuit Q, but factors in the region of 100 can be achieved with good design. If a 10mV signal is applied to a tuned circuit with a Q of 100, the voltage developed across it will be 100 × 10mV or 1V.

The fact that the signal magnification peaks at a particular frequency enables a radio receiver to select one signal from the many being transmitted across the r.f. spectrum.

COIL PACKS

Tuning to different frequencies is normally accomplished by making the capacitor variable. However, there are limits to the maximum capacitance which can be employed, and a number of coils of different inductance are switched into circuit to enable a receiver to tune from, say, 150kHz to 30MHz. The collection of coils and the switch are usually referred to as a "coil pack".

Inductors of this kind can be wound by hand without too much difficulty. Full details of a set of inductors to cover the above frequency range are given in Fig.1 and Table 1.

Table 2: Miniature cup-cored coils in 10mm x 10mm cans
Winding Details
(Stated coverage assumes a 360pF tuning capacitor and 25pF total stray capacitance)

Range	No. of turns	Wire S.W.G.	Wire A.W.G.	Nominal Inductance μH	Coverage MHz
1	100	44	40	360	0·45 - 1·6
2	40	44	40	45	1·25 - 4·75
3	15	36	32	5·5	3·5 - 13·5
4	7	36	32	1	8 - 30

Notes: (1) The cores permit a wide range of adjustment, typically ±20% of the stated inductance value.
(2) The material and construction of some cores may not be ideal for the Range 4 coil, but performance should be acceptable for non-critical applications.

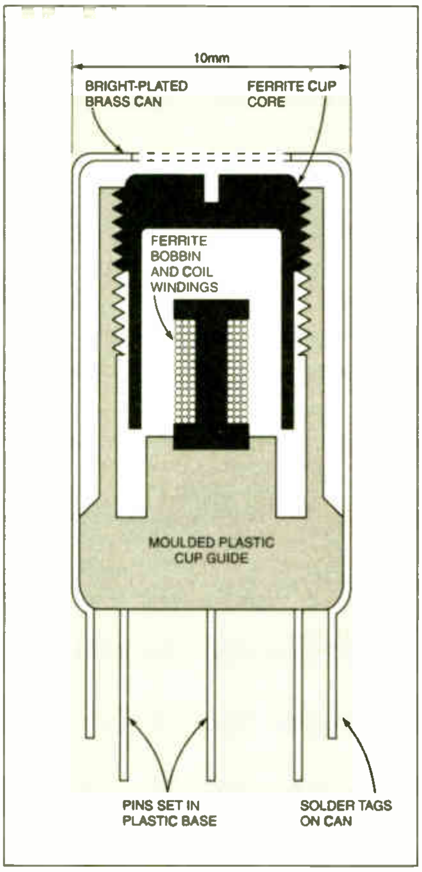
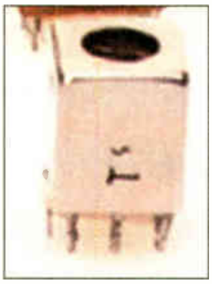


Fig.2. A much enlarged cross-section through a miniature ferrite cored coil (they are about 10mm x 10mm x 12mm tall). See Table 2 and Table 4 for winding details.



INDUCTANCE

When a switch is closed and current begins to flow through a coil, it builds up to its final level gradually, not instantaneously. The delay is caused by a voltage, induced by the growing magnetic field, which produces an opposing current. When the applied current is switched off, a reverse voltage is induced by the collapsing magnetic field. This tends to uphold the current and keep it flowing.

Apart from the brief switching periods, the coil has no affect on direct currents. However, with alternating currents, which repeatedly cycle on and off and change polarity, it continuously opposes the flow.

This phenomenon is known as self-induction or *inductance*. It is described more succinctly in Lenz's law, which states that: a voltage induced in a circuit always acts to oppose its cause.

MUTUAL INDUCTANCE

One coil, through its changing magnetic field, can induce a voltage in another. This phenomenon is known as *mutual inductance*. Its most common application is the mains transformer. Transformers step voltages up or down, and match impedances, simply and efficiently.

MINIATURE COILS

Modern receivers use miniature coils with adjustable ferrite or dust iron cores. The type in bright plated 10mm square cans is ubiquitous and will be recognised by anyone who has removed the back of a transistor radio.

With a little care, these coils can be salvaged and re-wound. Use de-soldering braid to remove as much solder as possible, then, very gently, ease the pins and can tags from side-to-side to free them from the p.c.b. The component can then be lifted clear and the coil in its cup core pushed from the can.

After removing existing windings and any tuning capacitor in the base, the core can be re-wound. An enlarged view of the construction of these coils is shown in Fig.2, and Table 2 gives winding details for a range of inductance values.

The central core can usually be separated from the plastic cup guide (insert a sharp blade *beneath* it) for rewinding and then re-fixed with Superglue. Alternatively, the wire can be fed down a short length of thin plastic insulation to permit re-winding in-situ.

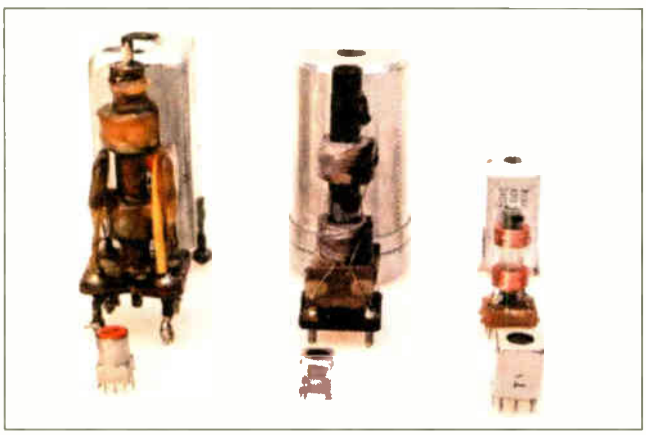
TOROIDS

Coils of very high Q can be wound on dust-iron or ferrite rings, the core material being graded to suit different frequency ranges. Manufacturers' of these toroids, as they are called, quote a simple formula which accurately relates number of turns to inductance.

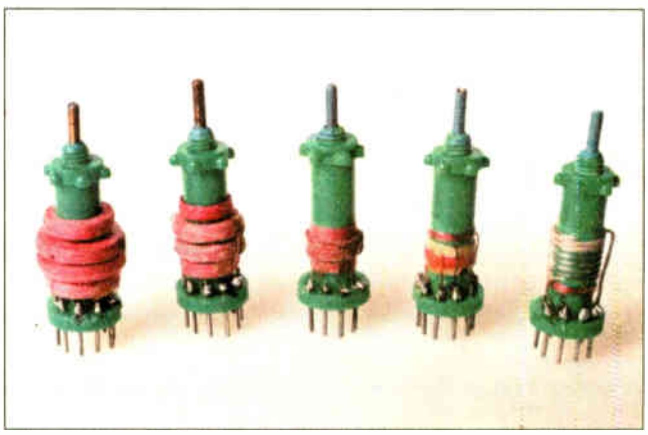
The toroidal form reduces the stray magnetic field to an absolute minimum, and coils of this kind do not require screening cans. Higher Qs can be achieved with ferrite materials, but the core is more easily saturated. In situations where frequency stability is important, iron dust toroids are to be preferred.

AUDIO FREQUENCIES

Combinations of inductors and capacitors are sometimes used to form frequency selective networks at audio frequencies. The fairly high value inductors, typically 10mH to 1H, are prone to picking up mains hum and have to be sited and orientated (relative to any power transformer core) with care. It is mainly for this reason that they have been largely replaced by active filters designed around operational amplifiers and RC (resistor/capacitor) networks.



Tuned r.f. transformers: These inductors tune and couple the stages in a radio receiver's intermediate frequency (i.f.) amplifier. The two large, double tuned transformers are for use with valves; the rest are for transistorised equipment. The component centre front is 7mm square.



Tuning coils: Machine-wound coils on 9mm diameter formers with dust iron cores. Five coils together with a 10pF to 330pF tuning capacitor cover 150kHz to 30MHz. Originally manufactured by Denco, we understand they are no longer in production.

INDUCTORS IN TUNED CIRCUITS

Connecting an inductor in parallel or series with a capacitor forms a tuned circuit that will resonate at a specific frequency. The formulae relating inductance, capacitance and frequency are:

$$f = \frac{0{\cdot}159}{\sqrt{LC}} \qquad L = \frac{0{\cdot}025}{f^2C} \qquad C = \frac{0{\cdot}025}{f^2L}$$

where frequency, f, is in Hertz; inductance, L, is in henries; and capacitance, C, is in Farads.

With these values the formula is only suitable for the lowest frequencies, and it is often useful to express it in smaller units. Accordingly, when f is in kHz and L is in mH and C is in μF :

$$f = \frac{5{\cdot}033}{\sqrt{LC}} \qquad L = \frac{25{\cdot}33}{f^2C} \qquad C = \frac{25{\cdot}33}{f^2L}$$

and when f is in MHz, L is in μH and C is in pF:

$$f = \frac{159{\cdot}155}{\sqrt{LC}} \qquad L = \frac{25330}{f^2C} \qquad C = \frac{25330}{f^2L}$$

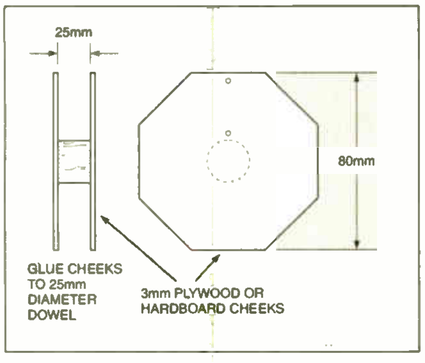


Fig.3. Details of former for loudspeaker crossover unit coils.

There are occasions, however, when an inductor represents the best solution, and a variety of miniature, ferrite cored coils are manufactured in a range of appropriate values. Larger ferrite cores, complete with bobbins, can be used for hand-winding. Again, the manufacturers give a simple formula relating turns to inductance.

Coils and capacitors are widely used in loudspeaker frequency dividing circuits. An inductor, placed in series with the bass speaker, will increasingly attenuate rising frequencies. A capacitor, wired in series with the treble speaker, will progressively attenuate falling frequencies. In this way a gradual crossover is produced: hence, crossover network.

These inductors are often air-cored and wound with heavy-gauge wire to minimise resistive losses. Laminated iron or ferrite cores are sometimes used to reduce the amount of wire, but care has to be taken to avoid core saturation at high power levels, which would introduce distortion. Inductor values depend on speaker impedances, the crossover frequency and the type of circuit adopted, and range from 0·5mH to 10mH.

Constructional details of crossover unit coils are given in Fig.3 and Table 3. Around 1kg (2lb) of wire will be needed for the largest coil.

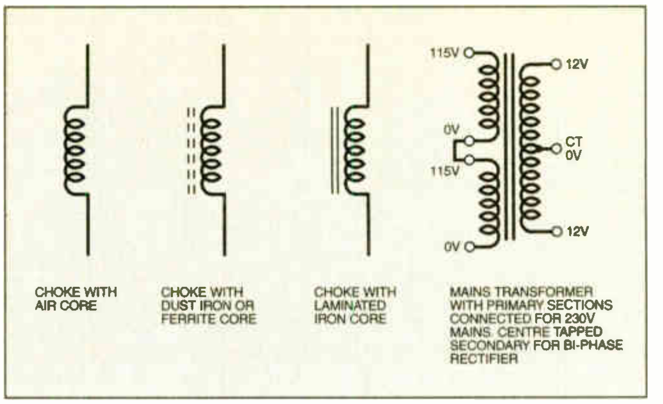


Fig.4. Typical circuit diagram symbols for inductors and mains transformer.

TRANSFORMERS AT R.F.

Tappings are often made, and coupling windings added, to the inductors which form tuned circuits in radio receivers. In this way the inductor can be made to match impedances as well as facilitate tuning. It is then known as a "tuned r.f. transformer".

Transformer action is made possible by *mutual inductance*. If two coils are wound reasonably close together on the same former, or share the same core, a signal voltage applied to one creates a changing magnetic field which acts on the other. Impedances are matched simply by adjusting the turns ratios of the two windings.

Table 3: Air-cored inductors for loudspeaker crossover networks.

(Inductance values approximate. Use 18 s.w.g. or a.w.g.).

Inductance (mH)	0.5	1	2	3	4	5	6	8	10
Turns	130	210	310	380	440	480	520	600	650

See Fig.3. for details of former.

CALCULATIONS

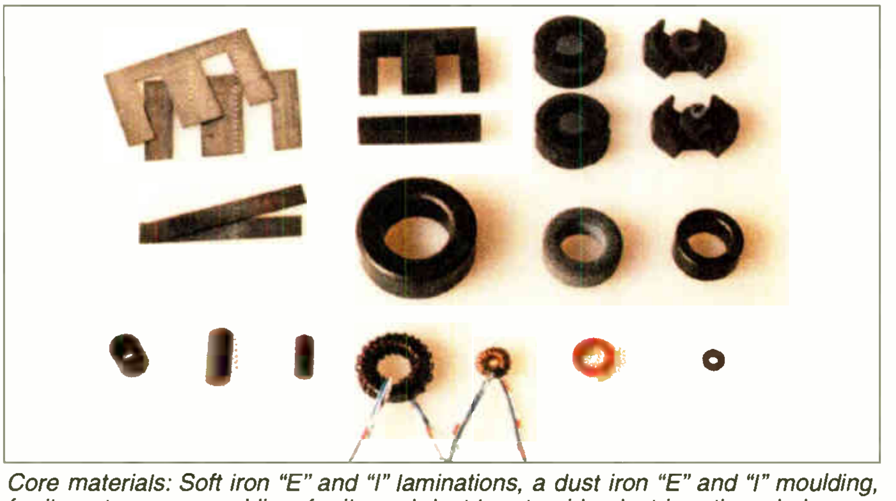
Formulae have been devised to enable the inductance of single layer and pie-wound air-cored coils to be calculated. They all give results which are approximate to varying degrees, and they are all rather complicated.

If a coil of known inductance is required and measuring equipment is not available, more reliable results will be achieved, with less effort, by using toroids or the special ferrite cores described earlier.

The impedance of a parallel tuned circuit is quite high. The impedances presented by the base and collector circuits of bipolar transistors are low. Connecting them directly across the tuned winding would, therefore, seriously impair performance. This problem is overcome by connecting the transistor via tappings or coupling windings which have fewer turns than the main tuned winding.

Whilst there is a formula relating impedance ratios to turns ratios, tuned

Loudspeaker crossover coil: Commercially produced 1mH loudspeaker crossover unit inductor. This air-cored coil has an outside diameter of 50mm and is 25mm long.



Core materials: Soft iron "E" and "I" laminations, a dust iron "E" and "I" moulding, ferrite pot core assemblies, ferrite and dust iron toroids, dust iron threaded cores: different materials for different frequencies. The wound toroids are large and small versions of the broadband transformer illustrated in Fig.6.

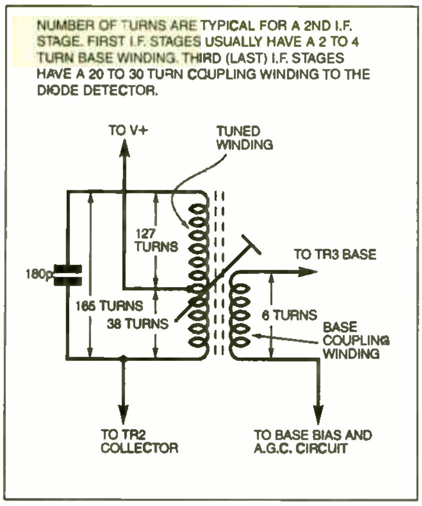


Fig.5. Tuned radio frequency transformer. The tapping and coupling winding arrangement is typical of a 455kHz intermediate frequency transformer (i.f.t.) used with bipolar transistors. See Fig.2 for details of cup core.

Table 4: Tuning coil coupling and feedback winding ratios
(Expressed as a percentage of the turns on the tuned winding)

Winding	Per cent	Notes
Long wire aerial	25	Loosely couple with air-cored coils
Transistor base	2-15	Selectivity/signal transfer compromise
Transistor collector	20-60	Selectivity/signal transfer compromise
F.E.T. gate	100	Direct connection to tuned circuit.
F.E.T. drain	20-60	Selectivity/signal transfer compromise
Diode detector	30-100	Selectivity/signal transfer compromise
F.E.T. Armstrong oscillator: drain feedback	10-50	10% on coil ranges up to 2MHz, then increasing to 50% at 20MHz and above. Tightly couple to tuned winding.
Hartley oscillator: emitter or source feedback tapping	4-25	Keep low for regenerative detectors and *Q* multipliers: 4%-5% up to 20MHz, then 20%-25% on highest frequency coil.

Increasing the size of inter-stage coupling windings reduces the stability margin.

circuits are sometimes under-coupled to minimise damping and improve selectivity, or over-coupled to increase signal transfer. Typical coupling and feedback winding ratios are given in Table 4.

The intermediate frequency (i.f.) transformers used in radio receivers are the perfect example of components of this kind, and of the practice of modifying turns ratios. The first i.f. transformer is usually under-coupled in order to improve strong-signal handling: the last over-coupled to the diode detector to maximise signal transfer.

The winding arrangement of a typical i.f. transformer, for use with bipolar transistors, is shown in Fig.5.

TRANSFORMERS AT A.F.

Transformers are now seldom used to match impedances in audio amplifiers. Even the designers of inexpensive transistor radios have largely abandoned the practice.

Audio transformers were almost universal during the early years of the valve era and were resurrected again during the 'sixties when transistors were first introduced. By matching the impedance of the anode or collector of one stage to the grid or base of the next they optimised signal transfer and made the best use of the then expensive valves and transistors.

Frequency response and distortion figures are inferior to those realised with *RC* (resistor/capacitor) coupling, but this is not noticeable when the final link in the chain is a small loudspeaker in a plastic box.

Audio transformer core laminations were generally of soft iron, but silicon steels were used in quality components. Microphone transformers, which are still widely used, often have Mumetal cores. Whilst this special steel has otherwise excellent magnetic properties, it saturates easily and can only be used at very low power levels.

The windings comprised a great many turns of fine wire in order to produce the inductance values necessary to maintain a response at low audio frequencies. Primary and secondary windings were sometimes sectionalised and interleaved to improve performance at high frequencies.

CORE SATURATION

Chokes and most audio transformers carry direct current to valves or transistors. Increasing the direct current reduces inductance as the core is driven towards magnetic saturation. Most manufacturers quote an inductance value for chokes at or below a particular current level.

To minimise the effect in components with laminated cores, the "E" and "I" stampings are butt-jointed rather than interleaved, and a layer of thin paper is inserted to separate the two sections. The gap significantly reduces the magnetising effect of the direct current flow.

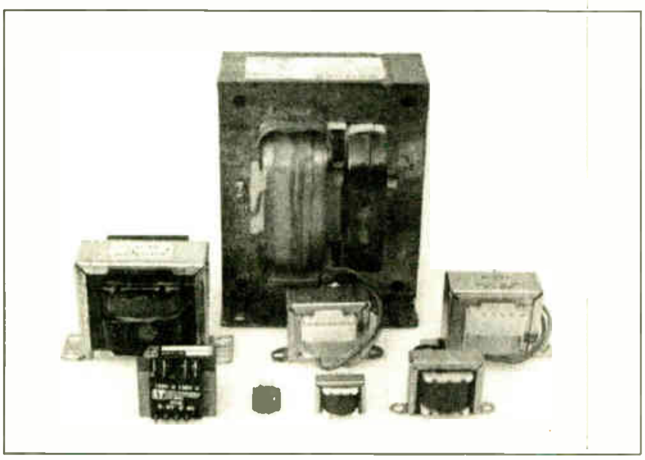
POWER TRANSFORMERS

By far the most common application of mutual inductance is the mains transformer. Indeed, the ability to step voltages up or down so easily is the dominant reason why alternating current power supply systems are virtually standard, world-wide.

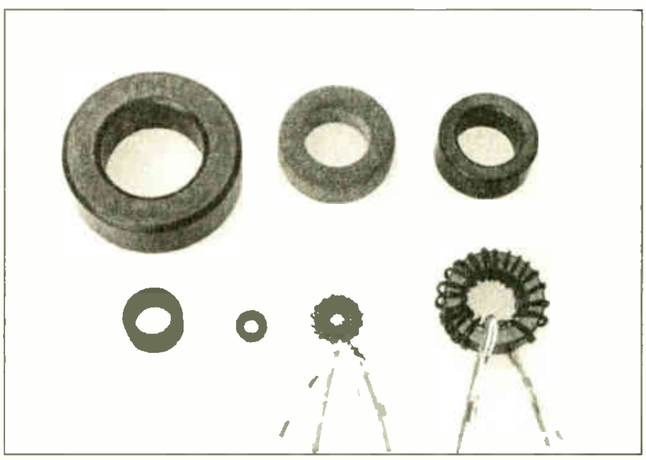
Separate *primary* (mains) and *secondary* windings isolate equipment from the lethal (in Europe) supply voltages. When isolation is not necessary, the transformer can have a single winding with tappings to produce the desired voltages. It is then known as an autotransformer.

Voltage ratios are the same as the ratios between the number of turns on the windings. The power, *volts × amps*, which can be delivered by the transformer is determined by the cross sectional area of its laminated iron core. The number of turns-per-volt on the windings is also related to core size (bigger cores need fewer turns).

A properly designed transformer will run at little more than room temperature and its output will not vary excessively with changes in load. In low cost equipment, reliance is often placed on electronic regulators to eliminate output variations, and skimping on core size and turns-per-volt results in the transformer becoming quite hot.



Transformers and chokes: These mains and audio frequency transformers and chokes all have cores built up from soft iron laminations. The largest transformer is 14cm tall, the smallest 10mm.



Ring cores: Ferrite and dust iron ring cores can be used from 100kHz to 250MHz (usually dust iron above 30MHz). The wound toroids at the front are small and large versions of the broadband transformer illustrated in Fig.6.

IMPEDANCE

The formula relating impedances to transformer ratio, n:1, is:

$$n = \sqrt{\frac{\text{higher impedance}}{\text{lower impedance}}}$$

MAINS POWER TRANSFORMERS

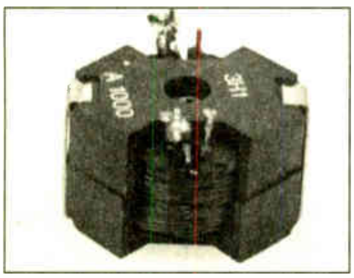
The minimum cross sectional area of the core is governed by the power, VA (volts x amps), to be delivered by the secondary. It can be calculated with the following formula:

$$\text{Core area in square inches} = \frac{\sqrt{VA}}{5{\cdot}58}$$

When the core area has been established, the number of turns per volt can be calculated by using one of the following formulae:

$$\text{Turns per volt (50Hz mains)} = \frac{8}{\text{core area (sq in)}}$$

$$\text{Turns per volt (60Hz mains)} = \frac{6{\cdot}5}{\text{core area (sq in)}}$$



Ferrite core assemblies of this kind are ideal for hand winding accurate inductors in the 1mH to 1H range. An adjustable core enables the inductance to be trimmed by ±2%.

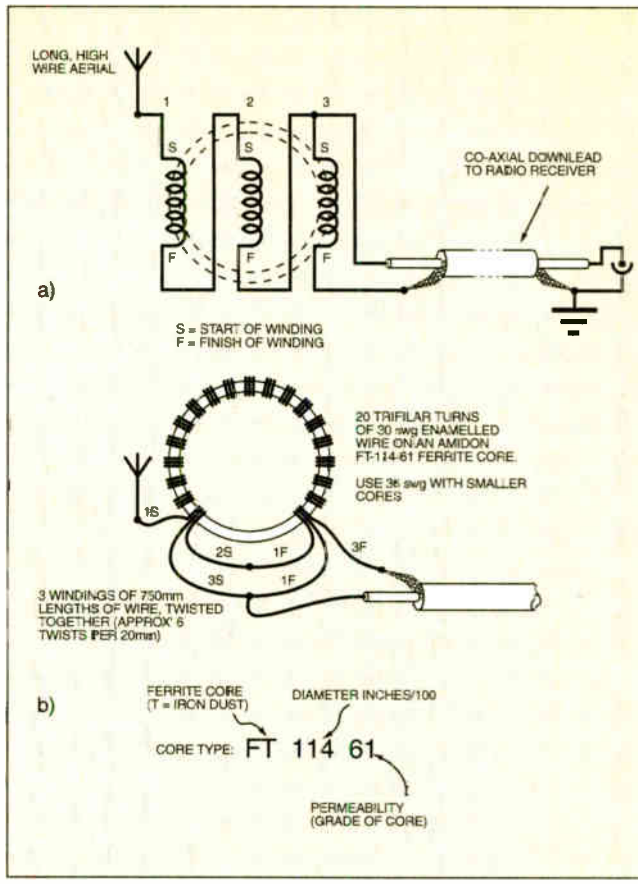


Fig.6. Broadband, toroidal r.f. transformers for connecting a long wire aerial (10m plus) to receiver, via a screened download to minimise interference pick-up. (a) circuit and (b) connections to coil. A type 61 ferrite (0·2 to 30MHz : permeability 125) should be used, but smaller cores are acceptable, down to FT37 (0·37in. or 9·4mm O/D). Smaller cores will cause some signal loss below 1MHz.

Transformers produced for sensitive equipment sometimes incorporate a "Faraday screen" between the primary and secondary windings. This comprises a layer of thick copper foil, insulated to prevent it acting as a shorted turn. The screen is earthed to limit the transfer of r.f. noise and voltage spikes to the equipment, or the escape of interference from the equipment into the mains wiring.

REWINDS

Transformer secondaries are fairly easy to rewind to change the output voltage. Small transformers often accommodate the primary and secondary windings on a two-section plastic former, and this makes the process a little easier.

But first we have to determine the number of turns per volt adopted by the manufacturer. **Warning: You must disconnect from the mains first BEFORE carrying out any of the following operations. Also, always check your set-up for safety BEFORE switching on.**

Connect the transformer to the mains and measure the off-load output voltage of the secondary winding with a decent multimeter. Switch off. Then remove the frame and any bolts which hold the core laminations together. Bend the outermost "E" stamping clear of the stack, grip it with pliers and withdraw it. This may take considerable effort. Continue until the entire core is removed.

Unwind a round number of turns from the secondary. Ten should suffice with large transformers: twenty with small. Reassemble the core and check the voltage again.

The number of turns removed divided by the voltage reduction represents the number of turns-per-volt. The turns which will have to be removed to produce the reduced voltage can now be calculated.

If the transformer is to be operated close to its maximum ratings, it is a good idea to allow in the calculation for the secondary to be 5 per cent or so over voltage, off load, to allow for winding resistance and other losses.

Sometimes there is enough space for turns to be added when a small increase in output voltage is required. It is usually necessary, however, to rewind the entire secondary with finer wire. Refer to wire tables, which quote turns per square inch and safe current ratings, in order to select a suitable gauge of wire.

The rewinding must be neat or it will not be possible to accommodate the required number of turns, despite the thinner wire. Moreover, a scrambled winding is more vulnerable to shorted turns which would make the transformer useless.

Readers who have no experience of working with mains powered equipment are reminded that the voltages involved are LETHAL. If you feel you lack the skill and confidence to carry out a rewind, it is better and safer to purchase another transformer.

BALUNS

Balun is an acronym for **bal**anced to **un**balanced. Baluns are transformers used to couple a balanced impedance or signal source to an unbalance transmission line, e.g. a dipole aerial to coaxial cable.

Dust iron and ferrite beads and toroids are commonly used for transformers of this kind. The various sections of the winding are twisted together (about six twists per inch), before being wound onto the core, in order to ensure the tightest possible coupling. Bi, tri, and quadrafilar arrangements permit a variety of transformer ratios.

BROAD BANDS

The term balun has come to be used somewhat loosely, and incorrectly, to describe any broadband r.f. transformer wound in this fashion, even when it is being used for impedance matching rather than balancing.

Ferrite materials are usually preferred for untuned, broadband transformers operating at low power levels, and the grade of core material has to be selected to suit the frequency of operation. However, when used in this way, the useful frequency range is extended by a factor of ten or more.

Details of a broadband transformer suitable for matching a "long wire" aerial to a coaxial downlead are given in Fig.5. (Use a multimeter, set to an Ohms range, to identify the start and finish of the three windings).

This arrangement works extremely well with little or no loss of signal from 150kHz to 30MHz. It is not suitable for transmission purposes, but serious listeners who use an external aerial and suffer from local electrical interference will find it makes a great improvement.

Long wire aerials present an impedance of between 400 ohms and 800 ohms and the input impedance of a communications receiver is usually 50 ohms. The 3:1 transformation provided by the trifilar winding is, therefore, accurate enough when the aerial is used only for reception. (See formula panel). □

INTERFACE

Robert Penfold

MULTI-CHANNEL ANALOGUE-TO-DIGITAL CONVERTER PC INTERFACE

THOSE who can remember back to the days when home computers such as the BBC Model B were all the rage will no doubt also remember that computers such as these were bristling with ports. In addition to standard serial and parallel ports the BBC Model B had a user port, an expansion bus, and an analogue port.

The latter was a 12-bit type, although due to noise problems its usable resolution was somewhat less than this. By any standards the conversion rate was slow, but it was still adequate for applications such as temperature interfaces and simple test equipment.

The usefulness was boosted by the provision of four analogue inputs. In a temperature measuring application for example, it was quite possible to simultaneously measure temperature in four locations.

usually of any great consequence, but it does mean that the maximum sample rate per channel reduces as more channels are used.

If the converter can handle 100,000 conversions per second, when used in four channel operation it would offer an absolute maximum of 25,000 conversions per second (100,000/4 = 25,000) for each channel. In many practical applications a sample rate of only 100 per second or less is required, so even using 10 or 20 inputs would not overtax a typical analogue-to-digital converter chip.

4-Channel A/D Converter

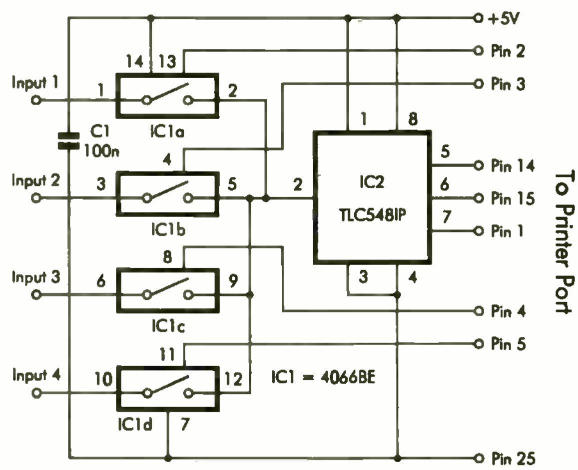
The circuit diagram for a four-input analogue-to-digital converter that is based on a TLC5481P 8-bit serial converter chip is shown in Fig.1. This is the same

Table 1: 4-way Channel Selection

Decimal Value	*Input Selected*
1	Input 1
2	Input 2
4	Input 3
8	Input 4

This method works well enough, but it is not very efficient in that it requires one output line per input. Also, care has to be taken to avoid setting more than one control line high, which would select two or more inputs at once. This would be slightly risky since two or more of the outputs driving the converter would be connected together via the CMOS switches.

The resistance through each switch is a few hundred ohms, which should be sufficient to avoid any damage, but it is best



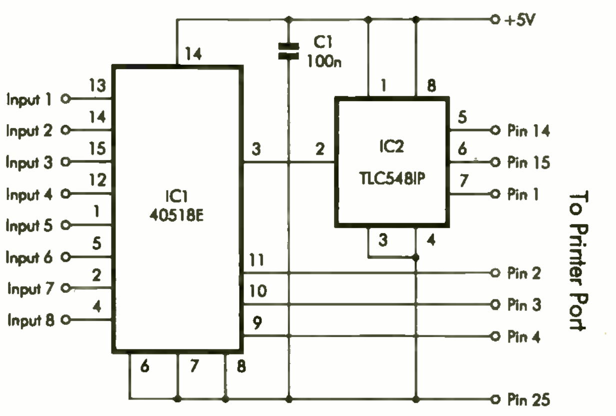


Fig.1 (left). A 4-channel A/D converter using four CMOS analogue switches.
Fig.2 (above). An 8-input A/D converter using a CMOS 8-way analogue switch.

All Change

Although a PC equipped with a games/MIDI port does have a multi-input analogue port of sorts, as pointed out in previous *Interface* articles, it is of very limited use in serious measuring applications. It was designed for use with joysticks and games paddles, and that is about its limit.

Adding an analogue interface to a parallel port has been covered in previous *Interface* articles, but the designs featured were only for single channel operation. However, providing multi-channel operation from a single channel converter is quite easy, and it is basically just a matter of adding an electronic switch at the input of the converter. The switch is controlled by one or more digital outputs of the PC.

With (say) a four-way switch, four channels can be provided, but only one input at a time can be connected through to the converter. This is not

converter design that has been featured in previous articles, and it will not be described further here.

It uses four CMOS analogue switches to provide the multiplexing. A single 4066BE integrated circuit provides the four switches, and in this application a 4016BE should work just as well.

Each switch is a simple s.p.s.t. type having a separate control input. Taking an input high turns on the corresponding switch, and taking it low turns off the switch. The control inputs are driven from outputs D0 to D3 of the printer port, and it is just a matter of taking the appropriate output high in order to select the desired channel. Table 1 shows the decimal value that must be written to the data outputs to select each input. It is assumed here that the upper four outputs (D4 to D7) are unused, and these outputs are simply set low.

not to put this type of thing to the "acid test". Also, with more than one input selected the readings obtained would be completely meaningless.

8-Input A/D Converter

The 8-Input A/D Converter circuit diagram shown in Fig.2 requires a more expensive CMOS analogue switch chip, the 4051BE, but it provides a neater solution. The 4051BE has eight inputs and a single output, and it contains eight s.p.s.t. CMOS analogue switches. The action it provides is equivalent to an eight-way rotary switch.

The required input is selected by applying the appropriate binary pattern on the control inputs at pin 9 to pin 11. These are driven by outputs D0 to D2 of the printer port. Just three output lines of the PC are used to select the required one of eight inputs. The internal decoding of IC1 ensures that only a single input can be selected at any one time.

In line with the current convention for this type of thing, the inputs are numbered from 1 to 8 but are selected by outputting decimal values from 0 to 7. A value of 5 would be used to select input 6 for example. It is assumed that printer port outputs from D3 to D7 are unused, and they are simply set low.

There is an inhibit input at pin 6 of IC1, but this is of no value in the current context and it is simply connected to earth (0V). There are separate analogue and digital ground terminals at pins 7 and 8 respectively, but in this circuit both pins are connected to a common digital and analogue earth (0V) rail.

Connecting-Up

The connections to the printer port are made via a 25-way male D-connector. The correct method of wiring this to the interface circuit is shown in Fig.3. It shows the connector viewed from the rear (i.e. from the side to which the soldered connections are made). Note that the integrated circuits used in both versions of the interface are static-sensitive and require the usual handling precautions.

Software

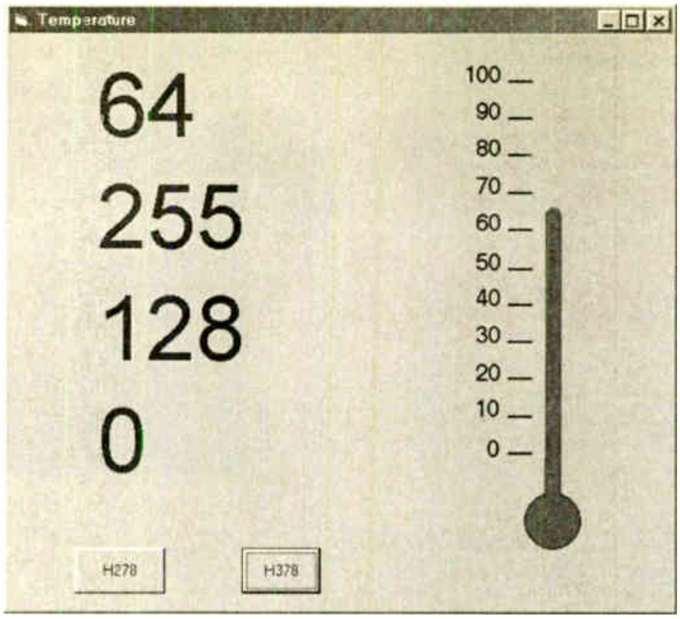
The listing for the Visual BASIC 6 program for the multi-input analogue interface is too long to reproduce here. However, the program is available on the *EPE* web site and from the Editorial office, complete with all the source and support files. (See *PCB Service/Software* page in this issue.)

If you wish to experiment with the source files you will require Visual BASIC 6 installed on your PC. Even the "Working Model" version is adequate for experimenting with the program and trying some variations, but it will not permit programs to be compiled. They can only be run from within Visual BASIC.

The program utilizes the freeware file called **inpout32.dll**, which adds the missing INP and OUT functions to Visual BASIC. The compiled program is an EXE file, but it will only work if **inpout32.dll** is available to the system. Either have this file in the same directory as the program file, or in the **C:\Windows\System** directory.

When experimenting with the source files the file called **inpout32.bas** must be loaded into Visual BASIC. Select the Add File option from the Project menu, and then open **inpout32.bas** using the pop-up file browser.

The program is designed for operation with the circuit diagram of Fig.2, but it is easily modified for operation with the circuit of Fig.1. It is an extended version of the temperature interface software featured in a previous *Interface* article (see *Oct '00* and *Dec '00* issues). The program retains the digital and analogue displays of the original program, and these respond to the voltage on input 1.



Screendump of the 4-channel program in action.

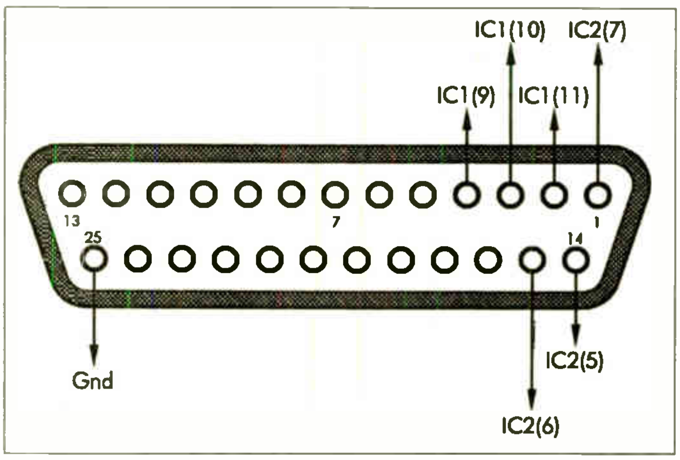


Fig.3. Connections to the 25-way male D-connector (rear view). The numbers in brackets refer to device pins.

The Temperature Interface has pin 1 of the converter chip fed from supply lines via a potential divider in order to give a full-scale value of 2·5V rather than 5V. If you wish to merge the temperature interface with this circuit, this potential divider must be included. Of course, all eight inputs will then have a full-scale value of 2·5V.

Digital Readouts

The main routine of the original program has been repeated three times so that three more digital readouts can be provided. These display the raw readings from inputs 2, 3, and 4.

Some additional program lines are needed in order to select the right input before a reading is taken, but this process does not work in quite the way one might think. On the face of it, outputting a value of 0 to the data lines before a reading is taken will select input 1, and provide a reading from that input.

In practice things do not work this way due to the TLC5481P converter's sample and hold system and the way the software reading routine functions. What actually happens is that the value output to the data lines in one section of the program controls the input read by the next section.

This happens because the software clocks out the data already in the chip, and latches the next sample voltage at the input of the converter. Hence, the sample read in one section of the program is clocked out in the next section. Consequently, the four sections of the circuit do not output values of 0, 1, 2, and 3 to read inputs 1 to 4. Instead, values of 1, 2, 3, and 0 are used, which gives the desired action as the program cycles continuously.

Expansion

Using Visual BASIC's "Cut and Paste" facility it is easy to add further sections to the program so that more inputs can be used. It would be neater to define the basic reading routine as a subroutine, which could then be called up as and when necessary.

However, the Cut and Paste approach is easier and produces quite compact compiled programs. The four-channel version of the program is only about 28k. Further label components and (or) analogue displays would have to be added to provide a means of displaying the values read from the other inputs. This type of thing is very easy using Visual BASIC, but with a large number of readouts try to group things sensibly so that it is easy to see which particular piece of data each readout is displaying.

The maximum conversion rate of the TLC5481P is about 45500 per second, but bear in mind that this is the limit for the converter and not the number per channel. Using all eight inputs the maximum conversion rate per input works out at about 5687 per second. In practice even this is unlikely to be achievable using Visual BASIC software, but this interface and software works well in applications where high speed is not a requirement.

Constructional Project

DIY TESLA LIGHTNING

NICK FIELD

Great balls of fire? Perhaps, if you live dangerously and try to match the skills of Zeus!

SHORT of divine intervention, most of us are never going to get to control nature's most spectacular effect – lightning. However, thanks to the genius of a 145-year old physicist, you can!

The purpose of this article is to enable you to build a working Tesla Coil with an arc output of at least 50cm, and to give you a general idea as to why and how it works.

It is stressed, though, that voltages and currents within a Tesla Coil are capable of killing you by accident without you deliberately letting them pass through your body. You undertake construction and use of this Tesla Coil entirely at your own risk.

HISTORY

Born to a Croatian priest in 1856, Nikola Tesla was a child prodigy, graduating first from the Real Gymnasium in Carlstadt, then Graz Polytechnic and finally Prague University. It was while studying at Prague University that a professor jokingly challenged him to invent a commutator-less a.c. motor – the type of motor which now powers most of our modern society.

After graduating, he proceeded not only to invent the polyphase a.c. motor, but also the polyphase system of power distribution to go with it.

This initial success allowed him to fund a large laboratory in New York. However, as he pushed the power levels of his equipment up, he ran out of space at these laboratories and decided to move to his famous Colorado Springs laboratory.

It was here that many of his later discoveries were made, including a unique system of high frequency power transmission, a bladeless turbine, fluorescent lights and radio (in 1948 the US Supreme Court ruled that Tesla's radio work preceded Marconi's patents).

TESLA COIL

The Tesla Coil is a remarkable device for producing radio frequencies at huge voltages. Due to the spectacular form in which these huge voltages manifest themselves, they have been popular "hobbyist" projects for much of the last century. Most of the plans published, though, have been based on rather flawed theoretical approaches and employing 1920's construction techniques and materials.

Having seen so many of these woefully outdated plans published, to the inevitable disappointment of the builders, the author has tried to present here an up-to-date and thorough design which can be built by anyone with a pair of hands and a keen mind.

It should be noted, though, that Tesla Coils are temperamental devices and that the output you can obtain may vary. However, it seems likely that you will achieve 50cm of continuous connected arc from the coil described.

WARNING

This project could kill you

This is not a suitable project for anyone who does not have experience of mains wiring and safety

Spectacular electrical discharges are what Tesla Coils are probably best known for. Over the years they have provided many lightning effects for films, TV and advertising. Some notable examples of Tesla Coil based effects are *Terminator II*, *Battlestar Galactica*, *The Incredible Hulk*, and the music video to *Too Hot* by Coolio.

HOW TESLA COILS WORK

Fundamentally, a Tesla Coil is a transformer. The most important difference between it and the transformers you will have worked with is that it has no iron core.

In a normal transformer the windings are so tightly coupled magnetically by the iron core that they transform voltage as a ratio of the turns. In a Tesla coil there is no iron core, which means that, because of resonant action, it can transform voltage by much more than the turns ratio.

Within an efficient Tesla Coil system, a voltage rise of 250 times or more across the whole system is perfectly possible, with the most efficient systems managing 500.

The diagram in Fig.1 shows the basic components of a Tesla Coil system. The circuit splits into two halves, the primary and secondary. The primary circuit capacitor, C1, is charged by the supply transformer to several thousand volts. At the voltage set by the spacing of two electrodes, the spark gap will "flash over", allowing the capacitor to discharge through the primary winding of the coil.

When the capacitor discharges through the primary coil, its energy is transferred to the coil which, being an inductor, stores it as a magnetic field.

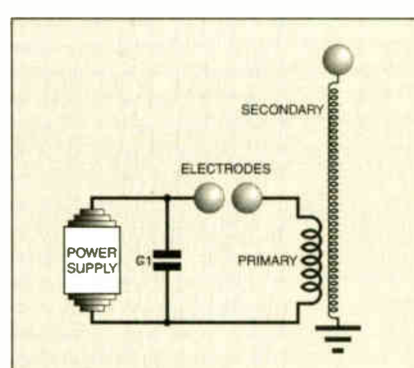


Fig.1. Basic components of a Tesla Coil system.

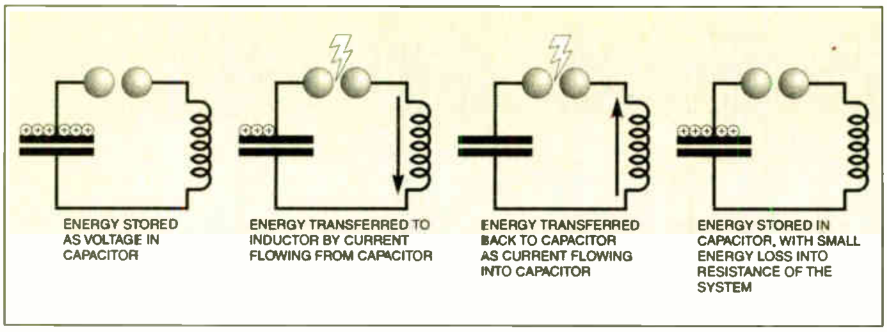


Fig.2. The charge/discharge cycle of a Tesla Coil.

When the capacitor has discharged, the magnetic field around the primary coil collapses and this voltage pulse flows back into the capacitor, which then discharges through the coil again, repeating the cycle until all the energy has been lost (see Fig.2).

This energy is lost into the resistance of the circuit and through the discharge. As the aim of the circuit is to deliver maximum power to the discharge, it is important to minimise the resistive losses. For this reason the wiring of the primary circuit must have a very low resistance. In the design described here, the primary circuit largely consists of copper pipe and very thick cable.

RESONANT FREQUENCY

The speed at which the charge/discharge cycle repeats is known as the resonant frequency of the circuit. In the case of this design's coil the frequency is about 300kHz.

It is this property of electrical resonance that allows a Tesla Coil to exhibit its large voltage rise. Any circuit containing a parallel inductor and capacitor (an L-C circuit) can resonate under the right conditions. At resonance the voltage coming out of the circuit can be many times that going into it.

As an example, the author fed the secondary of the Tesla Coil used in this project with a signal generator input of about 200mV and measured 8V being produced, a gain of about 40.

This voltage gain extrapolated for a 10,000V input means that well over a quarter of a million volts could be produced from a small coil under resonance!

The resonant frequency and the magnification or *Q* factor of an L-C circuit are calculated as:

$$F_{RES} = \frac{1}{2 \times \pi \sqrt{LC}}$$

$$Q = 1/R \sqrt{L/C}$$

In both these equations, inductance (L) is in Henries and capacitance (C) in Farads.

ENERGY TRANSFER

The magnetic coupling between the primary and secondary windings transfers the bursts of radio frequency energy to the secondary. Since the secondary also has inductance and capacitance, it too forms a second resonant circuit, at the same frequency as the primary. This resonance, not damped by the close coupling of a conventional transformer, generates an even greater voltage rise.

The resulting massive voltage issues forth from the discharge terminal as a display of artificial lightning, which can be up to 18 metres (60 feet) long. However, it should be noted that, due to the square law, to produce such sparks requires vast amounts of power. To produce an 18 metre discharge, for instance, would require a power input of over 100kVA.

COIL DESIGNS

It is important that as little as possible of the generated power is lost into spurious discharges (known as *corona*). It is for this reason that all the parts of the discharge terminal should have a very large radius of curvature, largely being toroidal or spherical in shape.

There are many variations of Tesla Coil design. Some designs, for example, have features such as a smoothed d.c. power supply, rather than the unrectified transformer output commonly used (and used here), and rotary spark gaps to allow a variable number of firings per second to take place.

The coil described here has been designed primarily for ease of construction. With some experience and minor design improvements it can be made to produce arcs of well over a metre in length while still using the same basic power supply. It will provide a good basis for anyone who wishes to carry this fascinating hobby further, while still being an interesting and diverting project in its own right.

TESLA CIRCUIT

The block diagram for the Tesla Coil system is given in Fig.3. This diagram also serves as the circuit diagram.

Mains a.c. power is brought in through switch S1, neon indicator LP1 shows when it is present. The positive supply line passes through 3A fuse FS1 to keyswitch S2. This provides a securely locked method of ensuring that high voltage discharges can only be produced when required.

Further safety precautions are included through the use of Fire switch S3 and Kill switch S4.

With keyswitch S2 on, the pushbutton Fire switch has to be pressed in order for the relay, RLA, to be switched on and allow power to reach the Variac transformer, T1. The pushbutton Kill switch allows the relay to be instantly deactivated in an emergency, so killing power to the transformer.

The Variac transformer is an autotransformer whose single (unisolated) winding is tapped at variable turns ratios by a moveable wiper, controlled by an external insulated rotary knob. Output voltages greater than the standard 230V a.c. mains input voltage can be achieved, about 270V a.c. in the case of the recommended Variac.

Capacitor C1 is used to "mop-up" voltage spikes which may be induced into the circuit when the high voltage discharges occur, and also to correct for the phase angle of the highly inductive load, reducing the current drawn.

Although not shown in the diagram, it is recommended that the controller is plugged into the mains via a commercial "mains filter" unit, to prevent inductive spikes from being fed into the mains.

VOLTAGE RAISING

The a.c. output voltage from the controller is connected via plug and socket PL1/SK1 to the coil unit. The power is first fed into a commercial Neon Power Supply unit whose purpose is to step up the mains voltage to around 10kV.

The voltage produced by this unit then charges the primary capacitor (C2), which discharges across the spark gap, producing the pulses which excite the resonant circuit, comprising C2 and the primary and secondary coils, L1 and L2.

Capacitor C2 is made up of 48 polypropolene/foil capacitors connected in a series/parallel configuration, whose effective value is 15·6nF at 19·2kV. These form the 'C' of the primary L-C resonant

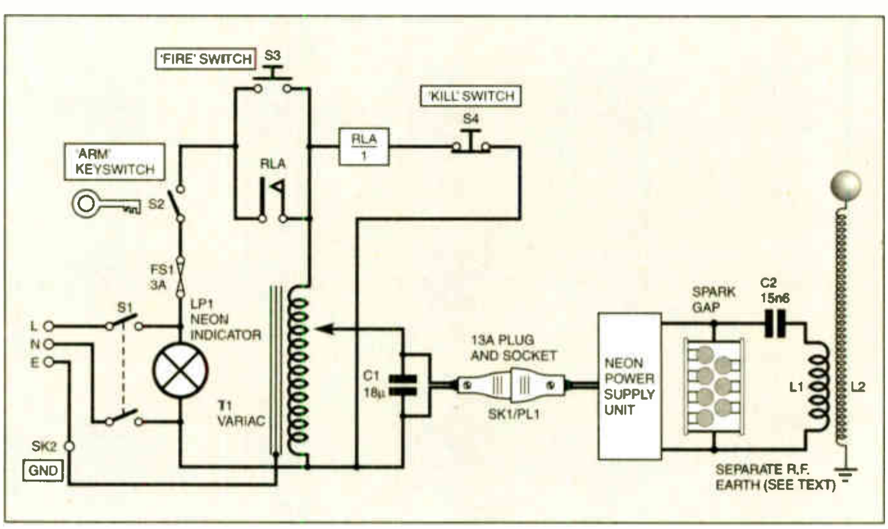
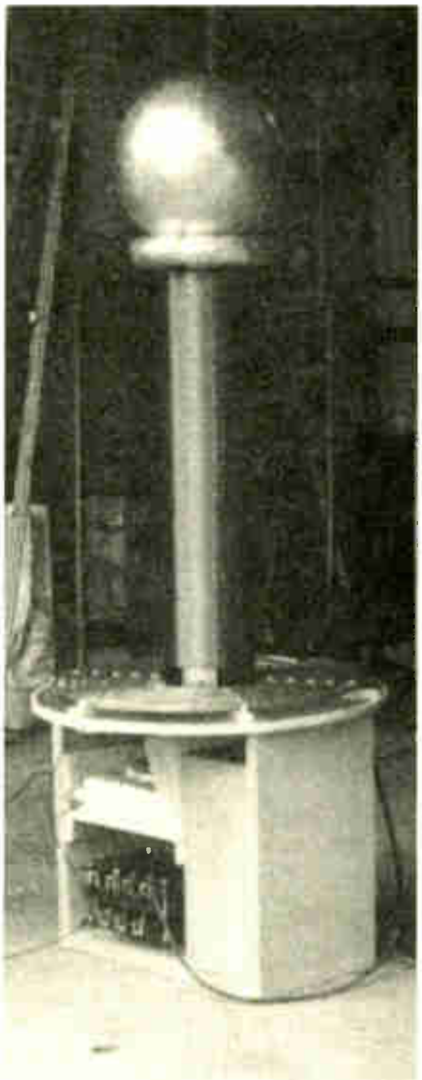


Fig.3. Block diagram for the DIY Lightning Tesla Coil system.

circuit. Commercial impulse capacitors are the preferred capacitor type. However, this unit is designed for light duty and low cost, therefore a large number of small "off the shelf" capacitors are used to make up one larger capacitor.

Photographs of the author's Tesla Coil system "tower" and Variac control unit are shown below.



The Tesla Coil system "tower" in the author's workshop.

COMPONENTS

Approx. Cost Guidance Only **£95**
excluding neon PSU

Power Controller

T1	Variac transformer, Claude Lyons type 403, 3A 240V a.c.
S1	d.p.s.t. toggle switch, mains rated, 5A
S2	s.p.s.t. keyswitch, mains rated
S3	s.p.s.t. normally-open pushbutton switch, mains rated, red
S4	s.p.s.t. normally-closed pushbutton switch, mains rated, black
RLA	s.p.s.t. relay, 230V a.c. coil, 230V a.c. 5A contacts
LP1	red neon indicator, mains rated
C1	18μF 450V a.c. capacitor
FS1	20mm fuseholder plus 20mm motor-rated fuse, 3A
SK1	mains socket, chassis mounting

See SHOP TALK page

Line filter, 230V a.c. 5A (see text); cable entry grommet, 4mm; aluminium sheet 2·5mm x 200mm x 300mm; 7mm MDF (see text)

Neon Power Supply
Neon sign transformer, 10000V, 50mA, Tunewell Transformers (Tel: 0181 8073671) or a local neon sign shop
Neon sign cable, 10kV, 1 metre
3-core cable, 13A, 4 metres (outdoor type)

Primary Capacitor
C2 47nF polypropelene capacitor, 1500V (48 off), Arcotronics (RS 114-474)
Silicone sealant, clear (B&Q)

Primary Coil L1
Copper refrigeration tubing, soft, 0.25in. 9 metres (30 feet)
LDPE chopping board, white (not of the disinfectant impregnated type)
Snap-lock ties, 100mm (30 off) (B&Q)
Plywood 9mm x 400mm x 400mm
Welding cable (see text)

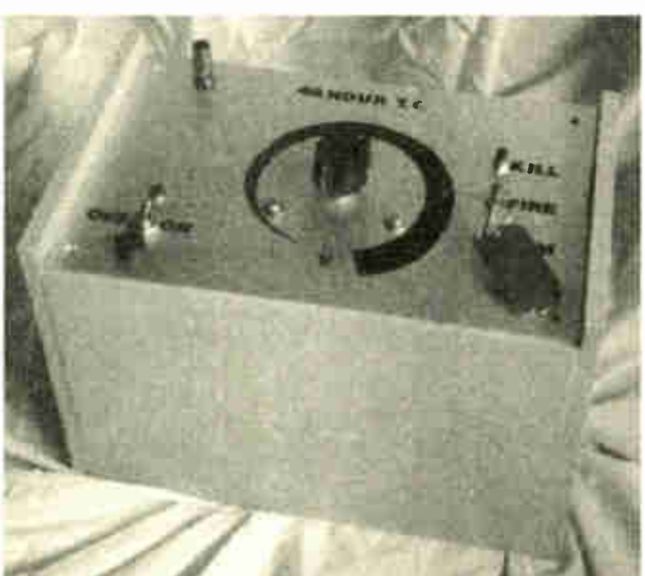
Spark Gap
Perspex sheet, 5mm x 20mm x 150mm (2 off)
U-channel aluminium, 840mm x 15mm x 15mm (B&Q)
Copper heating tubing, 22mm x 840mm (B&Q)
Machine screws, brass, M5 x 25mm (14 off)
Brass nuts, M5 (14 off)
Nylon studding, M4 x 400mm
M4 nuts (8 off)

Base Unit
MDF (or ply, chipboard etc), 10mm x 360mm x 200mm
MDF (or ply, chipboard etc), 10mm x 300mm x 250mm (2 off)
Wood strip, 10mm x 25mm x 240mm

Secondary Coil
PVC tubing, 4in dia. x 20in (B&Q) (avoid black tubing as this has carbon filler in it and will break down more easily)
Magnet wire, 0.6mm x 300m (try a motor or transformer winding company as this amount is not available in one length from High Street stockists)
Hardglaze polyurethane varnish (B&Q)
Aluminium sheet, 2.5mm x 30mm x 50mm
M4 machine screw, 2mm
M4 nut
MDF disc 10mm x 95mm dia. (2 off)
Wood screws, small (6 off)

Discharge Terminal
Expanded polystyrene sphere, 25cm dia. (Hobby Craft)
Expanded polystyrene doughnut, 17cm dia. (Hobby Craft)
Aluminium cooking foil (Tesco)
Craft glue (stationers)

Radio Frequency Ground
12swg cable (see text) (B&Q)
Copper tubing, 1m x 15mm (3 off) (B&Q)
Jubilee hose clips (3 off) (B&Q)



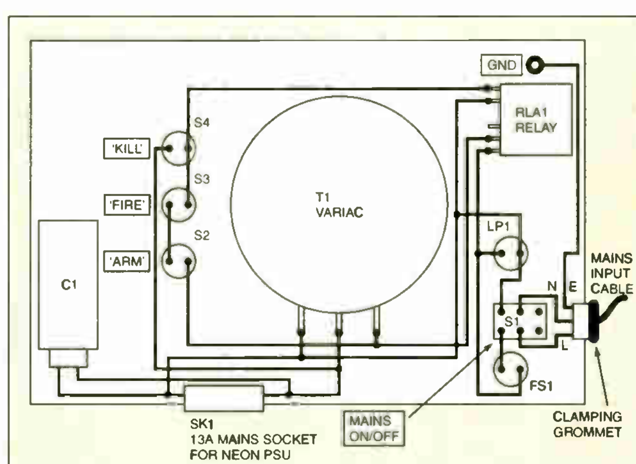
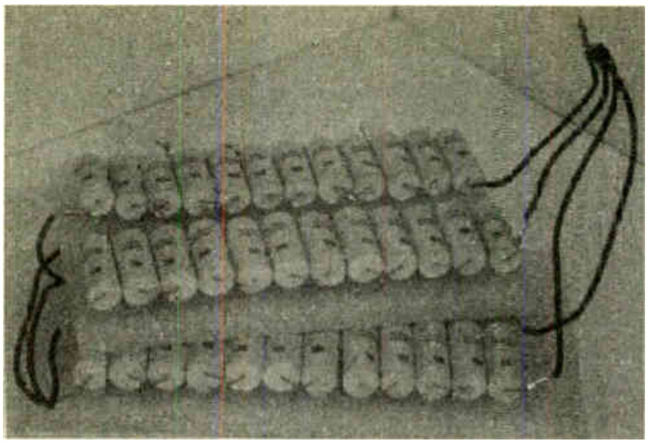


Fig.4. Wiring details for the main control unit. Mains rated cable must be used throughout.

Left: Completed main control unit.



Secondary coil's capacitor (C2) assembly.

CONSTRUCTION

For the prototype, the author selected the cheapest and best components available from High Street stockists. It should be emphasised that whilst you may be able to replace them with cheaper substitutes, no guarantees on the performance can be given if the design or component sources are altered.

It is particularly essential that the specified capacitors are used, they are exceptionally high quality units and most other brands will fail quickly in this application.

Most components should be fairly easy to get hold of. If you have any real trouble, get in touch with the TCBOUK (Tesla Coil Builders of UK), their contact details are given at the end of the article.

DIY enthusiasts will probably have all the equipment needed to built the system. A pillar drill would be an advantage, but is not essential. To cut some pieces, the use of a fretsaw or electric jigsaw is preferable. A blow torch is needed as well. Observe standard workshop safety procedures!

POWER CONTROLLER

The first stage in building the Power Controller is to build the case, which mainly consists of 7mm MDF and measures 285mm × 180mm × 200mm (l × w × h). Its top plate is aluminium sheet.

Having planned your component layout, it is very important that you drill the top plate first, as drilling while components are installed risks aluminium swarf getting into them and creating short circuits.

Install and wire up the components as in Fig.4. ***Use 3-core mains flex of at least 3-metre length linking this unit to the mains plug, and a 3-metre long fly-lead for the trailing socket (SK1) into which the Neon Power Supply plugs.***

Test the controller by plugging a 100W table lamp into the socket and varying the Variac's voltage setting. The brightness of the lamp should vary with the Variac control knob position.

CAPACITOR C2 NETWORK

The secondary coil's capacitor network (C2) is assembled on two pieces of chopping board. The first piece is 210mm × 120mm and the second 180mm × 120mm. First trim the legs of all 48 × 47nF capacitors to a length of 2cm. To do this you may find it helpful to make up a jig into which the capacitors fit, ensuring a consistent leg length.

Squeeze thick lines of silicone sealant on to the chopping board pieces. Separate the capacitors into groups of twelve. Each lot of twelve should have the legs twisted together zigzag fashion for mounting on the board, pressed into the sealant, as can be seen in the photograph.

Solder the capacitor leads together to ensure a good joint, and add flying leads to the ends of each row, using 10A hookup wire about 10cm long.

PRIMARY COIL BASE

For the primary coil, first cut a 400mm diameter baseboard disc from the plywood. Varnish it with a polyurethane varnish and leave to dry. From the white chopping board cut six 150mm × 15mm strips. Drill 11 × 5mm holes centrally at 0·25in intervals in each strip.

Take the disc, mark its centre and scribe a 110mm diameter circle around it. Scribe a series of radial lines at 60° intervals outward from the centre. These mark the positions of the primary supports.

Now take each strip of chopping board and coat it on one of the wide sides with Thixofix or a similar contact adhesive. Also apply a thin coat to the areas of the baseboard where the strips will be mounted. Allow the glue to set for about 10 minutes, then press the supports firmly into position.

Note that the supports are not merely arranged radially from the edge of the inner circle, they are progressively offset to allow for the shape of the flat spiral coil.

Having done this, drill two 15mm holes in two adjacent segments, just outside the perimeter of the 110mm central circle. These allow wires be connected to the primary coil and the secondary ground.

Also drill on through the baseboard from the holes in the supports to allow for the ties, which secure the primary coil, to pass through the baseboard and back up. Varnish the baseboard, but be careful not to get any varnish on the supports.

COILED TUBE

The refrigeration tubing used for the primary coil will probably be supplied as a flat spiral. Put on a pair of work gloves, as much to protect the tubing as you, and place the tubing on the base. Hold the inner turn in place and then slowly uncoil the spiral from the outside until 10 turns of it fit in the width of the primary supports. Now remove the tubing from the coil and place it on a heat resistant surface.

Heat the end of the inside turn with a blow torch until the second oxidation colour has passed. Feed a few centimetres of solder into the inside turn to tin it internally. Place the tinned end of a 20cm length of large (welding) cable into the tinned end of the primary and heat strongly.

Now re-position the primary on the base and fix it down with cable ties. Feed the welding cable through the hole at the beginning of the primary (see Fig.5).

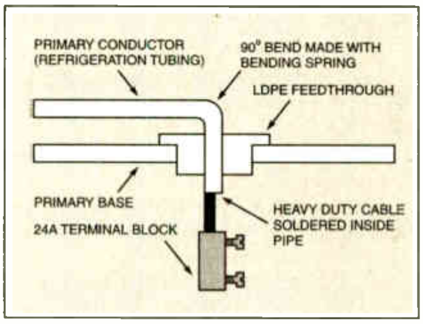


Fig.5. Primary coil mounting on base board.

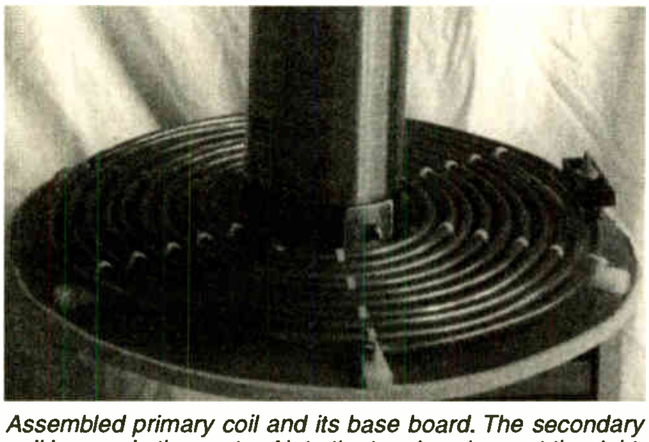
To help insulate the primary and secondary connections, small feed-through insulators can be made from the chopping board. Use a 20mm circular cutter to cut a pair of holes in the chopping board. Shape the insulators to fit, using a sharp craft knife.

SPARK GAP

The spark gap is the part of a small Tesla Coil which is most frequently badly built and/or set up and which is the most common cause of poor performance. The spark gap design used on this coil is in fact several spark gaps in series. This is necessary to provide sufficient cooling capacity and quenching speed. You can alter the voltage at which the spark gap fires by the number of gaps you use.

First cut seven 120mm lengths of 21mm copper heating tubing. It is preferable that these are cut with a pipe cutter rather than a hacksaw. If a hacksaw must be used the ends should be cleaned up very thoroughly with a file.

Next cut seven 120mm lengths of 15mm × 15mm U-channel. Take the Perspex sheets and drill mounting holes for the U-channels, spaced at 30mm apart. Roughen the Perspex with fine sandpaper, coat the bottom side of each piece of U-channel with a good quality epoxy adhesive, such as Araldite.



Assembled primary coil and its base board. The secondary coil is seen in the centre. Note the tapping clamp at the right.

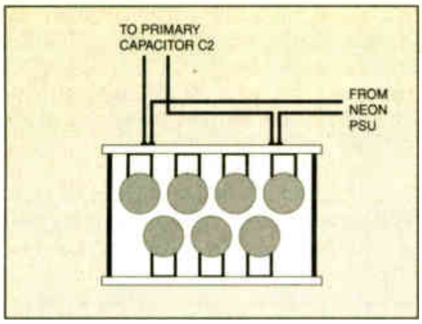


Fig.6. Spark gap assembly.

Lightly clamp the two Perspex assemblies together for about two hours, being careful not to stick the two sides together, but ensuring that good pressure is maintained between the Perspex and the U-channels.

Drill a pair of 5mm holes 10mm in from each end of the pieces of tubing. When the epoxy has dried, separate the two sections and drill 5mm holes through the Perspex and U-channels, 10mm in from the end of each piece of channel and central to it.

Now cut four 100mm lengths of the M4 studding. Assemble the gap as shown in Fig.6, taking care to keep all the electrodes parallel for their entire length.

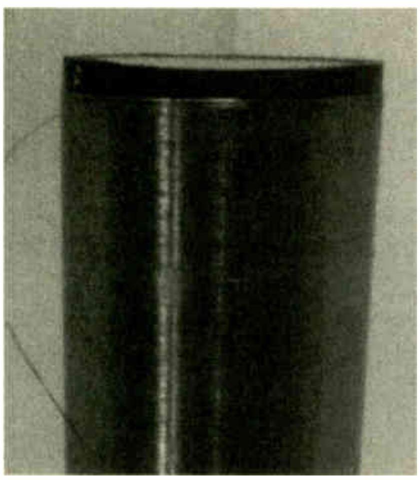
SECONDARY COIL

For the secondary coil assembly, first cut the PVC former to a length of 50cm. Clean up the cut ends with a file and lightly sand the whole length of the tubing using a fine grade sandpaper.

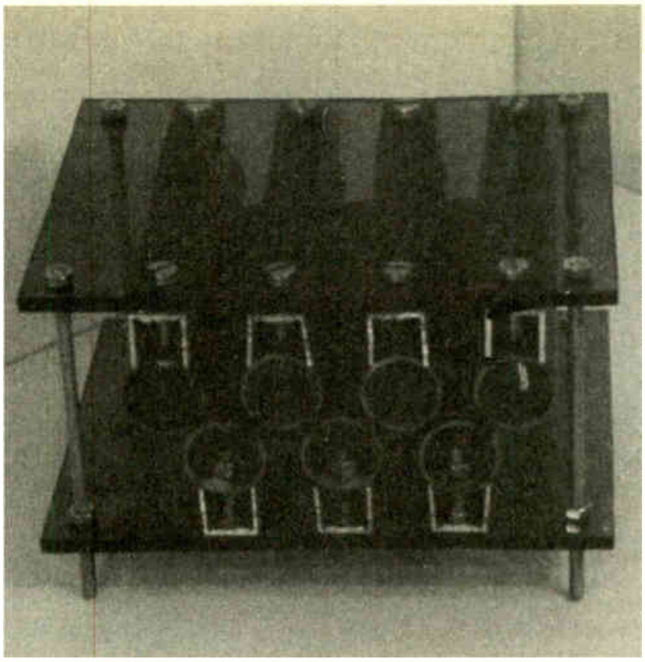
The tubing should be dried at about 50°C for twelve hours. You will have to improvise a method of doing this, placing a 100W electric light bulb inside the tube and capping the top is the method the author used.

While the tube is still hot give it a light coat of polyurethane varnish inside and out. Now place the former onto the 7mm MDF and draw around the inside of the tubing. Repeat this for each end of the tube, and then cut around the two marked circles with a jigsaw. These discs should fit snugly inside the ends of the tubing.

Drill a 5mm hole at the centre of each disc. Place one of the discs into one end of the tube and line it up until it is flush with it. Drill three 3mm holes through the wall of the PVC tubing and into the disc at 120° intervals. The holes should be countersunk to take 1/2in × 4 wood screws, which go into the disk to secure it in the coil former.



Top end of the wound secondary coil former.



The completed spark gap assembly.

Repeat this procedure for the other end of the former.

Drill a 2mm hole 15mm in from one end of the coil former, on its side. Using a 15mm circular cutter, cut a hole at the 2mm centre just drilled. Give the former and end caps another coat of varnish.

Take a piece of 2mm aluminium and cut it to 30mm × 50mm. Round off and de-burr the edges with a file. Drill a 5mm hole through the centre of the plate.

Strip 20mm of the enamel at the end of the winding wire and solder it to an M4 solder tag. Put an M4 bolt through the solder tag and aluminium plate and secure with an M4 nut. Take the plate and glue it to coil former with the bolt head and solder tag sticking back into it. Use a good epoxy adhesive and slightly roughen the surface before gluing.

File a small slot into the plate to allow the wire to pass between the plate and coil former.

COIL WINDING

Now the hardest part – winding the wire onto the former. It is strongly recommended that you use a winding jig for this as hand wound coils are invariably very poor quality. A simple winding jig can be arranged as shown in Fig.7.

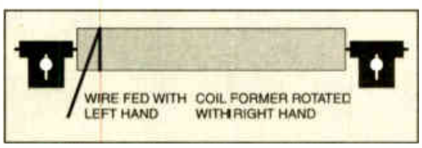


Fig.7. Improvised winding jig.

Alternatively, if you have access to a lathe you can adapt the leadscrew to feed on the wire much more accurately than you can by hand.

The most crucial stage in winding is to get the first turn right. It should be as tight and straight as you can make it. After putting on about five or so turns, taking your time to make them close and straight, cover the first turn with masking tape to hold it straight.

You can now wind on quite fast. It is recommended that you stop every 20 or so turns to pack the turns together and check for winding imperfections.

Finish the winding 10mm from the end of the coil former and then tape down the last turn to make sure it does not come unwound.

It is stressed how important it is that at no stage in the winding process do you relax the tension on the wire, it is extremely frustrating to wind several hundred turns and then see them uncoil over your workbench!

Having finished the winding give the entire secondary assembly, including windings, another two coats of varnish.

Cut the wire left at the end of the secondary back to about 10cm and strip it of enamel. Use a solvent based craft adhesive to fix the toroidal terminal (discussed in a moment) onto the top of the secondary. Place the stripped length of wire along the terminal and then stick a strip of tinfoil over it with craft glue.

DISCHARGE TERMINAL

The discharge terminal is the simplest bit of the system, having two components – an expanded polystyrene toroid and a polystyrene ball, both covered in aluminium foil.

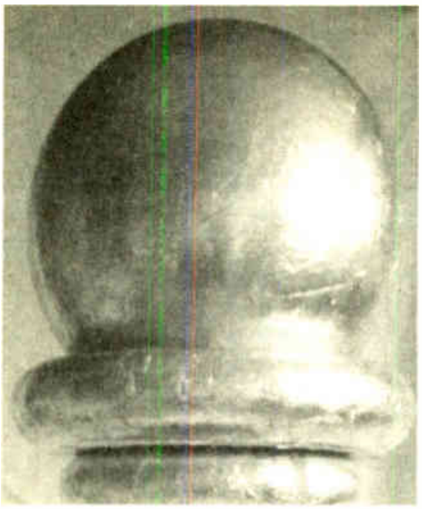
The foil is glued onto the polystyrene with a normal craft glue such as UHU or Pritt Stick.

Toroidal discharge terminal.

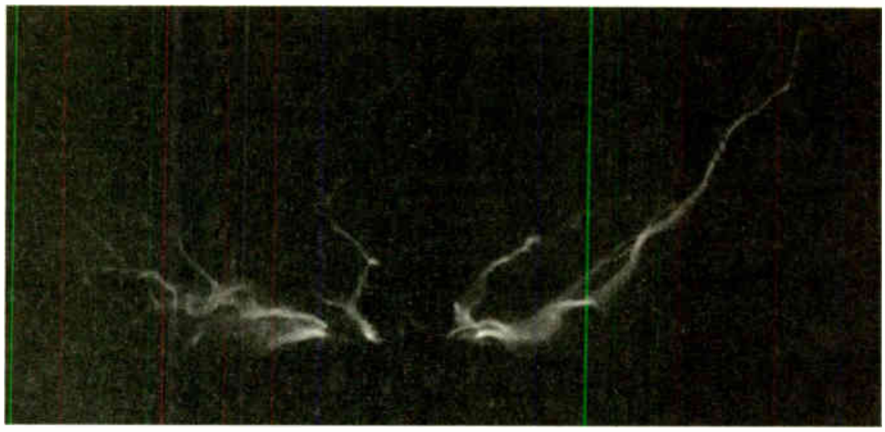
To achieve a decent finish it is important to follow closely these instructions for coating the toroid.

Cut 30 strips of aluminium cooking foil, each measuring 3cm × 30cm. Coat them with glue on the matt side and wrap around the toroid, making sure to allow enough overlap at the joint of each strip or the sparks will not travel smoothly over the surface of the terminal. Make sure the start and end of each strip is on the inside of the toroid.

The discharge ball should be coated in a similar manner, for which 50 foil strips will be needed.



Discharge terminal "ball".



"Zeus's Aura" – lightning erupts from the balled discharge terminal.

RADIO FREQUENCY GROUND

An independent earth connection must be given to the coil system. The normal domestic earth of the mains a.c. supply is inadequate to handle the radio frequency energy generated by the coils.

The radio frequency ground must be installed outdoors, in a lawn or similar area of open ground. Dig a trench about 1·5 metres long, 20cm wide and about 20cm deep.

Using a hammer, flatten each of the 15mm diameter copper tubes for a length of about 3cm. Drill a central 5mm hole through each flattened section. Drive the tubing, as stakes, into the prepared ground using a club hammer or sledge hammer, a stake at either end of 1·5 metre trench, and one in the centre. The centre stake should stand about 10cm above the level of the ground, while the other two are about 10cm below it.

Slip a jubilee clip over each stake and allow it to fall to the base. Take a 2m length of 12-gauge copper wire and strip the insulation from it, and find the centre of the wire by folding it. Double a 5cm length of the wire back on itself and slip this up the jubilee clip on the centre stake.

Tighten the centre jubilee clip and pass one end of the wire through the jubilee clip on one of the outer stakes. Tighten the clip and repeat for the other stake.

Put an M4 machine screw, with a pair of washers on one side, through the hole on the protruding connection piece.

This is then connected to the ground connection plate on the base of the secondary with a length of heavy-duty hookup wire.

ASSEMBLY AND TUNING

The completed components should be fitted into the base unit and wired up as shown in Fig.8. The controller should be mounted at the full length of its cable (3m of 3-core, 13A) from the assembled coil.

It is best to run the Tesla Coil in a well ventilated garage as a considerable amount of ozone is generated while it is operating.

This project is dangerous, take sensible precautions by standing well clear of the discharge zone during operation.

So that you can accurately measure the spark length, place a grounded terminal (a terminal connected to the radio frequency ground), which is easily movable, about 30cm from the coil.

Always make sure the Coil is switched off and disconnected from the mains before approaching it and before making any adjustments.

For initial testing, close the spark gaps until they fire at a Variac setting of 50 per cent. Connect the primary capacitor and coil into the circuit. Using the ball top electrode, tap the primary coil at turn six, using a suitable tapping clamp.

Increase the voltage until the spark gap fires. If the spark strikes the ground rod move it out a few centimetres and fire the coil again. Repeat this until the electrode is just too far away for the coil to strike.

Now move the tapping clamp half a turn either way and repeat. Continue this process until you have found the point where you get maximum output. Disconnect the tapping clamp, noting its position, and open up the spark gap until it fires at 70 per cent on the Variac. Reconnect the tapping clamp and fire again.

Once the spark gap has fired, bring the Variac up to 100 per cent to increase the spark length. To increase your spark length still further, put a sharp point on the discharge terminal, facing up and away from the coil.

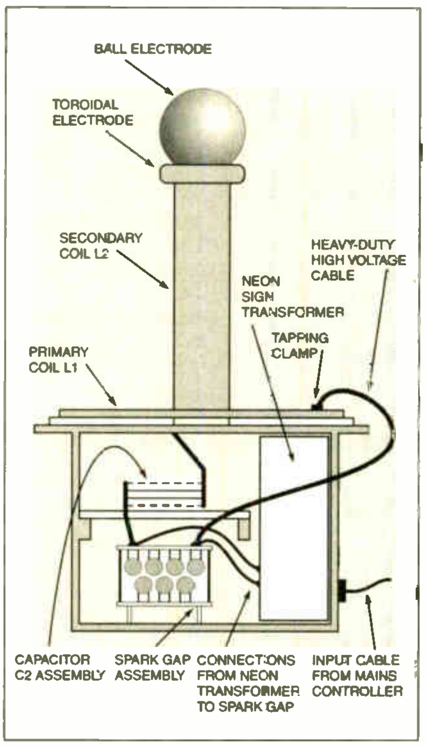
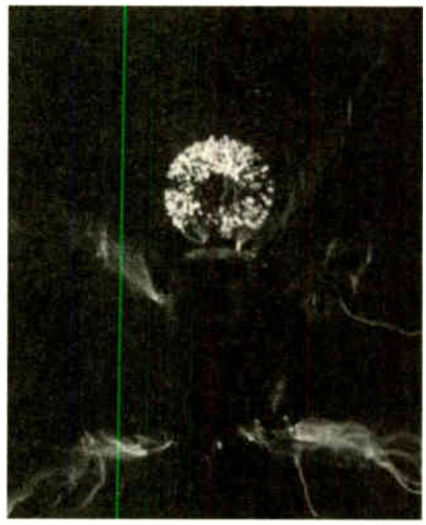


Fig.8. Final discharge assembly. The "electronic" components are housed in a suitable wooden enclosure on which the coils assembly is mounted.



"Ring of fire" – a CD-ROM disc is placed on the top terminal.

Once the coil is well tuned, the effect can be seen much better with the room lights switched off.

Spectacular effects can be produced by placing different objects on top of the terminal. You will notice that the sparks tend to break out from sharp points, due to the higher electric field stress around these. The CD placed on the terminal shown in the above photograph had been "zapped" in a microwave oven first to crack its metallic surface.

TAKING IT FURTHER

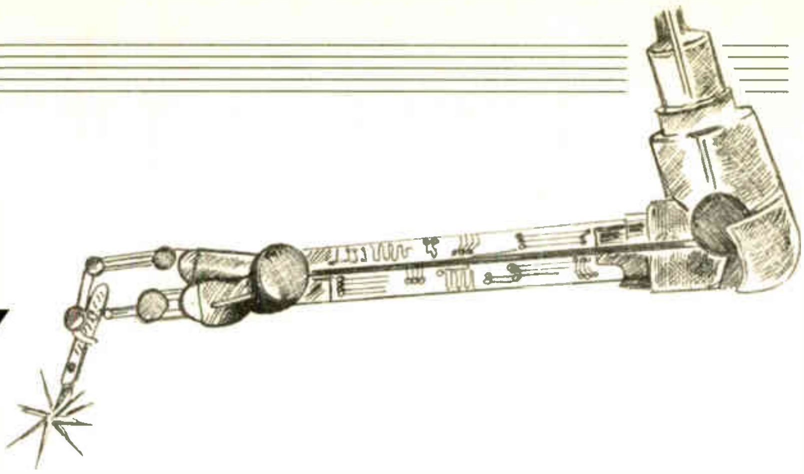
It is very easy to take this hobby further. With relative ease one can achieve sparks of over a metre in length from a small system, and two metres is not an unobtainable target even for a Tesla newcomer.

For more advice and practical experience, contact with other Tesla Coil builders is recommended. You could also attend some of the frequent "Teslathons" which take place around the UK. For details contact the TCBOUK at **www.tcbouk.org.uk**.

For a more detailed theoretical grounding, you are referred to *Modern Tesla Coil Design Theory* by Duane Bylund.

If you encounter any difficulty in the construction of this project go to web address **www.tesla-coil.co.uk/epe/** for troubleshooting help. □

CIRCUIT SURGERY



ALAN WINSTANLEY
and IAN BELL

This month, the complex world of phase-locked loops (PLLs) is opened up by our circuit surgeons.

Phase Locked loops

Regular *EPE* reader **Malcolm Wiles** E-mailed with an interesting tale:

For many years I was a software engineer, working on various kinds of embedded systems. On rare occasions we "softies" were known to adjourn to a local hostelry at lunchtime and swiftly down a half pint of the best mineral water before returning quickly to apply our noses to the grindstone once more. On such occasions, talking "shop" was banned absolutely, the penalty for any offender being immediately to buy in the next round of drinks.

We usually didn't go to the pub with our hardware colleagues, if only because they did nothing else but talk shop all the time – mostly about phase-locked loops. So much so, as I recall, that whenever one of ours was detected in the unforgivable crime, the Official challenge was a cry of "phase-locked loop". The guilty sinner would have to make his way to the bar to a general chant of "phase-locked loop, phase-locked loop", there to atone for his misdeed by buying in the drinks.

In all this time I never did find out what a phase-locked loop was, but I was left with the impression that they must be jolly useful things, because our hardware brethren found them so interesting. Would they make a suitable topic for your column in EPE sometime?

We liked this story a lot and will endeavour to reduce the mystery surrounding phase-locked loops (or PLLs as we shall call them) in the next month or two. PLLs are a big subject and an extremely important electronic subsystem with a multitude of applications.

To really understand PLLs you need a combination of some powerful mathematics and plenty of "real world" experience. Their basic structure is quite straightforward and yet a vast volume of academic papers and many textbooks have been published on their theory and use since their first implementation in the 1930s.

The complexity and "mysteries" of PLL theory and practice have tended to make some shy away from them, while others can enjoy many happy hours of PLL conversation over lunchtime drinks! Fortunately you do not need a PhD in PLL theory to make some useful circuits from them, particularly if you use the off-the-shelf PLL i.c.s which are available from a number of manufacturers. Allow us to present a fairly painless introduction to PLL theory.

Phase-locked loops have many applications in communications, including reconstruction of the carrier, demodulation of both a.m. and f.m. signals, decoding FSK (frequency shift keying) signals, and receiver synchronization for digital data transmission (including regenerating the clock from the data). PLLs are also used in frequency synthesis (which itself has a variety of applications), where a large range of frequencies can be produced using a single accurate reference (e.g. a crystal oscillator).

Many large digital i.c.s have PLLs as part of their clock system. The PLL can synchronize the internal clock with an external one, and allows the internal clock to be at a higher frequency than the external clock. Furthermore, the phase shift of the PLL clock can be set to give good synchronization between the timing of the chip's inputs and outputs. Similarly, the timing of data transfers on tristate buses can be improved using PLLs to synchronize output switching.

Basic PLLs

The basic structure of a PLL is shown in Fig.1, from which we can see that a PLL comprises a phase detector, a low pass filter, an amplifier and a voltage controlled oscillator (VCO). The frequency of oscillation of a VCO is determined by its control input voltage. The PLL is in fact a control system, rather like a servomechanism that you might find in a radio control model.

A "demand" input (the position we require a servo motor to move to, or the frequency/phase for a PLL) is input and compared with the present output. An "error signal" (i.e. the difference between the present and the demanded positions, or frequencies) is then used to move the output closer to the value we're demanding.

In a phase-locked loop, the phase detector compares the phase difference between its two input signals. If the signals are of different frequencies then the phase detector output will vary at the difference frequency. The phase detector output is smoothed by a low-pass filter (and buffered or scaled by the amplifier) to produce a control signal for the VCO.

If there is a difference between the frequency (or phase) of the input signal and that of the VCO, then the signal from the phase detector and filter will cause the VCO control voltage to change, such that the VCO frequency is moved closer to the input frequency.

Eventually the two frequencies will become equal and attain a fixed phase relationship, at which point the PLL is described as being "locked". The process of "homing in" on the input frequency is called capture, acquisition, or pull-in. Once locked the PLL can track changes in the input frequency (remaining locked) as long as these are not too large. Important parameters which measure PLL performance are:

- Capture time (how fast it locks onto a frequency)
- Lock range (what range of frequencies it will stay locked to, once locked)
- Capture range (the range of frequencies it will capture, starting in the non-locked state).

Other important PLL specifications relate to noise and stability, including the response of the PLL to noise on its input, the noise on its output, and the stability of the output signal's phase and frequency.

For different applications these specifications may take on a different significance. For example, a small capture range will be useful for some tasks but not others. A large capture range makes the PLL more susceptible to noise, whereas a small capture range

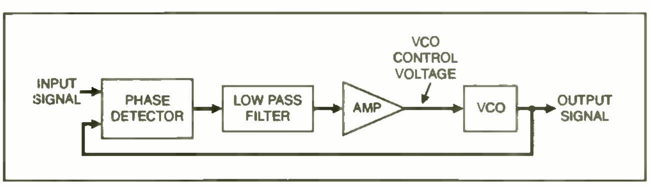


Fig.1. Basic phase-locked loop.

makes capture more difficult to achieve. It's possible to switch the properties of the filter after lock is obtained to get the best overall performance. The ability of the PLL to "lock" to noisy signals is key to its usefulness in communications systems where high levels of noise may be present.

The way in which a PLL attains lock is complex – the VCO control signal during capture (i.e. when the PLL is not locked) is not a simple d.c. representation of the difference in frequencies between the two signals. Furthermore, the phase difference between the signals needs to be considered. It is basically the d.c. component, or average value over time, of the VCO control signal that moves towards the value required to lock the PLL. The typical form of the VCO control signal during capture is shown in Fig.2.

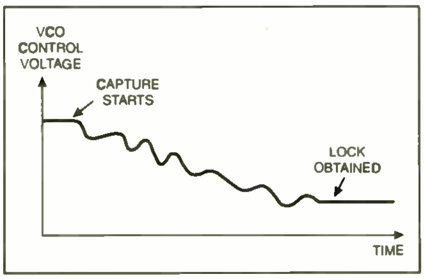


Fig.2. Stabilising complexity of PLL signal lock capture.

Good Vibrations

The application of phase-locked loops can help produce excellent quality, ultra high stability oscillators. PLLs can be controlled digitally to produce a range of frequencies, instead of (for example) having to physically select different quartz crystals in a high accuracy oscillator circuit.

In Fig.3 is shown a simple block diagram of a PLL-based frequency synthesizer capable of producing a wide range of frequencies using a single fixed crystal-controlled oscillator. The frequency is digitally programmable, i.e. it could be set by logic circuitry, by a microcontroller such as a PIC, or by a PC.

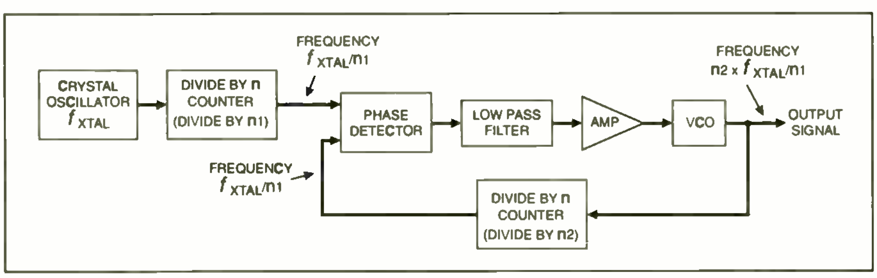


Fig.3. Block diagram of PLL-based frequency synthesiser.

The circuit is a basic PLL with a couple of programmable divide-by-*n* counters added. These counters are sequential logic circuits that divide an input frequency by *n*, where *n* is a binary number provided on a control input. They are available as i.c.s such as the CMOS 4059.

The first counter divides the crystal oscillator frequency f_{XTAL} by the integer value $n1$ to give the reference input to which the PLL will lock. Thus the PLL will lock onto $f_{XTAL}/n1$. The second counter divides the VCO output, so that the phase detector is comparing the input with a divided version of the VCO frequency.

The PLL will lock when the divided VCO frequency matches the input frequency – so the VCO will be running at $n2$ times the input frequency, i.e. $n2 = f_{XTAL}/n1$. The PLL is acting as a frequency multiplier.

The output from the frequency synthesizer is the PLL's VCO output. The VCO can have any waveshape (sine, square, triangular etc) and by selection of $n1$ and $n2$ a range of possible frequencies can be produced.

Frequent Loops

As readers will know, an f.m. (frequency modulated) signal such as that broadcast by your favourite radio station offers superior quality to that of an a.m. (amplitude-modulated) signal. In an a.m. signal it's the carrier's amplitude which is modulated. An a.m. radio signal is degraded by noise and interference, and furthermore its lower bandwidth affects the quality of audio that can be broadcast. The principle of detection enables us to listen to the a.m. radio programme.

In an f.m. signal, it's the frequency of a carrier signal which is modulated: which means that it isn't degraded by noise spikes or external interference. The process of demodulating an f.m. signal enables us to access the signal.

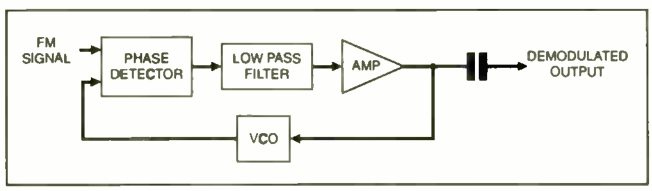


Fig.4. Using a PLL as an f.m. demodulator.

In Fig.4 is shown an f.m. demodulator based on a PLL. This is very straightforward – when locked, the VCO control voltage varies in proportion to the input frequency, so when the PLL is locked onto (and therefore tracking) the f.m. signal, the a.c. component of the VCO control voltage will represent the f.m. modulating signal.

Note that the d.c. component of the control voltage simply represents the f.m. "centre frequency", or frequency when the modulating signal is zero. The a.c. component of the VCO control voltage is obtained simply by capacitively coupling it to the output.

In fact a PLL-based circuit can also be used for a.m. detection but the circuit is not so intuitively easy to understand, so we will not describe the details.

PLLs can also be used to extract stereo from broadcast f.m. signals. Broadcast f.m. signals are a bit more complex than the basic f.m. described above as they contain a left-plus-right channel signal, a left-minus-right channel (difference) signal, a 19kHz pilot carrier and "other information", such as radio station identification data.

Again we do not have space for all the details, but it involves using the PLL to lock to the 19kHz pilot so that it can extract the stereo channel difference signal. Despite the lack of details, we hope this helps give you some idea of the wide application of PLL-based circuits.

Frequency Shift Key

An FSK (Frequency Shift Key) demodulator using a PLL is shown in Fig.5. An FSK signal switches between two frequencies to represent the 1s and 0s of a digital data stream, perhaps for transmitting digital data over radio links or down telephone lines: think of it as digital f.m.

When the PLL is locked onto (and hence tracking) the FSK signal, the VCO control voltage will switch between two voltages that represent the two frequencies. A second low pass filter, which has a long time constant compared to the data rate, is used to average the two voltages, thus providing a reference point midway between them. The reference point and the VCO control voltage are input to a comparator to provide a digital data output.

PLLs can be implemented in all-analogue, mixed, or all-digital form. They can also be implemented in software where the signals are available in digital form (and if the processor is fast enough), for example using a DSP (digital signal processor) chip.

So, software engineers such as Malcolm can have a go at PLLs and then join their hardware colleagues in the pub for some stimulating conversation!

We'll look at some PLL circuits next month. *I.M.B.*

CIRCUIT THERAPY

Circuit Surgery is your column. If you have any queries or comments, please write to: Alan Winstanley, *Circuit Surgery*, Wimborne Publishing Ltd., Allen House, East Borough, Wimborne, Dorset, BH21 1PF, United Kingdom. E-mail (no attachments) **alan@epemag.demon.co.uk**. Please indicate if your query is not for publication. A personal reply cannot be guaranteed but we will try to publish representative answers in this column.

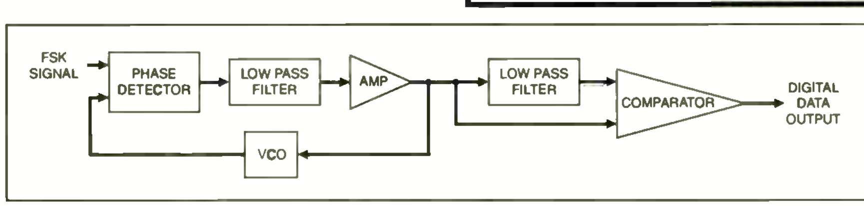


Fig.5. Using a PLL as an FSK demodulator.

SHOP TALK
with David Barrington

Doorbell Extender

Several of the components called for in the *Doorbell Extender* project are special items and could give readers local sourcing problems, especially if they are to fit on the small printed circuit boards. Also, as mains voltages are present on the units, only new and high quality parts should be purchased.

We understand that the Philips NE567 or the National Semiconductor LM567 tone decoder chips should both be suitable for this circuit. The LM567 is stocked by **Maplin** (☎ ***0870 264 6000*** or ***www.maplin.co.uk***), code QH69A.

The small 13A plug/case, with a brass Earth pin, came from **Rapid Electronics** (☎ ***01206 751166***), code 30-3205. They also supplied the Clairtronic (3002) miniature 1·5VA mains transformer, with dual secondaries, code 88-3012.

The BSS295 *n*-channel MOSFET is an RS component and was ordered through their mail order outlet: **Electromail** (☎ ***01536 304555*** or ***http://rswww.com***), code 298-392. They also stock the 4-pin d.i.l. bridge rectifier for both the Receiver and Transmitter, code 183-4034 (used in the Transmitter) or 657-072 (1A 200V).

The Omron type G6RN1 5V 114 ohm coil relay, with s.p.c.o. contacts rated at 8A 240V a.c., came from **Farnell** (☎ ***0113 263 6311*** or ***www.farnell.com***), code 959-078.

We have been given two sources for the TOKO RHCS45328AC2 i.f. transformer (475kHz); **Sycon** (☎ ***01372 372587***) and **BEC Distribution** (☎ ***01753 549502***). We suggest readers check with them regarding any handling charges.

The four printed circuit boards shown in the article are available from the *EPE PCB Service*, codes 292, 293, 294 and 295 (see page 229 for prices).

Don't forget that you must specify the *minimum* 400V working voltage when ordering the 10nF (0·01μF) metallised polyester film capacitor C1.

DIY Tesla Lightning

Because of the hazardous nature of the *DIY Tesla Lightning* project, we strongly suggest that any would-be constructors adhere strictly to the author's recommended components. Most of our comments are reserved for the safety aspect of this project. We would point out that this is definitely NOT a suitable schools project or for anyone not familiar with mains wiring and its safety aspects. **You undertake construction and use of this Tesla Coil entirely at your own risk.**

A couple of items mentioned in the components list need adding to. The contact number for the Variac transformer type 403 is **Claude Lyons** at ☎ ***01992 768888***. The Arcotronics 47nF 1500V capacitor (48 required) can be ordered from **Electromail** (☎ ***01536 304555***), code 114-474. It is ***essential*** that the specified capacitors are used, they are exceptionally high quality units and most other brands could fail quickly in this application.

For more advice and practical experience, contact with other Tesla Coil builders is recommended. You could also attend some of the frequent "Teslathons" which take place around the UK. For more details contact the TCBOUK at **www.tcbouk.org.uk**. If you encounter any difficulty in the construction of this project go to web address **www.tesla-coil.co.uk/epe/** for troubleshooting help from the author.

Body Detector

The author places quite an emphasis on the temperature coefficient of the resistors, potentiometers and capacitors required to construct the *Body Detector* project and readers are advised to check with their supplier when ordering components. The ones used in the prototype came from **Maplin** (☎ ***0870 264 6000***), but most of our component advertisers should be able to help.

The above mentioned company supplied the National Semiconductor LM294OCT 1A 5V low-dropout regulator, code AV22Y. Anything similar, preferably a micropower type, rated at 150mA upwards should cope in this circuit.

They also supplied the plastic case, code BZ74R and the 1A p.c.b. mounting, 2-pole changeover, relay, code GU35Q. You have a choice of two 10-turn wirewound potentiometers, codes DA86T (200Ω) or DA87U (500Ω). These will set you back about £5 each.

We have no idea where to obtain stripboard with "phantom" printed strips on the topside.

Circuit Tester

We do not expect any component buying problems to arise when ordering parts for the *Circuit Tester*, this month's Top Tenner project. The MOSFET device should be widely stocked, but if any readers do have trouble finding the VN10KM device it is currently listed by **Electromail** (☎ ***01536 304555*** or ***http://rswww.com***), code 655-537 and **Maplin** (☎ ***0870 264 6000*** or ***www.maplin.co.uk***), code QQ27E.

PLEASE TAKE NOTE

Toolkit Mk2 V2.4 *Nov '99*

Software version V2.4C is now on the *EPE* FTP site and 3·5in. disk. It corrects two bugs reported in the MPASM handling routines, and the config routine has been updated to provide 14-bit control of PIC16x84 config and code protection bits.

Graphics Liquid Crystal Displays with PICs *Feb '01 (Supplement)*

Fig.3. Capacitor C6 on pin 31 of IC1 should read C8 and is 100nF. Resistor R4 should be hard-wired on the rear of the p.c.b. between IC1 pin 17 and the most convenient +5V track point.

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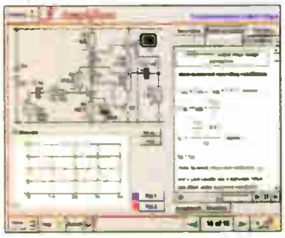
ANALOGUE ELECTRONICS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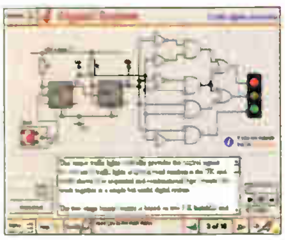
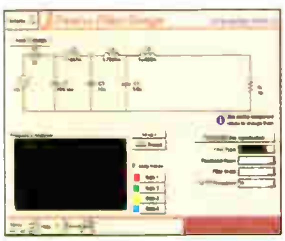
DIGITAL ELECTRONICS


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.
Covers binary and hexadecimal numbering systems, ASCII, basic logic gates, monostable action and circuits, and bistables – including JK and D-type flip-flops. Multiple gate circuits, equivalent logic functions and specialised logic functions. Introduces sequential logic including clocks and clock circuitry, counters, binary coded decimal and shift registers. A/D and D/A converters, traffic light controllers, memories and microprocessors – architecture, bus systems and their arithmetic logic units.

FILTERS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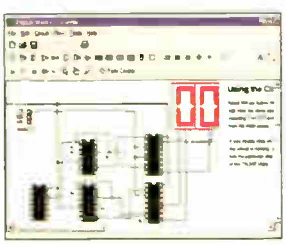
DIGITAL WORKS 3.0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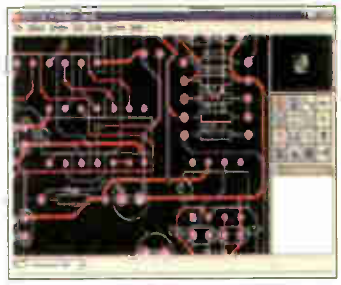
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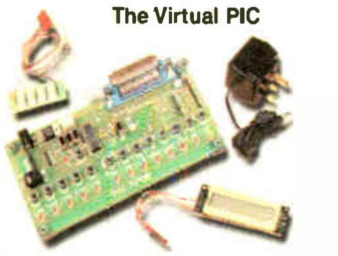
Interested in programming PIC microcontrollers? Learn with PICtutor by John Becker

The Virtual PIC



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HARDWARE

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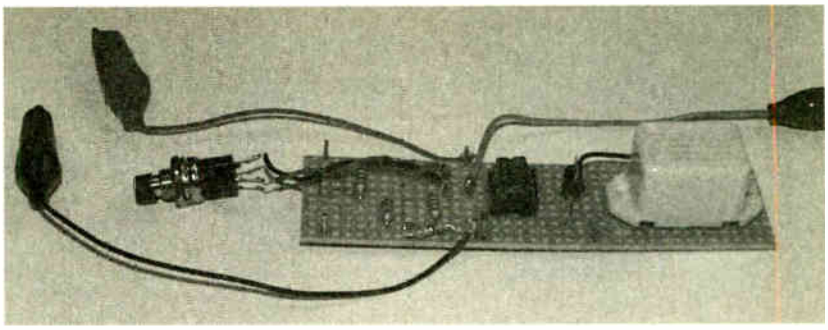
CIRCUIT TESTER



OWEN BISHOP

Project 7

This short collection of projects, some useful, some instructive and some amusing, can be made for around the ten pounds mark. The estimated cost does not include an enclosure. All of the projects are built on stripboard, and most have been designed to fit on to boards of standard dimensions. All of the projects are battery-powered, so are safe to build. In a few cases in which, by its nature, the project is to be run for long periods, power may be provided by an inexpensive mains adaptor. Again, the cost of such a unit is not included.

WHEN you switch on a newly built project and it fails to work, the reason is often an *open circuit*, a *short circuit*, or maybe a few of both. Open circuits are often due to faulty soldering. Greasy, dirty or oxidised surfaces, or failure to make both sides of the joint sufficiently hot, results in the solder not flowing evenly across the joint. The result is a *dry joint*, with very high or infinite resistance. In other words, an open circuit.

Occasionally you may completely forget to solder a joint, or an essential connecting wire may be omitted altogether. If you make your own p.c.b.s, you may sometimes leave a p.c.b. in the etchant for too long, so that one or more of the fine tracks disappears.

Short circuits are also mostly due to faulty soldering. Excessively large blobs of solder may spread across two adjacent tracks. Often, a fine "hair" of solder may bridge two or more adjacent tracks. Also, when making p.c.b.s, you may still leave bridges between tracks if you do not etch for long enough.

RIGHT CONNECTION

Therefore, in the absence of any other evidence (such as smoke issuing from one of the transistors) the first tests on a faulty circuit are to check for open circuits and short circuits. For example, a glance at the circuit diagram shows which points of the circuit should be connected to the 0V rail; check that they are.

Similarly, check for connections to the positive supply rail. This point is important when using CMOS i.c.s. These will often run without being connected to the positive supply, obtaining their supply of current through one of the input terminals. However, they will not function correctly without a proper connection to the supply.

Check also for short circuits between power rails and between tracks that are closely adjacent. Conversely, check that there is no low-resistance connection between the positive and 0V power rails.

CIRCUIT TESTER

There are a number of devices available for checking circuits in this way. Often a multimeter includes the facility for testing short-circuits (sometimes referred to as "continuity testing").

However, the borderline between a real short circuit and what is simply a low resistance is sometimes imprecisely defined. Some devices may indicate a short circuit when the resistance is as much as 10Ω. In the Circuit Tester, this month's *Top Tenner* project, a short circuit is taken to have a resistance of 1Ω (ohm) or less. Conversely, an open circuit is defined as a resistance of 10MΩ (megohms) or more.

HOW IT WORKS

The Circuit Tester (Fig.1) is a simplified version of the very precise resistance-measuring circuit known as a "Wheatstone Bridge". A true Wheatstone Bridge is able to measure the actual resistance between any two points in a circuit but, in this simplified version, we need to know only if the resistance is greater than or less than a fixed amount (1Ω or 10MΩ).

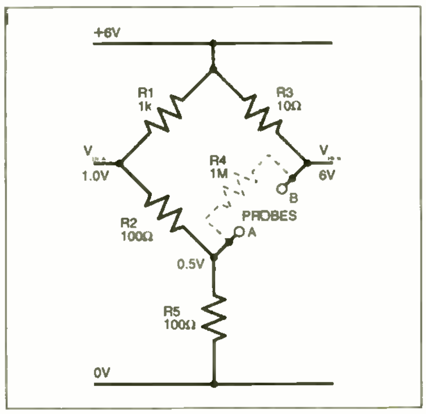


Fig.2. The circuit equivalent when testing for "short-circuits".

First we look at its action as a detector of short circuits. For this we use two probes connected at points *A* and *B* in circuit diagram Fig.1. To make the operation easier to understand, the circuit is redrawn in Fig.2, to look more like a conventional "bridge". In this application we can ignore the 1MΩ resistor (R4) as the resistances to be connected between probes *A* and *B* are only a few ohms and 1MΩ in parallel with these will have virtually no effect.

The state of the bridge is monitored by an operational amplifier IC1. We can ignore the small currents flowing into the inputs of IC1 because they are j.f.e.t. inputs with an input resistance of around 10^6MΩ.

We say that the bridge is *balanced* if $V_{INA} = V_{INB}$. This

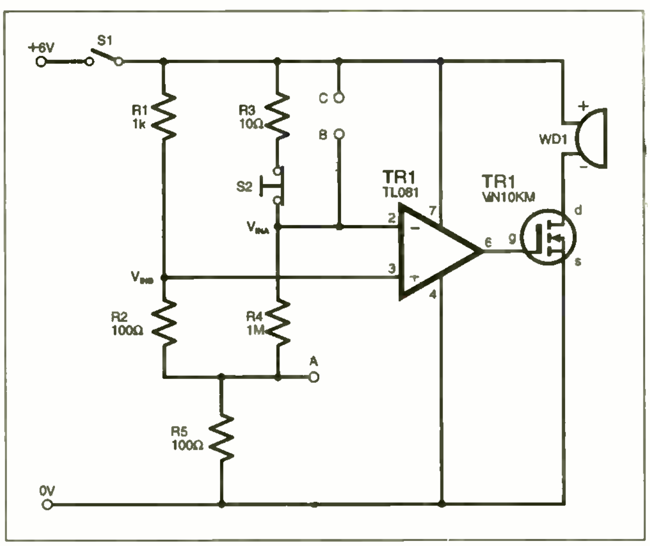


Fig.1. Complete circuit diagram for the Circuit Tester. Switch S2 is a push-to-break type.

happens when the ratio R1:R2 equals the ratio R3:R_{AB}, where R_{AB} is the resistance between probes *A* and *B* when they are in contact with the circuit under examination. The ratio R1:R2 is 10:1, so the bridge is balanced when R_{AB} = 1Ω.

When the bridge is balanced, the inputs to IC1 are equal, its output is 3V, which is not quite enough to turn transistor TR1 on, and the buzzer WD1 is silent. If R_{AB} is greater than 1Ω the voltage drop across R_{AB} increases. The bridge is *unbalanced* and then V_{INA} is greater than V_{INB}. This makes the output of IC1 swing down toward 0V.

Transistor TR1 is still off and the buzzer is still silent. But, if R_{AB} is less than 1Ω the voltage drop across R_{AB} decreases. The bridge is again unbalanced, but in the opposite direction and then $V_{INA} < V_{INB}$.

The op.amp is connected as a comparator, with an open-loop gain of about 200,000, so even a small increase of V_{INB} relative to V_{INA} makes the output swing sharply toward 6V. Transistor TR1 is turned on and the buzzer sounds, indicating a short circuit.

Detection of open circuits is illustrated in Fig.3, when the test piece is between probes *B* and *C*, with a resistance of R_{BC}. It

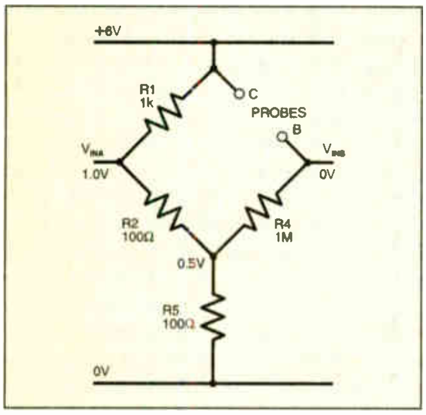


Fig.3. The circuit equivalent when testing for "open-circuits".

is necessary to hold switch S2 pressed to obtain this circuit.

As before, the bridge is balanced when the ratios are equal. The ratio R1:R2 is still 10:1 but now the balance point is reached when R_{BC}:R4 is 10:1. This occurs when R_{BC} = 10MΩ.

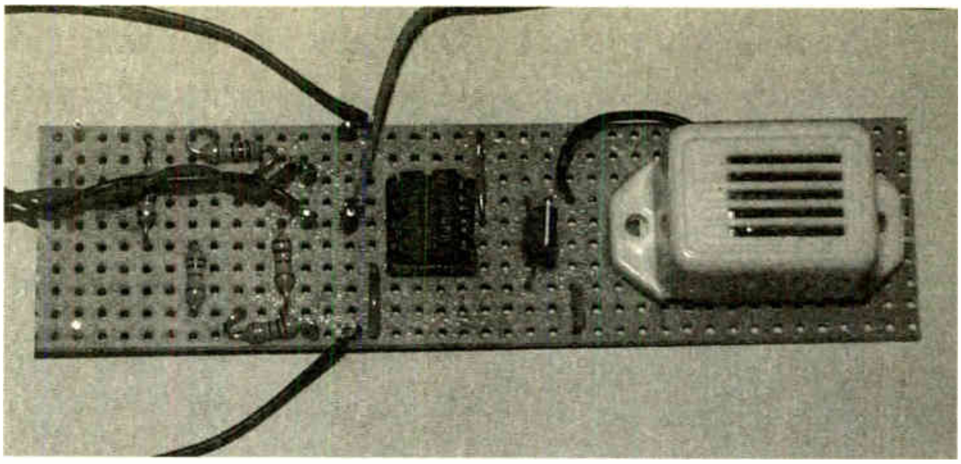
If R_{BC} is less than 10MΩ, the voltage across R_{BC} is reduced, making $V_{INA} > V_{INB}$. The bridge is unbalanced. The output of IC1 drops toward 0V and the buzzer is silent. If there is an open circuit with R_{BC} > 10MΩ, the bridge is unbalanced in the opposite direction. $V_{INA} < V_{INB}$ and the output swings sharply upward, turning on the buzzer.

CONSTRUCTION

This simple Circuit Tester is built on a small piece of 0·1in. matrix stripboard, having 10 copper strips by 39 holes. (Note, there is no row *I*.) The topside component layout, wiring and details of breaks in the copper tracks are shown in Fig.4.

The circuit board layout is very simple and assembly should cause no problems. It is recommended that an 8-pin d.i.l. socket is used for op.amp IC1.

There are several ways of realising this project. The simplest is to have the



Completed CircuitTester stripboard, minus power supply leads.

COMPONENTS

Resistors

R1	1k	
R2, R5	100Ω (2 off)	
R3	10Ω	
R4	1M	

All 0·25W 1% metal film

See SHOP TALK page

Semiconductors

TR1	VN10KM *n*-channel MOSFET
IC1	TL081 operational amplifier, j.f.e.t. inputs

Miscellaneous

S1	s.p.s.t. toggle, rocker or slide switch
S2	pushbutton switch, push-to-break
WD1	4V to 9V solid-state buzzer

Stripboard, 0·1in. matrix 10 strips by 39 holes; optional plastic case, size to choice; 8-pin d.i.l. socket; battery holder (4 x AA); 1mm solder pins (7 off); crocodile clip (3 off different colours) or other connectors (probes); multistrand connecting wire; solder, etc.

Approx. Cost Guidance Only **£7** excluding case & batts.

bare board with three short leads ending in crocodile clips. A more handy arrangement is to enclose the circuit board and battery box in a plastic container with one flexible lead with a crocodile clip wired to point *B* (the common point). The other two test points, *A* and *C*, are wired to a pair of probes mounted on the box.

It is possible to obtain proper probes for this purpose but two long narrow bolts will do almost as well. They can be mounted on opposite sides of the box. You then turn the box one way or the other for the two tests.

The pushbutton switch S2 should be located where it is in a convenient position to press when probe *C* is being used. To make the circuit completely automatic, you could substitute a tilt switch for S2, mounted so that it closes when probe *C* is being used.

A battery box is recommended as a power supply. One that holds four type AAA cells will fit neatly in most small project boxes. If you are leaving the circuit open, attach the battery box to the underside of the circuit board, using double-sided adhesive pads. Another pad can also be used to attach the buzzer to the board. □

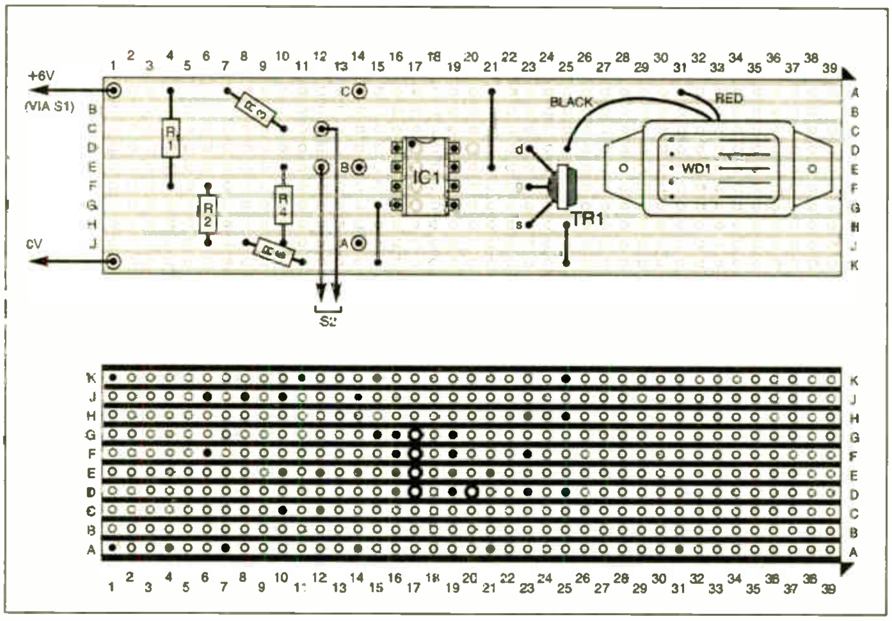


Fig.4. Stripboard component layout, wiring and underside view showing the four breaks in the copper strips. Points A, B, C are the lead-off solder pins for the probes.

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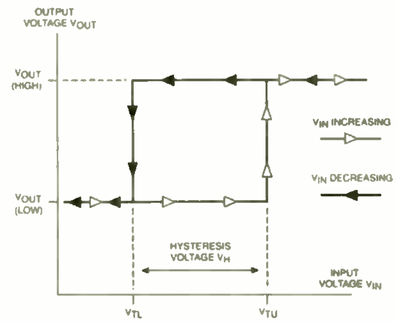

ANTHONY H. SMITH

Part 5

In this short series, we investigate the Schmitt trigger's operation; explore the various ways of implementing its special characteristics and also look at how we can use it to create oscillators and pulse width modulators.

Digital Applications

ONE OF the Schmitt trigger's most powerful attributes is its ability to convert a range of different waveforms – some of them having irregular shapes and slowly changing voltages – into a well defined, rectangular signal that makes rapid transitions from one voltage level to another. Therefore, it's not surprising that most digital logic families offer at least two logic functions with Schmitt trigger inputs, and in this article we'll see how these devices can be used to interface digital systems with "real world" analogue signals.

However, as we shall see later, the digital Schmitt trigger is by no means limited to signal interfacing applications; like the linear versions based on transistors and op.amps examined in previous articles, it can be used as the central element in many other interesting functions.

MEET THE FAMILY

Since the 1960s, many digital logic "families" have been introduced. One of the first TTL families was the 74-series (now largely obsolete), a hugely popular family of logic functions which has been followed over the years by other TTL varieties such as 74H, 74LS and 74F, each providing a unique blend of speed and power characteristics.

In the 1970s, the first 4000-series CMOS devices appeared, offering gates with minuscule power consumption and very high input impedance. Other CMOS families have followed: the 74C, 74HC and 74AC are some of the most common.

Almost all of these logic families have provided one or two gate types with Schmitt trigger inputs. However, as it would be impossible to review all the different variants, we will focus on the Schmitt devices in the 4000-series and 74HC/HCT families.

INVERTERS AND NANDS

Schmitt trigger logic devices tend to be found as *inverting* types only. For example, the 74HC14 and 40106B (also known as 4106B by some manufacturers) are hex inverters, whereas the 74HC132 and 4093B are quad, 2-input NAND gates (i.e., AND gates with logic inversion).

Table 5.1 lists some of the more important characteristics of these devices. Note that the supply voltage range for the 4000-series devices is around three times greater than that of the 74HC/HCT types. However, the 4000-series parts are much slower than the 74HC/HCT devices; both the *propagation delay* (the time taken for a signal to propagate from input to output) and the *transition times* (the time required for the output signal to traverse from one logic level to the other) are an order of magnitude greater than those of the 74HC/HCT devices.

Most manufacturers of Schmitt logic devices usually refer to the upper switching threshold as the *positive-going threshold* (usually denoted V_{T+}); similarly, the lower threshold is called the *negative-going threshold* (usually denoted V_{T-}). Notice that the thresholds have a fairly broad manufacturing tolerance, hence the minimum and maximum values. Also, note that the thresholds of the 74HCT parts are significantly less than those of the equivalent 74HC devices. We'll say more about threshold voltages later.

Not included in Table 5.1 are specifications for the output voltage levels, input current values and quiescent supply current. Generally, these tend to be the same as for similar logic devices in the same family. For example, when lightly loaded, the outputs of most 4000-series and 74HC/HCT devices will swing from one supply rail to the other.

CMOS input currents are extremely low, typically less than a nanoampere and no greater than 100nA at 25°C. This is a convenient feature which allows large resistance values to be used for biasing the inputs, and is particularly useful in timing applications that require large time constants.

Generally, CMOS devices have very low quiescent supply current (much lower than equivalent TTL parts). For example, the quiescent supply current for the 74HC14 is no greater than 2µA at 25°C; the 4000-series devices are similarly frugal with power consumption. Bear in mind, however, that these are *static* (i.e., "doing nothing") values: the supply current increases considerably when the device starts switching, and power consumption goes up as operating frequency increases.

Table 5.1: Characteristics of Common Schmitt Trigger Logic Devices

Part Number	Function	Supply Voltage Range (V)		Negative-Going Threshold, V_{T-} (V)		Positive-Going Threshold, V_{T+} (V)		Hysteresis Voltage, V_H (V)		Max. Propagation Delay t_p (ns)	Max. Transition Time t_T (ns)
		min.	max.	min	max.	min.	max.	min.	max.		
74HC14	Hex Inverter	2	6	1	2·5	2·5	3·5	0·4	1·4	22	14
74HCT14	Hex Inverter	2	6	0·55	1·3	1·3	2·0	0·4	1·45	34	15
74HC132	Quad 2-input NAND	2	6	1	2·5	2·5	3·5	0·4	1·4	22	14
74HCT132	Quad 2-input NAND	2	6	0·55	1·3	1·3	2·0	0·4	1·45	34	15
4093B	Quad 2-input NAND	3	15	1·5	2·25	2·75	3·5	0·5	2·0	450	145
40106B	Hex Inverter	3	15	0·7	2·0	3·0	4·3	1·0	3·6	400	200

Notes: Characteristics are representative of each part but may vary from one manufacturer to another.
Values are quoted for: positive supply voltage = 5V; negative supply voltage = 0V; ambient temperature = 25°C.

SYMBOLS AND PINOUTS

The circuit symbols for the Schmitt logic devices are shown in Fig.5.1. Notice how each symbol contains the "clockwise" hysteresis loop typical of inverting Schmitt triggers. The inherent Schmitt switching function does not alter the *logic* function in any way. For example, the 74HC14 performs the same logic inversion as the non-Schmitt 74HC04 inverter; similarly, the 4093B 2-input NAND logic function is exactly the same as the non-Schmitt 4011B 2-input NAND.

The pinout connection and internal structure diagram for each package is shown in Fig.5.2. The pinouts for the 40106B and 74HC/HCT14 are the same, but both packages have been shown to emphasise the different power supply terminology: generally, the positive supply (pin 14) is denoted V_{DD} for 4000-series devices and V_{CC} for 74HC/HCT parts; the negative supply (pin 7) is usually denoted V_{SS} for 4000-series parts and GND ("ground") for 74HC/HCT parts.

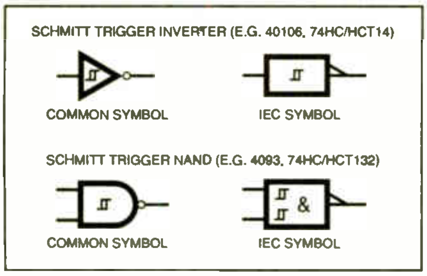

Fig.5.1. Some circuit symbols for Schmitt trigger logic devices.

Notice that the pinouts for the 4093 and 74HC/HCT132 are different, so it would not be possible to replace one part with the other in a breadboard or p.c.b. without making changes to the connections.

A handful of other devices provide Schmitt trigger inputs. For example, the 74HC123 and 74HC423 (Dual Retriggerable Monostable Multivibrators) and 74HC221 (Dual Non-retriggerable Monostable Multivibrator) provide Schmitt switching levels at the trigger inputs.

Specific manufacturers also provide Schmitt trigger action at the clock inputs of certain flip-flops and counters. For instance, Philips Semiconductors provide Schmitt clock inputs for the 74HC/HCT74 (Dual D-type Flip-Flop), 74HC/HCT112 (Dual JK Flip-Flop), and 4040B (12-stage Binary Counter), whereas other manufacturers provide only standard clock inputs for the same parts.

SWITCHING THRESHOLDS AND LOGIC LEVELS

It is important to make a distinction between the switching thresholds of a Schmitt device like the 40106B, and the input logic levels of a non-Schmitt inverter like the 4049UB. For example, with V_{DD} = 5V, the low level input voltage, V_{IL}, of the 4049UB is typically 1·5V and the high level input voltage, V_{IH}, is typically 3·5V. At first sight, it might appear that the 4049UB behaves as a Schmitt inverter with a hysteresis voltage of 3·5V – 1·5V = 2·0V, this is not the case.

The specifications for V_{IL} and V_{IH} simply define the guaranteed input logic level voltages for the particular device. Therefore, V_{IL} = 1·5V means that any voltage less than 1·5V will be recognised as a logic "0" by the input; similarly, V_{IH} = 3·5V implies that any voltage greater than 3·5V will be treated as a logic "1". However, unlike the Schmitt device, there is *only one* input switching threshold which may lie anywhere between V_{IL} and V_{IH}, and is usually around $V_{DD}/2$ for 4000 series devices.

Consequently, having no hysteresis voltage, the non-Schmitt devices cannot provide the same noise-rejection as their Schmitt counterparts. Furthermore, they are unable to deal properly with slowly changing input signals which can lead to erratic behaviour or output distortion.

JITTER, GLITCHES AND DISTORTION

Digital systems must often interface with "non-digital" signals that have long rise and fall times; examples are filter output signals, transducer output signals and signals derived from oscillators or transformers. Theoretically, the high gain between the input and output of a logic device would produce a rectangular output pulse regardless of the rise and fall times of the input signal. In practice, things are quite different.

When a slowly changing edge reaches the switching threshold of a standard logic element, it starts to switch, and a phenomenon called "charge-dumping" causes slight shifts in the power supply voltage levels within the i.c. This pulls the circuit back into its pre-switching state, thereby causing a "jittering" output. Also, as the input signal passes through the switching threshold, the complementary transistors in the input stage conduct *together*, causing a relatively large current flow through the device and a corresponding increase in power dissipation. This can also lead to gross distortion in the output waveshape.

For standard logic devices, the only way to avoid these problems is to ensure that the input signal's transition times are kept very short. Indeed, most logic devices specify a maximum value for the rise and fall times; for instance, the 74HC04 requires input signal transition times that are less than 500ns for reliable operation.

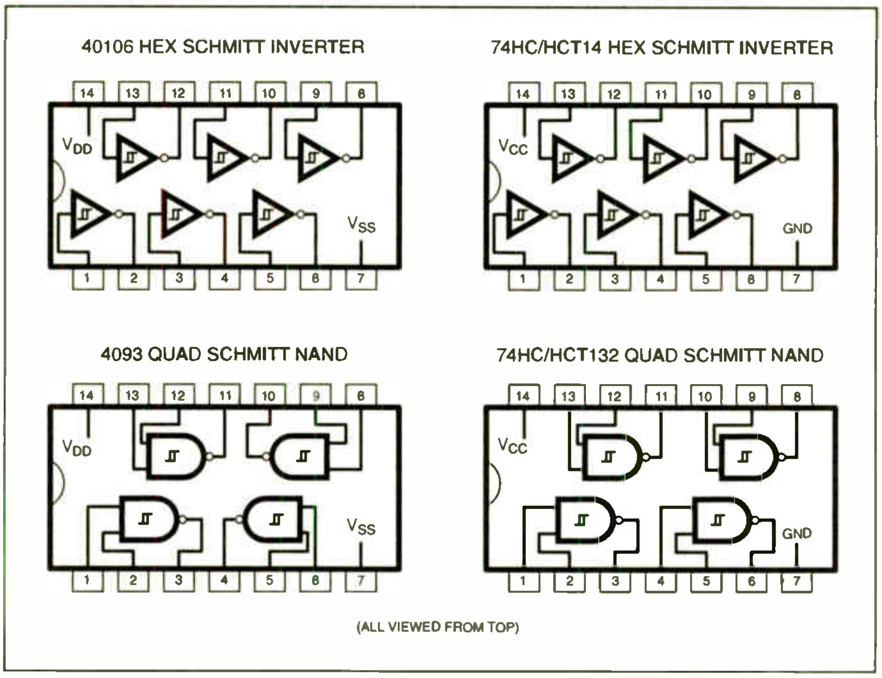

Fig.5.2. Internal structures and pinout details for a group of Schmitt trigger logic i.c.s.

Therefore, for systems where slowly changing signals are unavoidable, a Schmitt trigger device is essential to prevent jitter and to keep power dissipation low. Of equal importance is the Schmitt's ability to reject noise: provided they are of lower amplitude than the hysteresis voltage, any glitches occurring as the signal crosses the switching threshold will have no effect on the output signal.

TYPICAL INTERFACE CIRCUIT

A circuit that can be adapted to interface the Schmitt logic element with almost any kind of input signal is shown in Fig.5.3. Although IC1 is shown as a Schmitt inverter, it could be a Schmitt NAND or any other logic device having a Schmitt trigger input.

Although the Schmitt is often used for sine-to-square conversion, the input signal V_S can take almost any shape, and can range in amplitude from a volt or so, up to several hundred volts with suitable attenuation. Each of the components before the inverter plays a unique role, but, depending on the application, some or all of them may be omitted.

Capacitor C_C is used for a.c. coupling and is necessary when the average, d.c. level of the input signal exceeds IC1's supply rails. Capacitive coupling can also be necessary where the d.c. level lies within the supply rails but is somewhat distant from the inverter's mid-hysteresis voltage level.

Input resistor R_{IN} may be required to protect IC1's input against overload. Resistor R_{IN} may also be used with R1 and R2 to form an attenuator; this is necessary where the amplitude of input signal V_S exceeds the Schmitt's supply rails.

Resistors R1 and R2 are required when the input is capacitively coupled via C_C, and are used to establish a bias voltage, V_{BIAS}, at the Schmitt's input. As we shall see later, R1 and R2 should be chosen to make V_{BIAS} equal to the mid-hysteresis voltage level.

Diodes D1 and D2 are protection components which "clamp" excessive voltages to safe levels. To some degree, D1 and D2 augment IC1's own *internal* protection diodes and can therefore be omitted in certain applications. However, it is good practice to include D1 and D2, particularly where extreme voltages could be present.

Finally, capacitor C_F can be used with R_{IN} to form a simple low-pass filter. This can be useful if the input is subject to large amplitude, high frequency noise, and together with the inverter's hysteresis provides a powerful degree of noise immunity.

Table 5.2: Threshold Voltages for 40106-type Hex Schmitt Inverters

Manufacturer	Part Number	Negative-Going, Threshold V_{T-} (V) min.	typ.	max.	Positive-Going, Threshold V_{T+} (V) min.	typ.	max.	Hysteresis Voltage, V_H (V) min.	typ.	max.
Fairchild/National Semiconductor	CD40106BC	0·7	1·4	2·0	3·0	3·6	4·3	1·0	2·2	3·6
Philips Semiconductor	HEF40106B	1·5	2·2	3·0	2·0	3·0	3·5	0·5	0·8	N·S·
Motorola (On Semiconductor)	MC14106B	0·9	1·9	2·8	2·2	2·9	3·6	0·3	1·1	2·0

Notes: Values are quoted for: V_{DD} = 5V; V_{SS} = 0V; ambient temperature = 25°C·
N.S.: Not Specified

In a moment, we'll work through some simple examples to see how the circuit can be adapted to suit different applications. First, however, we must take a closer look at the Schmitt's input characteristics.

INPUT CHARACTERISTICS: ON THE THRESHOLD

As an example, Table 5.2 lists the 40106B threshold voltages for three different manufacturers. The values were taken directly from the manufacturers' data sheets and illustrate the spread in thresholds at room temperature for V_{DD} = 5V and V_{SS} = 0V.

The first thing to note is that the specifications differ considerably from one manufacturer to another, even though they relate to the same kind of device! Furthermore, the values given can be confusing.

For example, we would expect the minimum hysteresis voltage to be the difference between the minimum positive-going threshold and the maximum negative-going threshold, or V_H(min) = V_{T+}(min) – V_{T-}(max). Similarly, we would expect the maximum hysteresis voltage to be the difference between the maximum positive-going threshold and the minimum negative-going threshold, or V_H(max) = V_{T+}(max) – V_{T-}(min).

If we calculate V_H(min) and V_H(max) for the Fairchild/National Semiconductor part using the minimum and maximum values for V_{T+} and V_{T-}, we find that the results agree exactly with the specified values for V_H(min) and V_H(max). However, if we perform the same calculations for the Philips and Motorola parts, the results differ significantly from the specified values for V_H(min) and V_H(max). In fact, for both of these parts, the data suggest that V_{T-}(max) can actually be *greater* than V_{T+}(min) – clearly impossible if the device is to work properly!

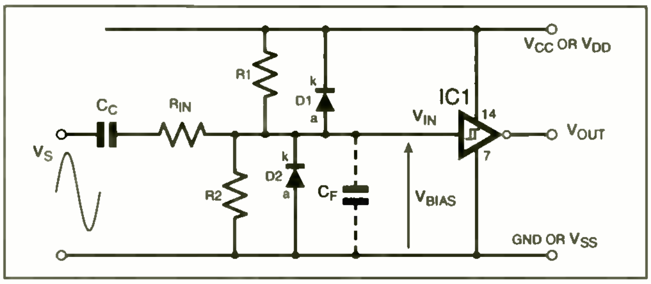

Fig.5.3. Circuit diagram for a Schmitt trigger interface.

SUPPLY VOLTAGE VARIATIONS

Changes in supply voltage cause corresponding changes in the threshold voltages. This is shown graphically in Fig.5.4, where the spread in each threshold voltage is shown as a band which widens as the supply voltage increases. Clearly, the hysteresis voltage, being the difference between the thresholds, will also grow larger as the supply voltage increases.

To make matters worse, the relationship between threshold voltage and supply voltage is not necessarily a linear one as shown in Fig.5.4, but can actually be highly non-linear. In other words, the value of either threshold voltage is not necessarily a fixed percentage of the supply voltage.

To see how the ambiguities in threshold levels can have a significant effect on circuit behaviour, we'll refer again to the interface circuit in Fig.5.3 and consider a simple example.

Let us assume the input signal is derived from an active filter circuit working on a single 15V supply. The filter output is a sinewave with a frequency range from 100Hz to 500Hz. The signal amplitude can vary from 7Vp-p (peak-to-peak) to a maximum of 10Vp-p, and swings symmetrically about a mean, d.c. level of 7·5V.

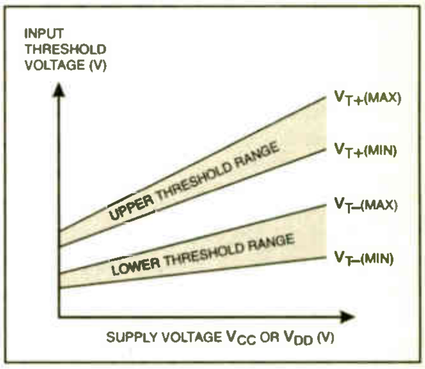

Fig.5.4. Input threshold voltages vary with supply voltage.

The sinewave must be converted to a rectangular signal for the digital part of the system working on a single 5V rail. We decide to use the Fairchild/National Semiconductor CD40106BC as the input device, so in Fig.5.3 IC1 is one sixth of the CD40106BC package, V_{DD} = 5V and V_{SS} = 0V.

Since the input signal, V_S, swings about a 7·5V d.c. level, coupling capacitor C_C is essential, and resistors R1 and R2 must be selected to set the d.c. bias level, V_{BIAS}, to a suitable value. As we are designing the circuit for a production run of thousands of units, it is impossible to measure the threshold levels of each individual Schmitt inverter, so R1 and R2 must be chosen to satisfy all possible values of V_{T-} and V_{T+}.

MID-HYSTERESIS LEVEL

By setting V_{BIAS} equal to the mid-hysteresis level denoted $V_{H(MID)}$, we ensure the circuit will be triggered by peak-to-peak signal amplitudes which are equal to, or greater than, the hysteresis voltage. In other words, we ensure the circuit has *maximum sensitivity*.

However, this is where our problems begin. The mid-hysteresis level is given by:

$$V_{H(MID)} = V_{T-} + \frac{V_H}{2} = V_{T-} + \frac{(V_{T+} - V_{T-})}{2} = \frac{V_{T-} + V_{T+}}{2} \quad \text{(volts)}$$

Which values do we choose for V_{T-} and V_{T+}? Referring again to the specifications for the Fairchild/National Semiconductor CD40106BC in Table 5.2, if we choose *maximum* values for each threshold, we find that $V_{H(MID)}$ = (2·0 + 4·3)/2 = 3·15V. On the other hand, selecting *minimum* values gives $V_{H(MID)}$ = (0·7 + 3·0)/2 = 1·85V.

Faced with this kind of design dilemma, it is often necessary to choose a middle course and use the *typical* threshold values, which yield $V_{H(MID)}$ = (1·4 + 3·6)/2 = 2·5V. In other words, we set V_{BIAS} equal to V_{DD}/2, which is simply a case of making R1 = R2. This "typical value" approach is illustrated in Fig.5.5a, which shows that the minimum peak-to-peak amplitude of V_{IN} (the signal at the inverter's input) required to cross both thresholds is equal to the hysteresis voltage, V_H (in this case, 2·2V).

The values chosen for resistors R1 and R2 should not be too small, otherwise they will excessively load the signal source and will necessitate a relatively large value for coupling capacitor C_C. However, the values must not be too large, or IC1's input leakage current (±0·1μA max) which must flow through either R1 or R2 will cause a significant voltage drop which could offset the intended value of V_{BIAS}. Values in the range 100kΩ to 560kΩ are usually suitable.

SIGNAL ATTENUATION

Resistor R_{IN} forms a potential divider with R1 and R2 and must be selected to attenuate V_S such that the amplitude of V_{IN} does not exceed IC1's input voltage range. Under normal operating conditions, the input voltage to the Schmitt devices listed in Table 5.1 should not exceed the supply rails.

Therefore, for the circuit of Fig.5.3, the peak-to-peak amplitude of V_{IN} must not exceed 5V. However, since V_S can be as large as 10Vp-p, we must attenuate it by a factor of two.

IC1's input voltage, V_{IN}, is related to V_S as follows:

$$V_{IN} = V_S \times \frac{R_{TH}}{R_{IN} + R_{TH}} \quad \text{(volts)}$$

where R_{TH} is the Thévenin equivalent resistance of the R1-R2 potential divider:

$$R_{TH} = R1//R2 = \frac{R1 \times R2}{R1 + R2} \quad \text{(ohms)}$$

where // means "in parallel with".

By making $R_{IN} = R_{TH}$, we obtain the required factor of two attenuation, that is, $V_{IN} = V_S/2$. Also, since R1 = R2 in this example, we find that R_{TH} is simply half the value chosen for R1 and R2. Suitable *preferred* values are R1 = R2 = 360kΩ, R_{IN} = 180kΩ.

By attenuating V_S, we have ensured that V_{IN} cannot exceed V_{SS} or V_{DD}, therefore protection diodes D1 and D2 shown in Fig.5.3 are not required. Also, since V_S is not affected by excessive noise or interference, filter capacitor C_F is not needed.

Coupling capacitor C_C must be selected to present a low impedance to V_S at the *minimum* operating frequency, which in this example is 100Hz. If the reactance of C_C is, say, fifty times less than R_{IN}, the capacitor will have negligible effect on the overall attenuation. A value of C_C = 470nF would be suitable, having a reactance of 3·4kΩ at 100Hz.

Note that in certain applications, a *small* value of C_C may be used such that its reactance is relatively large, thereby contributing to the attenuation. However, this approach should be used with caution, since capacitor tolerance (often as large as ±10%) will have an unpredictable effect on the attenuation factor, and the reactance – and hence attenuation – will vary if the frequency changes. Furthermore, the phase shift introduced by a small value of C_C could cause problems in certain applications.

WORST CASE PROBLEMS

The amplitude of V_S needed to trigger IC1 will depend on the actual hysteresis voltage of the device used. If we are lucky and the thresholds are at their typical values as shown in Fig.5.5a, the smallest peak-to-peak amplitude of V_{IN} that will cross both thresholds is simply equal to the hysteresis voltage, which is typically 2·2V as shown. Taking the attenuation into account, this means that V_S must be at least 4·4V p-p.

However, referring to Table 5.2, we see that the CD40106BC hysteresis voltage can be as large as 3·6V. Therefore, the *worst case* conditions would require V_{IN} = 3·6Vp-p, and thus V_S = 7·2Vp-p, to cross both thresholds. Now, we saw earlier that V_S could be a minimum of 7Vp-p, in which case the sinewave would simply not be large enough to trigger IC1.

A further problem arises when the thresholds do not lie symmetrically about the chosen value of V_{BIAS}. This is shown in Fig.5.5b, where the thresholds are both 0·6V lower than in Fig.5.5a. Consequently, the mid hysteresis level, $V_{H(MID)}$, is also 0·6V lower at 1·9V. Since R1 = R2, the bias voltage, V_{BIAS}, remains the same (2·5V). Even though the hysteresis voltage is exactly the same as in Fig.5.5a, the amplitude of V_{IN} has had to be increased considerably in order for the sinewave to cut the negative threshold, V_{T-}.

The shift in $V_{H(MID)}$ away from V_{BIAS} also has a marked effect on IC1's output waveform, V_{OUT}. In Fig.5.5a, where the thresholds are symmetrical about V_{BIAS}, the output squarewave has a 50% duty cycle. However, in Fig.5.5b, the duty cycle of V_{OUT} is significantly less than 50%.

Whether or not this change in duty cycle is a problem will depend on the application. Interestingly, this effect can be used as a crude technique for varying the duty cycle of a pulse waveform: by feeding the Schmitt device with a sinewave or triangle wave of suitable amplitude, and by varying V_{BIAS} (for example, by replacing R1 and R2 with a potentiometer), the duty cycle of V_{OUT} can be varied over a narrow or relatively large range, depending on the hysteresis of the device used.

HIGH VOLTAGE PROTECTION

The fact that the threshold levels can vary considerably from one part to another means that the Schmitt devices listed in Table 5.1 cannot always be guaranteed to trigger correctly on a given waveform, especially where the amplitude of the input signal can vary as in the example above. In certain cases, it may be necessary to replace the "digital" Schmitt device with one made using op.amps or comparators, where the thresholds and hysteresis can be set precisely. One of the many circuits described in Part Two or Part Three of this series should be suitable.

Nevertheless, despite the somewhat ambiguous nature of the thresholds, the devices listed in Table 5.1 are often more than adequate for interfacing a digital system to the "real world". However, as we will see in the next example, the real world can be a noisy and dangerous place.

A sensor located in a manufacturing plant outputs a crude digital signal with TTL logic levels. The sensor is activated once every few minutes, producing a relatively slow change in the output voltage. The sensor must be interfaced to a digital system located several hundred meters away, and it will be connected using cables that run near some high voltage switch gear. During maintenance, it is possible that the cables could accidentally be connected to the 230V mains voltage supply.

In this example, typical of many industrial applications, the slow change in the sensor's output signal means that some kind of Schmitt interface is essential to provide a clean, jitter-free signal for the digital system. The proximity to the switch gear means that the cables may pick up significant amounts of electrical noise, and the possibility of mains voltage on the cables means that protection measures are essential.

TTL LEVELS

The sensor's TTL (Transistor-Transistor Logic) output specification means that the low level (logic "0") output voltage could range from 0V to 0·4V; the high level (logic "1") output voltage could be as little as 2·4V (assuming a 5V supply voltage).

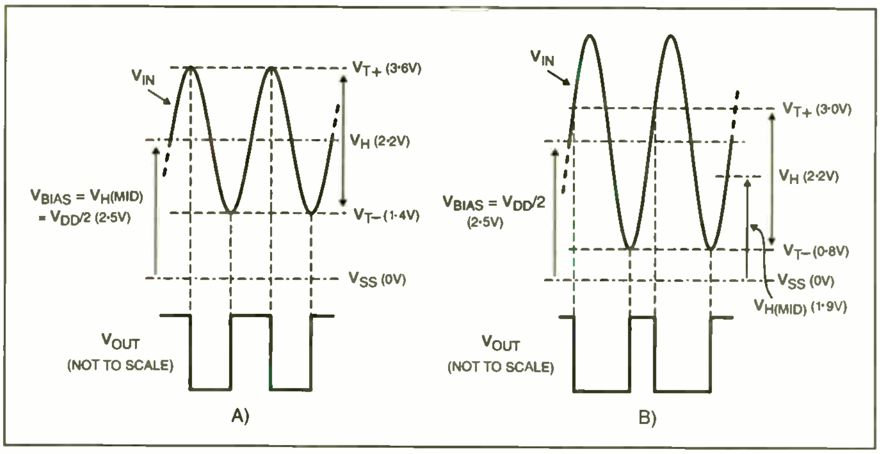

Fig.5.5. Waveform showing biasing and threshold levels.

Therefore, the Schmitt device chosen for the interface must have a negative-going threshold no less than 0·4V, and the positive-going threshold must be no greater than 2·4V. Referring to Table 5.1, we see that all the devices listed have V_{T-} (min) greater than 0·4V; however, only the 74HCT14 and 74HCT132 guarantee V_{T+} (max) to be less than 2·4V. This is not surprising, since the "T" in HCT implies that the devices are specifically intended for interfacing with TTL voltage levels.

Referring again to Fig.5.3, we do not require C_C, R1 and R2 since the input signal has d.c. voltage levels and need not be capacitively coupled on to a bias voltage set by R1 and R2. However, resistor R_{IN}, and diodes D1 and D2 are essential.

Since it is possible that mains voltage could accidentally be connected, the *peak* voltage that could be applied to R_{IN} is around ±350V. Therefore, IC1 must be protected against this degree of "overvoltage". Although all of the devices listed in Table 5.1 usually feature a low-value current limiting resistor and voltage clamp diodes located on-chip at every input, these components are only really intended to protect against short-duration overloads, such as those caused by ESD (Electrostatic Discharge). They should not be relied upon to protect against sustained overvoltage conditions.

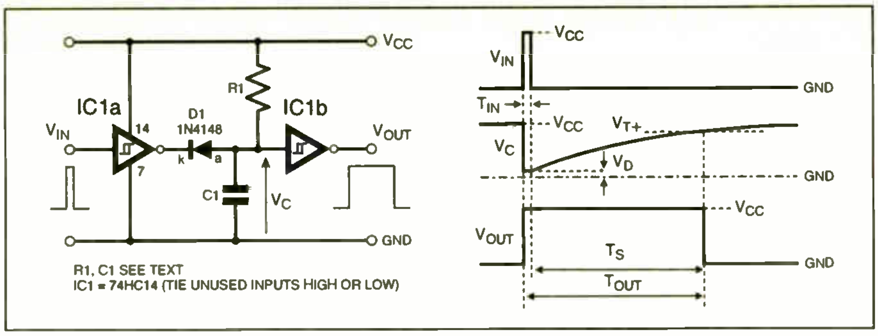

Fig.5.6. Circuit diagram for a positive-going pulse stretcher (a) and typical waveforms (b).

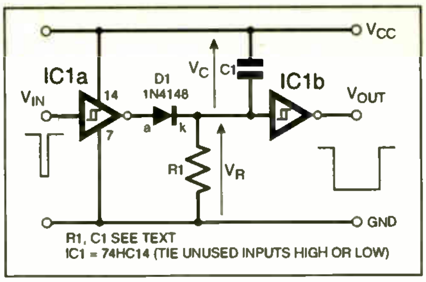

Fig.5.7. Negative-going pulse stretcher circuit. (Compare with Fig.5.6.)

Therefore, diodes D1 and D2 (usually signal diodes like the 1N4148) should be connected as shown to clamp the input voltage to safe levels (typically GND – 0·7V and V_{CC} + 0·7V). Resistor R_{IN} must be chosen to limit the input current to a safe value.

The 1N4148 diode has a maximum current rating of around 150mA. Therefore, assuming all of the 350V overvoltage is dropped across R_{IN}, it would appear that the minimum acceptable value for R_{IN} is simply: 350V/150mA = 2·3kΩ. However, we must also consider the power rating of R_{IN}.

POWER AND VOLTAGE RATINGS

If we chose R_{IN} to be, say, 2·4kΩ, its power rating would need to be $(V_{RMS})^2$/2·4kΩ, where V_{RMS} is the mains voltage, giving a rating of: 230^2/2,400 = 22W! Clearly, a 22W resistor would be enormous, so the correct approach is to start with a suitable power rating and "work backwards".

If we select a 0·5W type for R_{IN}, the minimum resistance value required is: $(V_{RMS})^2$/0·5W = 230^2/0·5 = 105·8kΩ. A suitable, preferred value would be 120kΩ, which would limit the peak input current to around ±3mA under overload conditions.

Remember that resistor R_{IN} must also have a suitable voltage rating. Some resistor types only have a maximum voltage rating of around 200V, or less. Therefore, it may be necessary to use two or more resistors connected in series. For example, two 68kΩ resistors rated at 200V each would be adequate: this approach has the added advantage that the power dissipation is shared between the series resistors.

Finally, we must consider the noise that could be induced in the cables by the high voltage switch gear. Ideally, the maximum noise voltage that could be present should be measured in order to choose the optimum value for filter capacitor C_F. If this is not practical, it may be sufficient to make C_F as large as possible without affecting the circuit's response to the sensor output signal.

For example, with capacitor C_F = 470nF, the low pass filter formed by resistor R_{IN} (2 × 68kΩ) and C_F would attenuate 50Hz interference by a factor of twenty, whilst delaying the rise and fall of V_{IN} by no more than 80ms, or so. Note how R_{IN} performs a dual role as both a current limiting device and a filter component.

DOING A STRETCH

Although intended mainly as an interface element and for "squaring up" slowly changing signals, the digital Schmitt trigger can be used to implement a variety of other functions.

A common requirement in digital systems is to extend the width of a narrow pulse. This can be achieved using a monostable multivibrator such as the 74HC221 or the 4538B, but a simpler and cheaper approach known as a *pulse stretcher* is shown in Fig.5.6. The waveforms shown in the diagram can be used to understand how the circuit works.

When the input voltage, V_{IN}, is low, the output of the first inverter, IC1a, is high and diode D1 is reverse biased; provided V_{IN} is low for some time, timing capacitor C1 will have fully charged via timing resistor R1, such that $V_C = V_{CC}$.

When the narrow input pulse arrives, IC1a's output goes low, and D1 becomes forward biased, rapidly discharging C1 and clamping V_C to a diode drop above GND, i.e., $V_C = V_D$, where V_D is the drop across diode D1. Since V_C has been pulled below the negative-going threshold of IC1b, its output, V_{OUT}, immediately goes high.

At the end of the narrow input pulse when V_{IN} goes low, IC1a's output goes high again and D1 becomes reverse biased. Capacitor C1 now starts to charge via resistor R1, and V_C rises exponentially toward V_{CC}. When V_C crosses IC1b's positive-going threshold voltage, V_{T+}, the circuit output goes low again.

TIME CONSTANT

The time taken for V_C to rise from V_D to V_{T+}, denoted T_S, is the amount by which the input pulse is "stretched", and is given by:

$$T_S = \tau \ln\left\{\frac{V_{CC}-V_D}{V_{CC}-V_{T+}}\right\} \quad \text{(seconds)}$$

where τ is the circuit time constant, τ = C1 × R1, and ln denotes the natural logarithm.

The circuit of Fig.5.6 was tested using a 74HC14 for IC1 (although most of the other devices listed in Table 5.1 could have been used equally well). With V_{CC} = 5·00V, D1's diode drop, V_D, and V_{T+} of IC1b were measured as 0·5V and 2·75V, respectively. With a value of 1nF for capacitor C1 and 1MΩ for resistor R1 (giving τ = 1ms), the value of T_S calculated using the equation above was 693µs. With an input pulse width, T_{IN}, of just 2µs, the actual value of T_S was found to be 690µs.

Note that the overall width of the output pulse, T_{OUT}, is the sum of T_S and T_{IN}, i.e.: $T_{OUT} = T_S + T_{IN}$. In this respect, the pulse stretcher differs from a "proper" monostable multivibrator whose output pulse width is *independent* of the input pulse width.

Also, note that T_S will vary with changes in V_D and V_{T+}. Although T_S can be "trimmed" by using a variable resistor (potentiometer) for R1, the circuit is not intended for precision timing applications. In such cases, a device such as the 74HC221 or 4538B would offer superior performance.

CURRENT LIMITATIONS

When stretching very narrow pulses, IC1a's output must have good current sink capability in order to discharge capacitor C1 during T_{IN}. If the inverter cannot provide adequate sink current, V_C will not be clamped to V_D but to some higher voltage, resulting in a shorter output pulse.

For a given time constant, it is best to use a large value for resistor R1 and a small value for capacitor C1: a smaller capacitor can be discharged more quickly with a given sink current. However, C1 should not be too small or IC1b's inherent input capacitance (typically 5pF for a 74HC14 or 40106B) must be taken into account. Similarly, R1 should not be too large or IC1b's input leakage current could have a noticeable (and unpredictable) effect on T_S.

Provided the input pulse has good rectangular shape, IC1a does not need to be a Schmitt device: any inverter with adequate current sink capability and an output swing down to the negative rail (GND or V_{SS}) could be used. IC1b must be a Schmitt device, of course.

Despite its simplicity, the circuit is remarkably tolerant of supply voltage variations. For example, increasing V_{CC} by 20 per cent from 5V to 6V caused T_S to fall from 690µs to 688µs: a decrease of just 0·3%!

The reason for this surprising stability is a kind of "balancing act". The increase in V_{CC} results in a similar increase in the charging current flowing through R1, making V_C rise more quickly; however, IC1b's positive-going threshold, V_{T+}, also increases, and tends to compensate for these effects.

By making slight changes to the circuit, we obtain the negative-going pulse stretcher shown in Fig.5.7, where the narrow, negative-going input pulse results in a much wider negative-going output pulse of duration T_{OUT}, which again equals $T_{IN} + T_S$. However, T_S is now given by:

$$T_S = \tau \ln\left\{\frac{V_{CC}-V_D}{V_{T-}}\right\} \quad \text{(seconds)}$$

where τ = C1 × R1, and V_{T-} is the negative-going threshold of IC1b.

Again, IC1a does not need to be a Schmitt inverter, and most of the devices listed in Table 5.1 could be used for IC1b.

Note that pulse stretchers are sometimes called "edge delay" circuits, since the falling (or rising) edge of V_{OUT} is delayed by an amount T_S relative to the falling (or rising) edge of V_{IN}.

A CASE OF DISCRIMINATION

Taking a different perspective on things can often lead to surprising results. If we consider the circuit of Fig.5.7 in terms of positive-going pulses rather than negative-going ones, the circuit provides an alternative, but equally useful, function.

The waveforms of Fig.5.8 illustrate the effect of two, positive-going input pulses applied to the circuit in Fig.5.7.

When V_{IN} is low, diode D1 is forward biased, pulling the voltage across resistor R1 (denoted V_R) to a diode drop below V_{CC}, i.e., $V_R = V_{CC} - V_D$. Therefore, for V_{CC} = 5V and assuming V_D is approximately 0·5V, V_R will sit at 4·5V; since this is greater than IC1b's positive-going threshold, the output voltage, V_{OUT}, is low.

When V_{IN} goes high on the rising edge of the first input pulse, diode D1 becomes reverse biased, allowing C1 to charge via R1. As V_C increases exponentially, V_R falls exponentially, as shown by the middle waveform in Fig.5.8. If V_{IN} goes low again before V_R has fallen below IC1b's negative-going threshold, V_{T-}, the output voltage, V_{OUT}, remains low and is unaffected by the relatively narrow input pulse.

On the rising edge of the second input pulse, D1 again becomes reverse biased, and C1 begins to charge again. Once more, V_R starts to decrease exponentially, but this time, because the pulse is much wider than the first, V_R has time to fall below V_{T-}. As soon as it does so, V_{OUT} immediately goes high.

The time T_{MIN} needed for V_R to fall below V_{T-} denotes the *minimum* pulse width needed to trigger IC1b and make V_{OUT} go high. Thus, the circuit *discriminates* between pulses of short and long duration. Like T_S above, T_{MIN} is given by:

$$T_{MIN} = \tau \ln\left\{\frac{V_{CC} - V_D}{V_{T-}}\right\} \quad \text{(seconds)}$$

By choosing a suitable time constant, the circuit will indicate when the input pulse width has exceed the required value of T_{MIN}. The pulse stretcher shown previously in Fig.5.6 will behave as a pulse width discriminator for *negative-going* pulses. With the input normally high, the output will also be high and will go low only if the negative-going input pulse width is greater than the minimum time set by C1 and R1.

An interesting case arises when either of the pulse width discriminator circuits is preceded by a toggle-connected flip-flop, such that the width of the flip-flop's output pulses is equal to the period of its clock signal. In this arrangement, the circuit behaves as a *frequency* discriminator, since the output will be asserted only when the clock frequency is *less than* a preset value determined by the circuit time constant.

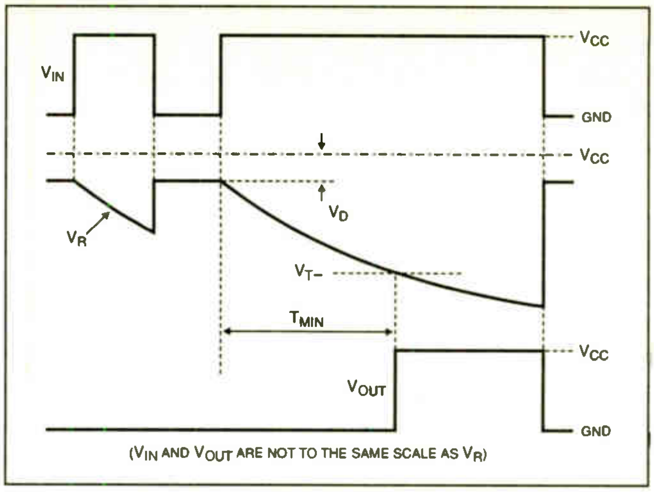

Fig.5.8. Pulse width discriminator waveforms.

DIGITAL DIFFERENTIATORS

By rearranging either of the pulse stretcher circuits, we can create a circuit which performs the "opposite" function, i.e., one which generates a relatively narrow output pulse in response to a wider input pulse. A circuit that works with positive-going pulses is shown in Fig.5.9.

This kind of circuit is sometimes called a "digital differentiator", in that it performs the digital equivalent of the mathematical *differentiation* function. Referring to the waveforms in Fig.5.9, we can understand how the circuit works by assuming that capacitor C1 is initially uncharged (V_C = 0) and that the circuit input, V_{IN}, is low. In this state, IC1a's output and the input to IC1b, denoted V_{IN}(b), are both high, and V_{OUT} is low.

When the input pulse arrives, IC1a's output immediately goes low on the rising edge of V_{IN}, and (since the voltage across a capacitor cannot change instantaneously) this low-going pulse is coupled to V_{IN}(b) via C1, forcing IC1b's output high.

Capacitor C1 now begins to charge via R1, and as it does so, V_{IN}(b) rises exponentially. When V_{IN}(b) crosses IC1b's positive-going threshold, V_{T+}, V_{OUT} immediately goes low, resulting in a narrow, positive-going output pulse of width T_{OUT}, given by:

$$T_{OUT} = \tau \ln\left\{\frac{V_{CC}}{V_{CC} - V_{T+}}\right\} \quad \text{(seconds)}$$

where τ again denotes the circuit time constant, τ = C1 × R1.

Provided the input pulse is wide enough, V_{IN}(b) will eventually reach V_{CC} when C1 becomes fully charged ($V_C = V_{CC}$). When V_{IN} goes low, IC1a's output immediately goes high, causing the "negative" end of C1 to rise to V_{CC}. In turn, this would normally cause the "positive" end of C1 to go to $V_{CC} + V_C = V_{CC} + V_{CC} = 2 \times V_{CC}$.

However, the presence of diode D1 prevents this by clamping V_{IN}(b) to one diode drop (V_D) above V_{CC}. The diode clamping is necessary to ensure C1 is rapidly discharged ready for the next input pulse, and also to provide a degree of overvoltage protection for IC1b's input.

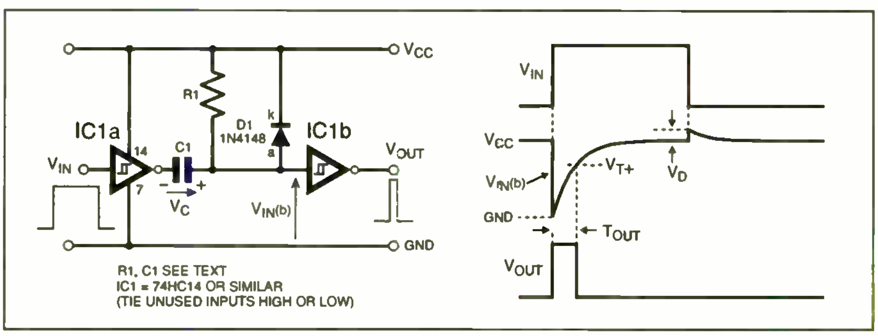

Fig.5.9. Positive-going "digital" differentiator circuit and waveforms.

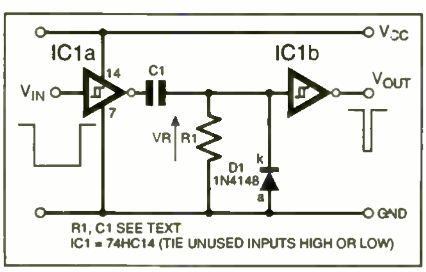

Fig.5.10. Digital differentiator circuit for negative-going pulses.

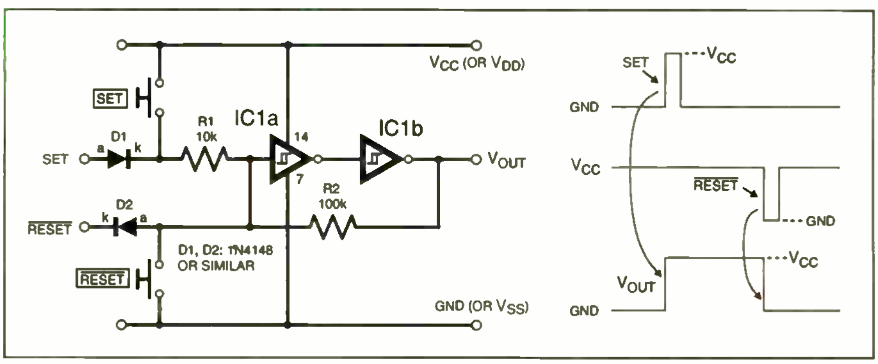

Fig.5.11. Circuit diagram for a simple Set/Reset (SR) latch using two Schmitt inverters.

CIRCUIT PERFORMANCE

The circuit of Fig.5.9 was tested using a 74HC14 for IC1, although most other Schmitt devices could be used. With V_{CC} set to 5·00V, IC1b's positive-going threshold was measured as 2·74V. With values of 1nF and 100kΩ selected for C1 and R1 (such that τ = 100µs), the theoretical value of T_{OUT} derived using the equation given above is 79·4µs. The actual, measured value was 80µs.

Digital differentiators are useful in clocking applications where it is necessary to generate a narrow pulse or "spike" coincident with the rising or falling edge of a relatively long-duration pulse. By connecting D1 and R1 to the negative rail (GND) as shown in Fig.5.10, we obtain a differentiator that operates on negative-going pulses, where T_{OUT} is given by:

$$T_{OUT} = \tau \ln \left\{ \frac{V_{CC}}{V_{T-}} \right\} \text{ (seconds)}$$

and V_{T-} is the negative-going threshold of IC1b.

A SIMPLE LATCH

Although the latch function is available in many digital i.c.s, such as the 74HC74 and 4043B, two Schmitt inverters can be pressed into service as a crude SR (Set/Reset) latch as shown in Fig.5.11. In this circuit, a high logic level at the SET input sets the latch (V_{OUT} goes high), and a low level at the $\overline{\text{RESET}}$ input resets the latch (V_{OUT} goes low).

To understand how the circuit works, assume SET is low and $\overline{\text{RESET}}$ is high such that diodes D1 and D2 are both reverse biased, and V_{OUT} is low. The low level at V_{OUT} is fed to the input of IC1a via resistor R2, effectively reinforcing the low output level (the two inverters together behave as a single, non-inverting buffer).

When SET goes high, the voltage at the junction of D1 and R1 is pulled up to a diode drop below V_{CC}. Resistors R1 and R2 now behave as a potential divider, but since R2 is much larger than R1, there is little attenuation, and so the input to IC1a also rises to a similar level. Since this is above IC1a's positive-going threshold, its output goes low, forcing IC1b's output (V_{OUT}) high. The latch is now "set" and the high level at V_{OUT} maintains the high level at IC1a's input, even when SET goes low again.

The latch remains in this state until a negative-going pulse is applied to the $\overline{\text{RESET}}$ input, which pulls down the voltage at IC1a's input to a diode drop above ground. Since this is below IC1a's negative-going threshold, its output goes high, forcing V_{OUT} low. The latch is now "reset" to its original state and the low level at V_{OUT} maintains the low level at IC1a's input, even when it goes high again.

In order for the latch to work properly, $\overline{\text{RESET}}$ must be high when SET is taken high, but SET may be high or low when $\overline{\text{RESET}}$ is taken low. Instead of logic signals, the latch can be operated using pushbutton switches connected as shown in the figure (the circuit has inherent switch contact debouncing). Note that resistor R1 provides short-circuit protection should SET go high and $\overline{\text{RESET}}$ go low together, or if both switches are closed together.

NON-RETRIGGERABLE MONOSTABLE MULTIVIBRATOR

The simple pulse stretchers shown in Fig.5.6 and Fig.5.7 are "retriggerable", in that any extra input pulses that arrive during the output pulse (i.e., during T_S) cause the output pulse to be extended (that is, T_{OUT} is lengthened). In applications where this is undesirable, it is necessary to use a "non-retriggerable" monostable instead.

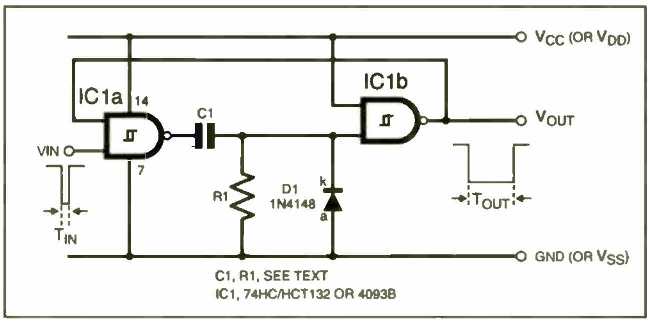

Fig.5.12. Circuit diagram for a non-retriggerable monostable multivibrator.

A circuit for a non-retriggerable monostable based on two Schmitt NAND gates is shown in Fig.5.12. The circuit is triggered by a narrow, negative-going input pulse, V_{IN}, and produces a much wider, negative-going output pulse, V_{OUT}. Therefore, in the stable state, both V_{IN} and V_{OUT} are normally high.

We can understand how the circuit works by assuming that timing capacitor C1 is initially uncharged. When V_{IN} goes low, IC1a's output immediately rises to V_{CC} (or V_{DD}), and this positive-going transition is coupled via C1 to the input of IC1b, causing its output, V_{OUT}, to go low.

Capacitor C1 now begins to charge via timing resistor R1: as the voltage on C1 increases exponentially, the voltage across R1 at IC1b's input decreases exponentially. Whilst C1 is charging, V_{OUT} remains low until the falling voltage on R1 reaches IC1b's negative-going threshold voltage, V_{T-}. At this point, V_{OUT} immediately goes high, terminating the output pulse, whose duration is given by:

$$T_{OUT} = \tau \ln \left\{ \frac{V_{CC}}{V_{T-}} \right\} \text{ (seconds)}$$

where τ is the circuit time constant: τ = C1 × R1.

The feedback from IC1b's output to IC1a's input prevents the monostable from being retriggered by any input pulses arriving during T_{OUT}: as long as V_{OUT} is low, IC1a's output is forced high due to the NAND function, effectively "locking out" any further input pulses.

Note that if V_{IN} is a "proper" digital signal, IC1a need not be a Schmitt NAND – an "ordinary" NAND gate would suffice. Also, IC1b could be replaced a simple Schmitt inverter. However, it is often convenient to implement the circuit using two Schmitt NANDs from either a 74HC132 or a 4093B. Diode D1 is necessary to clamp IC1b's input voltage to a diode drop below GND (or V_{SS}) when IC1a's output goes low.

Using a dual-trace oscilloscope, V_{T-} of IC1b can be measured by noting the value of the voltage on resistor R1 at the instant V_{OUT} goes high. However, remember to remove the probe from R1 when measuring T_{OUT}, otherwise the probe's resistance and capacitance will affect the timing.

With V_{CC} set to 5·00V, and using a 74HC132 for IC1, V_{T-} was measured as 1·78V. Values of 10·09nF and 99·8kΩ were used for C1 and R1, resulting in T_{OUT} equalling 1024µs, calculated using the equation above. With T_{IN} = 2µs, 20µs or 200µs, each at a repetition rate of 200Hz (one input pulse every 5ms), the actual, measured value of T_{OUT} was constant at 1023µs.

A disadvantage of this circuit is that T_{OUT} tends to decrease if capacitor C1 does not have time to discharge fully between successive input pulses. For example, with the input pulse rate increased to 500Hz (one pulse every 2ms), T_{OUT} had fallen to 999µs.

TOLERANT BEHAVIOUR

However, like the pulse stretchers described earlier, the circuit is highly tolerant to changes in supply voltage. If V_{T-} were a *constant* fraction of V_{CC} as shown by the "ideal" case in Fig.5.4, the logarithm term in the expression for T_{OUT} would reduce to a constant, and T_{OUT} would be unaffected by changes in V_{CC}.

In practical Schmitt devices, the relationship between thresholds and supply voltage is not a fixed constant. Nevertheless, supply voltage tolerance is still good. For example, with V_{CC} = 2V, T_{OUT} was measured as 1257µs. With V_{CC} increased to 6V, T_{OUT} had fallen to 1003µs. Clearly, a 200 per cent increase in V_{CC} has resulted in only a 20 per cent decrease in T_{OUT}. The performance using a 4093B for IC1 was even better: a 200 per cent increase in V_{DD} from 5V to 15V resulted in only a 9·2 per cent decrease in T_{OUT}.

Even with relatively narrow input pulses, the circuit can produce very long output pulses. For example, using a 4093B for IC1, and with C1 = 1µF, R1 = 1MΩ, and with V_{DD} = 5V, a 2µs input pulse produced an output pulse just over a second in duration, i.e., 500,000 times longer than the trigger pulse!

LOOKING AHEAD

Next month, in Part Six, we'll see how the "digital" Schmitt can form part of a superior monostable multivibrator which can be adapted to form a simple frequency meter. We'll also see how the Schmitt can be used to form oscillators that can be gated by a digital signal, or controlled by an external voltage.

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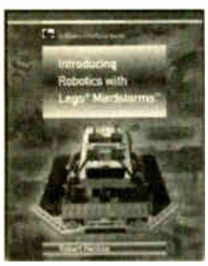

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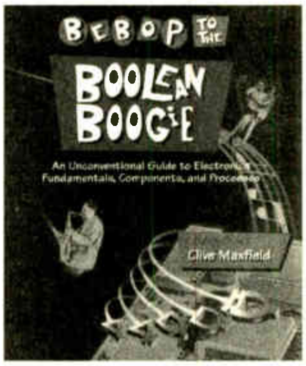

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There is a 'blow-by-blow' guide to the use of EASY-PC Professional XM (a schematic drawing and printed circuit board design computer package). The guide also conducts the reader through logic circuit simulation using Pulsar software. Chapters on p.c.b. physics and p.c.b. production techniques make the book unique, and with its host of project ideas make it an ideal companion for the integrative assignment and common skills components required by BTEC and the key skills demanded by GNVQ. The principal aim of the book is to provide a straightforward approach to the understanding of digital electronics.

Those who prefer the 'Teach-In' approach or would rather experiment with some simple circuits should find the book's final chapters on printed circuit board production and project ideas especially useful.

250 pages **Order code NE28** £17.99

DIGITAL GATES AND FLIP-FLOPS
Ian R. Sinclair

This book, intended for enthusiasts, students and technicians, seeks to establish a firm foundation in digital electronics by treating the topics of gates and flip-flops thoroughly and from the beginning.

Topics such as Boolean algebra and Karnaugh mapping are explainend, demonstrated and used extensively, and more attention is paid to the subject of synchronous counters than to the simple but less important ripple counters.

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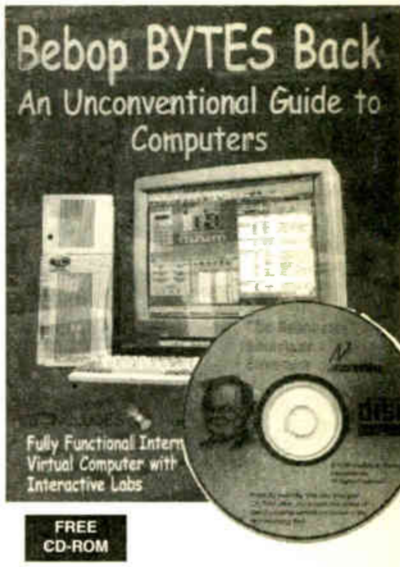

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V. Capel

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None of the designs requires the use of any test equipment in order to get them set up properly. Where any setting up is required, the procedures are very straightforward, and they are described in detail.

Projects covered: Simple MIDI tester, Message grabber Byte grabber, THRU box, MIDI auto switcher, Auto/manual switcher, Manual switcher, MIDI patchbay, MIDI controlled switcher, MIDI lead tester, Program change pedal, Improved program change pedal, Basic mixer, Stereo mixer Electronic swell pedal, Metronome, Analogue echo unit.

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Since *Foundations of Wireless* was first published over 60 years ago, it has helped many thousands of readers to become familiar with the principles of radio and electronics. The original author Sowerby was succeeded by Scroggie in the 1940s, whose name became synonymous with this classic primer for practitioners and students alike. Stan Amos, one of the fathers of modern electronics and the author of many well-known books in the area, took over the revision of this book in the 1980s and it is he, with his son, who have produced this latest version.

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Ian Sinclair
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Contents: waves and pulses, passive components, active components and ICs, linear circuits, block and circuit diagrams, how radio works, disc and tape recording, elements of TV and radar, digital signals, gating and logic circuits, counting and correcting, microprocessors, calculators and computers, miscellaneous systems.

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In the main little or no previous knowledge or experience is assumed. Using these simple component and circuit testing techniques the reader should be able to confidently tackle servicing of most electronic projects.

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Geoff Phillips
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Have you ever wished for a concise and comprehensive guide to electronics concepts and rules of thumb? Have you ever been unable to source a component, or choose between two alternatives for a particular application? How much time do you spend searching for basic facts or manufacturer's specifications? This book is the answer, it covers resistors, capacitors, inductors, semiconductors, logic circuits EMC, audio, electronics and music, telephones, electronics in lighting, thermal considerations, connections, reference data.

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The book covers: **Basics** – Voltage, current and resistance; Capacitance, inductance and impedance; Diodes and transistors; Op-amps and negative feedback; **Fault finding** – Analogue fault finding, Digital fault finding; Memory; Binary and hexadecimal; Addressing; Discrete logic; Microprocessor action; I/O control; CRT control; Dynamic RAM; Fault finding digital systems; Dual trace oscilloscope; IC replacement.

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R. A. Penfold
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80 pages **Order code BP121** **£4.49**

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E. A. Parr
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Included in this book are over 70 circuit diagrams and descriptions covering basic and general circuits, motor car and model railway circuits, alarms and noise makers as well as a section on 556, 558 and 559 timers. (Note. No construction details are given.)

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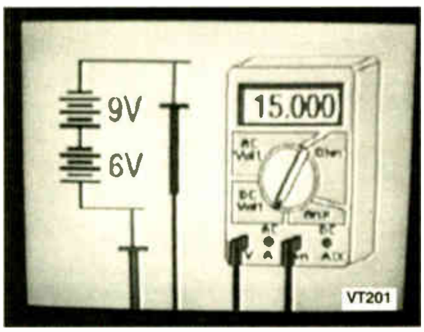

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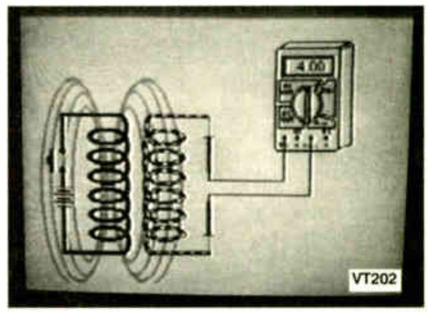

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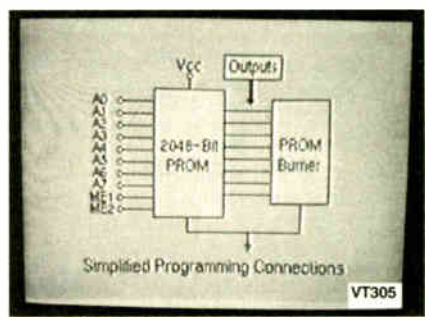

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Published on approximately the second Thursday of each month by Wimborne Publishing Ltd., Allen House, East Borough, Wimborne, Dorset BH21 1PF. Printed in England by Apple Web Offset Ltd., Warrington, WA1 4RW. Distributed by COMAG Magazine Marketing, Tavistock Rd., West Drayton, UB7 7QE. **Subscriptions** INLAND: £14.50 (6 months); £27.50 (12 months); £50 (2 years). OVERSEAS: Standard air service, £17.50 (6 months); £33.50 (12 months); £62 (2 years). Express airmail, £27 (6 months); £51 (12 months); £97 (2 years). Payments payable to "Everyday Practical Electronics", Subs Dept, Allen House, East Borough, Wimborne, Dorset BH21 1PF. **E-mail:** subs@epemag.wimborne.co.uk. EVERYDAY PRACTICAL ELECTRONICS is sold subject to the following conditions, namely that it shall not, without the written consent of the Publishers first having been given, be lent, resold, hired out or otherwise disposed of by way of Trade at more than the recommended selling price shown on the cover, and that it shall not be lent, resold, hired out or otherwise disposed of in a mutilated condition or in any unauthorised cover by way of Trade or affixed to or as part of any publication or advertising, literary or pictorial matter whatsoever.

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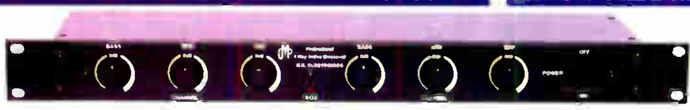

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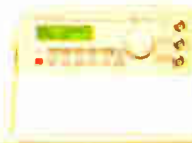

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