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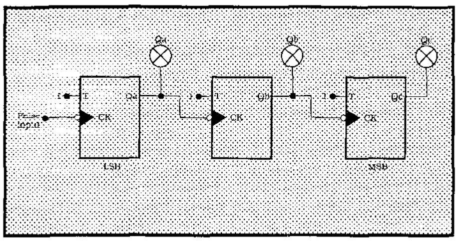

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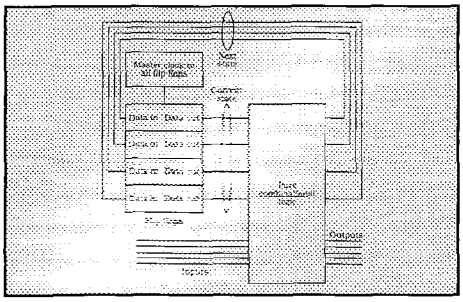

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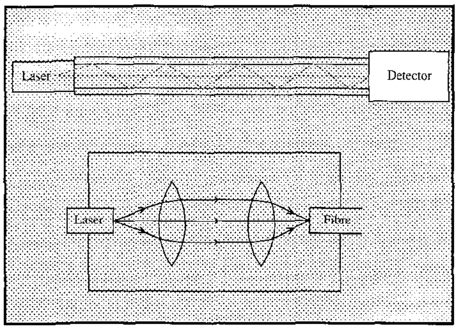



# NEXT MONTH

## POINTING THE WAY

For anyone who uses a MIDI and wants to know how it works and how to test it, the March issue will feature an analyser that reveals all. Other special features will include a review of Tsien Boardmaker, a low cost versatile PCB design system, and the culmination of our Basic Electronics tutorial. Watch out for the new look as we make the magazine more streamlined and more informative with new features such as Data Sheet, How it works and 25 years of PE plus a host of others.

★ DON'T MISS YOUR COPY OF OUR MARCH 1991 ISSUE

★ ON SALE FROM THURSDAY FEBRUARY 7TH

PRACTICAL ELECTRONICS

A WORLD OF TECHNOLOGY

★ ★ ★


# PRACTICAL ELECTRONICS

VOL 27 NO 2 FEBRUARY 1991


# CONTENTS

## BUILD IT FOR FREE!



## CONSTRUCTIONAL PROJECTS



## SPECIAL FEATURES



## REGULAR FEATURES

# NEWS

## WIRELESS NETWORKING

Computer giant NCR is currently fighting the Department of Trade and Industry for permission to launch its cableless computer networking system, WaveLAN, in the UK.

The trouble with computer networks is the need for special cables to link them. In new offices this is not too much of a problem, since the necessary wiring can be hidden in the walls with outlets at convenient positions. Connecting up a computer to the network is then just a matter of plugging the lead from the back of the machine into the socket in the wall – hoping, of course, that the lead is long enough.

With older offices, installing the cables required for a network may mean unsightly wires trailing along the walls, floors and ceilings. The same applies to anyone who is putting in a network and doesn't want to go to the trouble of making the whole thing tidy – PE's office is a good example of this.

The NCR system links computers together using a spread spectrum radio technique on frequencies from 902 to 926MHz at 600mW. Each computer interface to the network has its own transmitter and receiver and can be placed at any position in an office. The high–speed system can penetrate office partitions and transfer data at up to 2M bits per second - ten times faster than infra red systems.

Unfortunately, the radio bands required by the network are currently set aside for cellular telephones and, although NCR does not anticipate any interference, the DTI will not give permission for the system to be used in the UK. An alternative frequency of around 2.4GHz is under consideration but this would mean redesigning the system that is currently FCC approved and sold in the USA.

## BBC TV TO GO STEREO

To coincide with the start of the Autumn schedules, the BBC has announced that it will be transmitting stereo sound on its TV services. Using the now standard Near Instantaneous Companded Audio Multiplex (NICAM 728) method that has been available on some ITV stations for a while, the BBC aims to reach around 73% of the population.

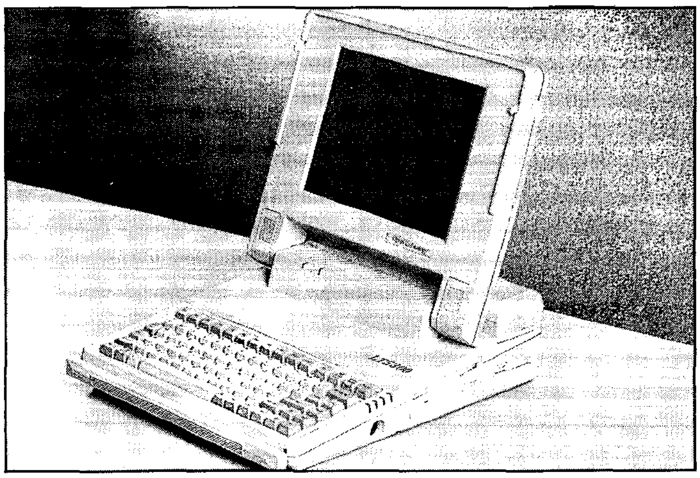
NICAM was originally developed by BBC engineers and accepted for use in the UK in 1986. A year later it was adopted by the European Broadcasting Union (EBU) as the terrestrial standard for stereo broadcasting. Experimental broadcasts were started by the BBC from its Crystal Palace transmitter in 1986 and test transmissions for the whole network are due to start in the summer of 1991 – they are already in progress in London and the South East though the BBC warns that signals are liable to interruption during the test period.

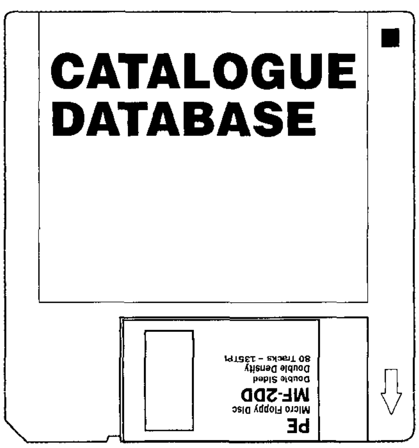
Initial transmissions will not cover Cornwall, most of the South Coast, North and Mid Wales, the Scottish borders, the Scottish Highlands and Northern Ireland.

## OPUS LAPTOP

Opus Technology has announced the launch of its new 386SX laptop computer. Featuring full AT compatibility, a clock speed of 16MHz, 1Mbyte of RAM, a built in VGA chip offering VGA, EGA, CGA, MDA and Hercules compatibility on its 640x480 10" gas plasma display, the system comes complete with 3.5" floppy and 40Mb hard disk drives.

Unlike many similar laptop style machines the Opus 386SX has an AT compatible 16–bit slot which allows standard expansion boards to be used. Weighing less than 9kg, the recommended retail price is £1999+VAT with a free external numeric keypad available to complement the standard 82 key keyboard. For more information contact: Opus Technology, Redhill Business Park, Bonehurst Road, Salfords, Redhill Surrey, RH1 5YD, Tel. 0293 821444






Our browse through recently received literature

**Lambda Photometrics** has recently made available its 1990/91 56-page catalogue of Seastar optical devices and laser diode instrumentation. Including all spectral characteristics as well as photographs, the catalogue covers a large range of laser diodes and drivers.

**Maplin Electronics** has added a number of new products to its 1991 catalogue: A new multi–channel receiving system which can pick up signals from thirty separate satellites with up to 100 pre-programmed channels including Sky TV. In addition, dishes are available in the non-acne colours brick-red, dark-green, slate-grey and beige. At 99cm, the dishes would not normally need planning permission.

A NICAM 728 stereo sound receiver kit which operates on 12V and supports automatic audio switching – mono, stereo, bilingual – in an all British design.

A selection of Kodak special purpose cameras from the Weekend 35 waterproof to the Fling 35 outdoor - the latter is a single use throw–away design that fits easily in the pocket.

The Casio digital diary offering 32 columns by six lines, 64k of memory and various expansion cards.

Mail order specialists **Electrovalue** have a new catalogue out for 1991. The new catalogue is an 88-page A4 issue, full of components, constructional tools and other necessities for the electronics hobbyist. The catalogue costs £1.50, which is refunded when you make your first order of £5.00 or more. And I'm sure you will very quickly, as the range of parts on offer here is so comprehensive!

The Electrovalue 1991 catalogue is available from Electrovalue Ltd. 28b St. Jude's Road, Englefield Green, Egham, Surrey TW20 0HB.

# NEWS

## A DREAM OF 3D

Three dimensional photography has been around for a long time and was once quite 'the thing' in the cinema. Unfortunately, it never really got anywhere because there was always the need for special gadgetry and the quality and colour suffered as a result.

The dream of 3D video has been with us since 50's pulp science fiction saw it as something that would be ubiquitous by the end of the century. Unfortunately, the end of the century is approaching fast with, so far, no sign of a commercial 3DTV system that is available to all.

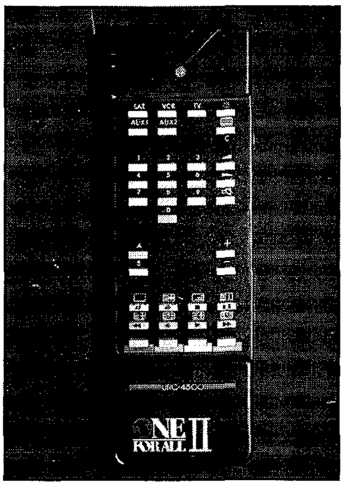
The problems with stereoscopy arise mainly from the need to produce a different image for each eye from a single box that can be viewed from across the room. Systems that use red and green or the more modern polarised spectacles surface occasionally but never seem to take off.

Recently, a possible solution has been developed by Inventor John Christian who has designed a system to produce full colour three dimensional images on a standard colour TV. Being a bit of a photographic and video buff and having a long–standing interest in still stereo photography he decided that the solution was simple and built the device. The basic idea involves splitting the picture going into the camera into two and positioning the resulting images side by side on the final recording. Once stored in this way, there are a number of ways of viewing the results.

A 3D image can be viewed through a box placed near the arm of a chair about 18 inches from the eyes. This produces a full colour three dimensional effect that has the advantage of not using any special electronics or filters and is therefore not tied to any particular video system. An alternative solution is to place two polarising filters over the TV screen, one at right angles to the other and view the result through similarly polarised spectacles. A third method is to use an LCD projector system to display the two images on a screen through polarising filters - again, the polarised spectacles are needed to see the final 3D image.

After recently receiving a Natwest/BP award for pioneering the development of affordable and accessible 3D video, Mr. Christian is now looking for a manufacturer who would be interested in producing the system on a large scale.

## MULTIZAP



With the proliferation of remote control equipment, the increase in the number of handsets can be confusing. It is far too easy to pick up the wrong 'zapper' and frantically press the buttons only to find that the TV stays on the same channel or the video continues rewinding.

One solution is the 'One for all II' from CelTel which allows up to five remote 'zappers' to be replaced by a single handset.

Unlike similar products, One for all II has all the codes for standard systems built in so that it doesn't have to learn from existing remote control units. A list is supplied with the device that gives a three digit code for each piece of equipment. Keying in the product codes tells the One for all II which products it is being used with. As well as TV, VCR, satellite and teletext, Celtel claims that its product list is comprehensive and can be used where existing remotes have been lost or even stolen.

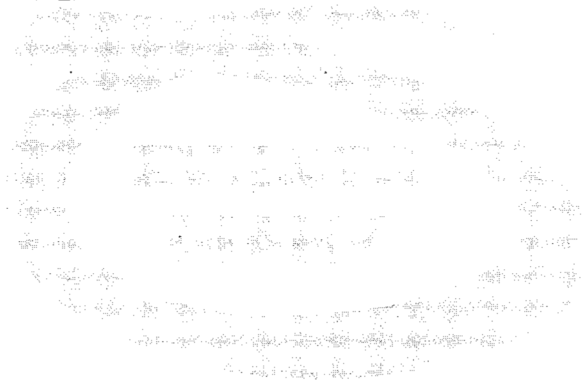
Priced at £40, the One for all II is available from many high street stores or directly from Celtel on 0256-474900. The sound of zap, zap, zap, zap, zap...zap, "Oh why is there never anything on!" could soon replace the dry comment "You're using the wrong one" among tele-addicts and couch potatoes.

## BT BREAKOUT

The location of most telephone sockets makes it a fairly awkward job to take them apart just to check the connections. Crawling around on the floor and removing the face of the socket requires a lot of fiddling with a screwdriver and usually reveals a set of wires which can only just be seen – especially when the socket is stuck under a large table or similarly unmoveable object.

The new 'breakout' plug brings all six standard connections to the outside world where they can easily be checked. Unfortunately, the user still has to crawl around the floor since the test gadget is directly connected to the BT plug. Perhaps the manufacturer should consider putting a longer lead between the plug and the test pins so that the use of hands and knees can be kept to a minimum. For more information contact:

J Dornan
OK Industries UK Ltd.
Barton Farm Ind. Est.
Chickenhall Lane
Eastleigh
Hants.
SO5 5RR
Tel. 0703 619841
Fax 0703 643279



If you are organising any event to do with electronics, big or small, drop us a line, we shall be glad to include it here.

**Please note** : Some events listed here may be trade or restricted category only. We cannot guarantee information accuracy, so check details with the organisers before setting out.

**Mar 19-21.** NepCon Europe and Electronics International (formerly British Electronics Week). NEC, Birmingham. 0799 26699.

**April 17-18.** Laboratory Manchester. Windsor Hall, G-Mex Centre, Manchester. 0799 26699.

**May 15-16.** Laboratory Scotland. Scottish Exhibition Centre, Glasgow. 0799 26699.

### IEE FARADAY LECTURES

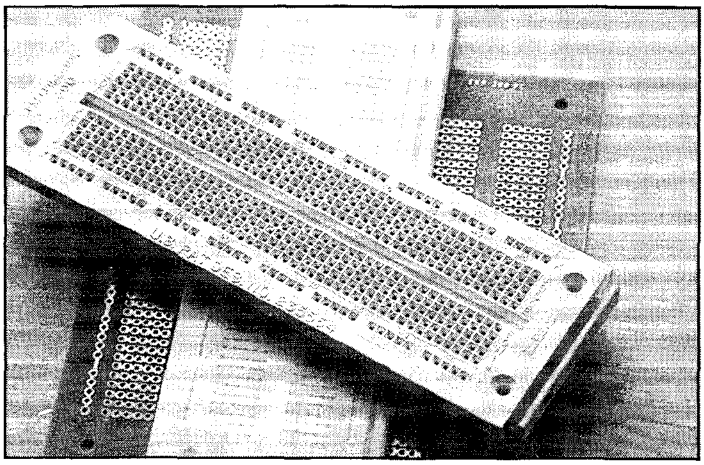
Presented by the Universities of Bath and Sussex.

Feb 5-7 London. Feb 12 Hanley, Stoke-on-Trent. Feb 27 Nottingham. Mar 6 Sheffield. Mar 13-14 Bath.

For free tickets and further information contact (enclosing SAE) The Faraday Officer, IEE, Michael Faraday House, Six Hills Way, Stevenage, Herts SG1 2AY.

### MICROPROCESSOR TRAINING COURSES

In conjunction with Colchester Institute, Flight Electronics is offering a range of intensive four-day microprocessor courses. Contact: Suzanne Kittow, Flight Electronics Ltd. Flight House, Ascupart Street, Southampton SO1 1LU. Tel: 0703 22721.



## GET AHEAD WITH A BREADBOARD

One of the most useful tools available to the electronics experimenter is the breadboard. For those who want high reliability, the Global Specialities' range offers a lifetime guarantee. Aimed to make developing and testing new circuits, as quick and easy as possible, the Experimentor 30 comes with two free special offers. The Matchboard is a pre-drilled PCB upon which a finished circuit can be produced and Scratchboard is a workpad which can be used to sketch out the circuit design for a permanent record.

In addition to the Experimenter 300, a full range of breadboards is available from Global offering no solder spill, dry joints or burns, speedy development and component lead sizes from 20 to 26 gauge. In addition there are common and bussed tie points for component leads and power supplies.

Priced at £5.95, the Experimenter 300 is available from Global Specialities, Rackery Lane, Llay, Wrexham, Clwyd, LL12 0PB. Tel. 0978 853920.

## TAPE DEBATE

The debate over whether to levy a tax on home taping is underway again as the European Commission prepares a directive on the subject. Whilst Britain and Greece spoke out strongly against the prospect of imposing a penalty on all users of blank tapes, Ministers from Germany, France, the Netherlands, Belgium and Spain did not share their concerns.

Two years ago, a green paper published by the EC stated that there was no need for a tape tax for the completion of the internal market. However, France and Germany already have a blank tape tax and a number of other countries have passed laws to implement such a levy, although they have yet to decide whether to actually go ahead with it.

A problem obviously arises in 1992 when the Single European Market comes into effect. This should mean that anyone wanting to buy blank tapes that are untaxed can simply import them from a country without the tax. Since both France and Germany are major players in the EC, it may be that a U-turn will have to be made and a tax imposed on all of the member states.

The whole reason for the levy is to try and claw back some of the revenue lost by music publishers when people copy records, CDs and pre-recorded tapes onto blank tapes. It is a matter of opinion as to whether this is reasonable or not. One argument is that the publishers don't really lose all that much and it is unfair and punitive to tax all blank tapes – there are, after all, other uses to which they can be put.

Sweden recently ditched its blank tape levy because it cost more to operate than was gained from it. There were also reports of people smuggling in cheap tapes from abroad and selling them 'duty free'. The tax should be repealed by 1993.

Along the same lines, DAT (Digital Audio Tape) was introduced into the UK last autumn but in the US it has been blocked. The problem is much the same as with blank tapes but the recording quality is far superior. A court action in the US against Sony, importers of DAT machines, by songwriters and music publishers claims losses of millions of pounds – which Sony obviously denies. The problem with law cases like this is that they can go on and on and on.

## PROMULATIONS

The PROMulator is a low cost ROM emulation system from Smart Communications designed to make the testing of single board microprocessor systems easier.

At some point during the design of a single board system the software must be tested on the board itself. Normally developed on a larger machine, the software is transferred to a ROM or EPROM which must been 'blown' or 'burned' with the necessary code and then plugged into the board. The problem with testing such systems is that correcting the inevitable mistakes in the software usually means 'blowing' an EPROM, trying it out, erasing it, correcting the mistakes and trying it again - a time consuming process.

There are a number of ways in which the turn around time for testing the software can be decreased. One is to use an EEPROM (Electrically Erasable Programmable Read Only Memory) which allows the software to be changed very quickly but still has the problem that the chip must be removed from the board every time an alteration is needed. Another option is to use a PROM emulator. These devices plug into both the board and the computer supplying the software. Changes can be made on the main machine and then moved 'onto' the board and tested without any messy 'blowing' or unplugging. Unfortunately, devices of this type are usually expensive.

The PROMulator is a low cost ROM emulator that comes in three sizes, 256k, 512k and 1M with prices starting at around £99. Data can be transferred from the master machine at speeds of up to 100k bits per second and chip emulations include 2716, 27010 EPROMs with access times down to 45nS.

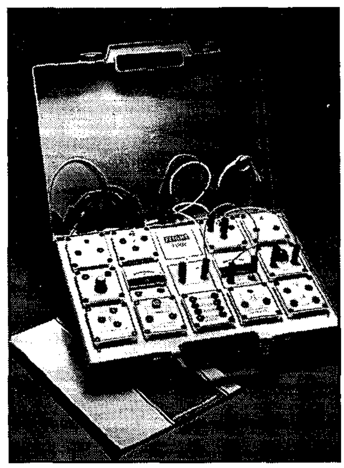
## TRAINING MODULE

As circuit boards get smaller and smaller, the packaging for the chips being put on them must shrink in proportion. In commercial printed circuit board production, the normal method of attaching a chip to the board is to use surface mounting rather than pins and holes. The chips are soldered directly to the board's surface making them fit into a smaller surface area and reduce the amount of work required to construct the board. Unfortunately, a limit is placed on the minimum size of a package by the number of pins and their dimensions - if they are two small then they cannot be reliably connected to a circuit board.

To help cram as much onto a board as possible, Impulse Electronics has designed a chip package that allows devices to be placed even closer together than normal. By producing a tiny surface mount memory packages with pinouts that are mirror images of the standard pack, devices can be mounted with their pins immediately adjacent. Manufactured by Hitachi, the two memory chips give 128Kx8 bits in a tiny TSOP outline and are numbered HM628128LTS8 and HM628128LR8 with the 'R' denoting the reverse or mirror image of the 'S' or standard package.

Access times are as low as 70nS with a low power standby mode available to reduce the normal 5V power consumption from around 75mW to 10μW.

For more information, contact Impulse Electronics on 0883 347011



## CLOSING PRICES

Billed as an exiting new concept in memory, Terabyte Electronics is proposing to buy memory at 'commodity' prices rather than wholesale. Although not exactly traded on international markets in the same way as O.J. and Pork Bellies, memory chips are fast becoming an item whose price fluctuates widely depending upon supply and demand. By purchasing the chips when they are cheap and selling them when the price goes up, profits can be made without actually putting the chips to any use.

By buying memory at international commodity prices,Terrabyte Electronics says that it will be able to undercut existing suppliers by as much as 50% - good news for computer owners who wish to use increasingly memory hungry software such as Windows 3. Indeed, Terrabyte suggests that machines could be purchased with only the minimum memory – say 512K in a PC – and then upgraded to 'full size' with the cheaper 'commodity memory'. However, the example price given, four 80nS 1Mx8 SIMMs for £115 is about the going rate from most good sources.

## DON'T TOUCH THAT DIAL!

The new H-6 FM tuner from Revox takes another step towards simplifying the use of Hi-Fi equipment. Just plug in an aerial, connect to the mains and press two buttons to get it to scan the whole FM waveband and load up the position of all the available stations.

The H-6 is also selects stations that use Radio Data Services to transmit identification information and stores them in alphabetical order. If more than one of these appears during the scan, only the best signal will be selected. RDS is a method of transmitting digital information along with the FM signal to identify the station – see Barry Fox's Leading Edge in PE October 1990.

Up to 35 pre-sets are available and each station can be selected at the touch of a button. Controls are kept to the absolute minimum with just on/off, station up and station down, either on the front panel or on a remote control. Available from F W O Bauch' Ltd. Tel (081) 953-0091. Prices start from £911 inc. VAT. anyone who has had to mess around with BT's phone sockets may find this new gadget from OK Electronics a very useful addition to their toolkit.

## MIRROR IMAGES

Designed to illustrate the operation of the most commonly used electronic components the Cascade 100 is a new training system from Flight Electronics.

The trainer is aimed at students from the age of 12 upwards and is based around 11 plug in modules which can be linked together to form various circuit configurations. Additional modules are also available to expand the basic capabilities and provide further experiments.

The system is portable and comes in a rugged carrying case with built in voltmeter, ammeter, PP3 battery housing and mains adaptor. The manuals cover 16 experiments with a total of 22 circuit configurations illustrating the use of resistors, capacitors, diodes and transistors.

Priced at £99.95+VAT, each of the four add–on modules is available at £5.90+VAT from Flight Electronics Ltd, Flight House, Ascupart Street, Southampton, S01 1LU Tel. 0703 227721

## CONSPICUOUS DISPLAY

The MDD4201 is a new high efficiency four digit LED display module. It is available as either a multiplexed BCD version with four data lines and four digit select lines or as a microprocessor version with a four bit data bus, two address lines and write inputs.

The display features 14.2mm high LEDs and has inputs which are both CMOS and TTL compatible. The brightness can be controlled digitally via the display enable and the bezel comes with an anti–glare filter. The supply voltage is 5V at 120mA with an operating temperature range from 0° to 50°C.

For more information contact Martel Instruments, Tanfield Lea industrial Estate, Stanley, Co. Durham, DH9 9QX, Tel. 0207 290266.

## CORRECTION

Due to production difficulties an out of date advertisement appeared on last month's back cover. Certain details that appeared were incorrect:

The Maplin Catalogue 1991 is available from all Maplin shops and W H Smiths for £2.45 and, if ordered by post, 50p P&P should be added to this.

The Map Card system has been discontinued.

The statement regarding the carriage should read: 'Please add £6 carriage and handling charge'

Maplin has added Brighton to its list of shops.

# CHIP COUNT

## COMPUTER INTERFACE

The PSD301 from Wafer Scale Integration Inc (WSI) is a sophisticated programmable peripheral device (Interface Adaptor) able to work directly with eight or 16–bit micro–systems. Features include input/output ports, buses, address mapping, port tracking, 256k of EPROM and 16k of static RAM. Suitable for industry standard programmers, the PSD301 should allow designers to quickly design and implement a peripheral solution.

**Micro Call** Tel. (0844) 261939 Fax. (0844) 261678

## PHILIPS SELECTION

Philips Components have announced that they will now be supplying the 87C52 micro–controller. This is a stand-alone microprocessor based on the industry standard 80C51. Running at 16 or 20MHz with an EPROM of 8kx8 bits and RAM of 256x8 bits it has 32 input/output lines, three 16-bit counter timers and a six-source two-priority-level nested interrupt structure. A serial port is also included to allow inter–microprocessor communications or form the basis of a full duplex UART. Oscillator and clock circuits are built into the chip keeping the number of components required for an implementation to a minimum.

Using their new QUBiC manufacturing process, Philips have also introduced five new BiCMOS devices. The Octal buffers, latches and D–type flip–flops offer 64mA output drive, 50μA supply current in their high impedance states and 40mA when running at 50MHz. Using the new process, which allows either MOS or bipolar transistors to be used at any location, these devices offer the best of both CMOS and bipolar manufacturing techniques.

With typical access times of 5nS, the new inverting and non-inverting RAM (74F189A and 74F219A) chips are the latest in Philips' FAST TTL family of ICs. Both chips are 16 word by four–bit arrays and are designed to be used as stacks, buffer memory and scratch pad memory for high speed applications.

The 74F835 is another addition to Philips FAST family of chips. Defined as a parallel/serial in shift register, it integrates three different operations, an eight–bit bidirectional universal shift register, two quad 2–input data selector/multiplexers and an octal transparent latch. Originally designed for video operations, it can operate up to speeds of 150MHz.

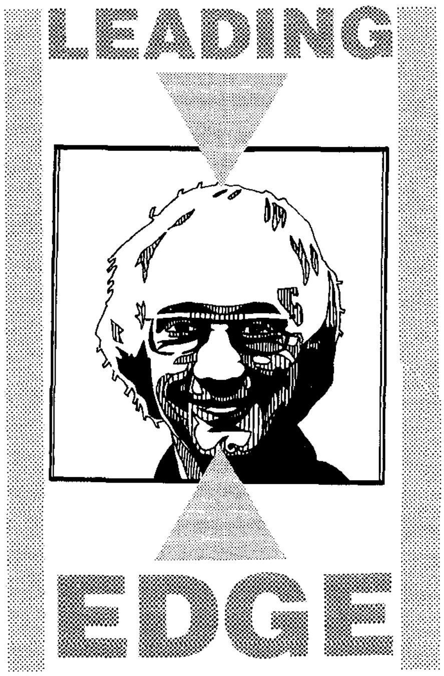
**Philips Components Ltd.** (071) 580–6633 Fax. (071) 580–0394

## FAST PALS AND VIDEOS

The PALCE16V8H–10PC4, apart from having one of the longest serial numbers seen in a long time, is a new high speed programmable logic array (PAL). Capable of emulating any 20 pin device, the chip takes advantage of Advanced Micro Device's (AMD) EE4 0.8 micron process and is electrically re–programmable.

Designed to eliminate over 20 ICs, the Maxim MAX456 provides a monolithic 8x8 video crosspoint switch. It can be used to connect eight video input channels, or any high frequency signal, to any or all of the eight output channels. The channel control logic and eight 35MHz 250V/μS video buffer amplifiers are also included on the chip. The digital interface can be either seven-bit serial, seven-bit parallel or 32-bit programming data.

**Kudos Thame Ltd.** 55 Sutton's Park, London Road, Reading, Berks RG6 1AZ Tel. (0734) 351010.




# IT'S FOR WHO?

**BY BARRY FOX**
**Winner of the UK Technology Press Award**

## In the United States Caller ID is stirring up a political storm.

In the USA telephone subscribers in some states can use gadgetry which displays the number of whoever is calling them. The system is called Calling Line Identification (CLI) or Caller ID.

At first this sounds like a fine idea and a sure way to stop malicious calls. But a lot of people do not like it. They see it as an intrusion on privacy and a way of getting ex–directory numbers and the numbers of single women, for instance by placing an advert for secretarial aid and then logging applicants' calls.

So enterprising US firms are now offering a beat–the–system service which routes calls into and out of an agency which works as the telephone equivalent of a Postal box number. This costs $2 a minute for local calls and $5 for foreign numbers. Some states, lead by Pennsylvania, are now banning CLI altogether. One phone company in Dakota is giving telephone subscribers the opportunity to block their numbers if they wish. But the agencies, state bans and options to defeat CLI are being criticised for making life too easy for criminals, especially kidnappers. But those against CLI say that criminals will use callboxes to make ransom calls anyway. It's a debate with no end in sight.

In this country there is no such thing as CLI as a result of a policy decision taken by British Telecom.

BT's trunk network is all–digital. Local exchanges can be either digital or analogue. Around 18 million subscribers, out of a 25 million total, are connected either to digital (TXD) or enhanced analogue (TXE4) local exchanges. On either type of exchange, when a call is made a computer at the local exchange stores both the calling number and the called number in computer memory. This information, known as the CN/CN pair, is needed for billing. It is also passed over the trunk network to control call routing.

The local exchange of the called number therefore gets information on the calling number. But this information is not passed any further down the line. Calling line identity stops at the local exchange. The multiple frequency (MF) tones needed to signal a calling number do not go down local telephone lines to the called telephone.

BT says this is not because it refuses to do so but because neither its digital (TXD) nor modified analogue (TXE4) exchanges were designed to send multi–frequency signalling tones to customers. And without these tones customers' equipment cannot display the calling number.

There is a fine line between refusing to do something and installing equipment which makes doing it impossible.

BT's official view is that CLI would be attacked as an intrusion on privacy, likely to create more problems than it solves. But I would have thought that BT would have done better to install exchange equipment which makes CLI possible, thereby leaving the options open. Could it be that BT's policy–makers simply forgot about CLI?

This seems likely because there is one exception to BT's no–CLI rule. Where calls are routed on the new, more modern, Integrated Services Digital Network, which is end–to–end digital, the system can identify calling numbers. But only a few large businesses are using ISDN.

British Telecom is now concerned that subscribers are being sold expensive accessories which claim to offer CLI but cannot work as claimed. Although customers are unlikely to realise it until after they have paid over £150 for one of the new gadgets, they rely on the caller's honesty! In the case of nuisance calls this is obviously a fatal fallacy.

"Unwanted telephone callers and sex pests are a problem of the past with the new electronic marvel" claims one firm now advertising in the national press. The 'electronic marvel" costs £139.50 plus VAT plus post and packing and is claimed to let a subscriber 'identify and show the caller's telephone number before you answer'. This, promises the advert, enables the owner to "determine who the caller is, so stopping sex pests and nuisance callers". The sales company says it has been "inundated" with customer enquiries.

The units now on sale work quite differently from North American CLI units, which sense the MF tones coming down the line from the exchange. The British units act as an interrogating filter for incoming calls.

The filter unit plugs into a standard BT wall socket, alongside a conventional telephone. Whenever there is an incoming call, the filter snatches the line before the telephone has a chance to ring. The filter then plays an announcement message down the line which asks the calling party to key their number into the keypad of their telephone. The caller's keypad generates MF pulses which are received by the filter and displayed on an LCD screen. At the same time the filter rings the house or office telephone. The called party then looks at the number displayed on the filter screen and decides whether or not to answer the telephone.

As BT points out, the calling party can key in any number, true or false, for display on the LCD. "We know of no way such a device can authenticate the number", says BT. The firms selling the filters argue that this does not matter because people can refuse to answer unless they recognise the displayed number. But in practice few people will ignore a phone call simply because they do not want to recognise the calling number. They want to answer and note the number if the call is a nuisance. But if the caller is a nuisance, the number will be false.

BT is powerless to stop the sale of such gadgets, unless they have not been approved by the British Approvals Board for Telecommunications and are thus illegal to connect to BTs' network (approved products carry a green circle sticker, non–approved products must carry a red triangle sticker).

For the cost of a filter or less, argues BT pragmatically, people can buy an answering machine and record their own message which asks callers to leave their name and number to be called back. That way, reminds BT, callers are forced to leave a genuine number.

BT also offers a free service for people who are consistently pestered with nuisance calls. It is called MCI, Malicious Call Interception. With police approval BT gives the victim a secret code to key into their telephone keypad whenever an unwanted call comes through. Provided that the call has been routed through modern exchanges, the code triggers an immediate print–out at the exchange of the calling and called number pair, along with the date and time. This information then goes to the police. PE

# A DIGITAL FOCUS IN AN ANALOGUE WORLD

The main project this month stems from a number of enquiries received by PE about sensing magnetic fields. A couple of solutions are discussed in the article with the Hall Effect being chosen for its simplicity and ease of incorporation into a practical system. As well as being a project to construct a digital compass system, it provides information on how the basic elements, the sensor and amplifier, can be used as starting points for other projects that require magnetic sensing, whether for simple experimentation or leading on to more complex designs.

One of the major trends in the computer market these days is the move towards networking. Linking up a number of computers and other intelligent systems so that resources can be shared is an obvious step forward from the basic idea of one computer per desk. The problem with networks is that they can be very expensive – usually starting at around £150 per machine for a simple system and ranging upwards to prices in the thousands for more sophisticated layouts. The Serial Multiplexer (MUX) project, originally developed by the author to channel information from a number of sources to one computer, describes a system that can provide a cheap network using the industry standard RS232 interface. An advantage of this serial system is that many different machines use it – from the BBC micro and IBM PC clones, to Macintoshes and (for the ambitious) even minis and mainframes. There aren't many commercially availaible networks that allow machines with completely different operating systems to be connected and, although the project was designed for use with the BBC micro, there is no reason why it shouldn't be used with other computers. Because of this, the article only describes the basic system providing constructional details on a four way MUX. The next step of connecting up to other machines is easy once the fundamental concept is understood.

The Synchronous Logic design and A to Z of Digital Devices articles form a complementary pair.

The first looks at the problems that crop up when digital systems encounter feedback. Although it is possible to design simple systems that take their outputs back in as inputs without using any set method, there comes a time when the whole thing gets completely out of hand and there is no telling how a particular configuration of logic gates will operate. Fortunately, there is a standard design method available which ties down all the loose ends and forces the circuit to perform as planned.

To help put the theory into practice, the A-Z of Digital Devices takes a brief look at the main types of logic chips available. Many of these can be used to replace sections of synchronous logic circuitry since they incorporate standard synchronous devices, such as shift registers and flip flops, in a single package. It is worth looking through the list of what is available after completing the basic specification for a logic circuit to see whether there are parts which can be used instead, or even if there are chips which already perform the complete function.

To compensate for the digital slant of the issue, Mike Saunders moves on from his series about lasers and describes a technology in which they are used. Fibre optics are becoming more and more widely used as a replacement for electrical wiring. The feature looks at how they are made, how they work, what they are used for and why.

Also on the analogue side are the resistor calculator which describes a neat way of using geometry to work out resistances and the frost alarm.

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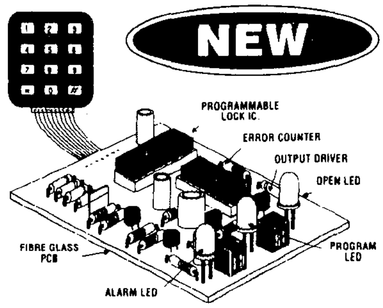


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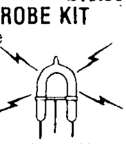

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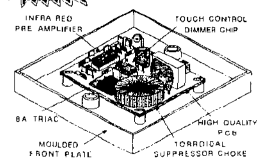


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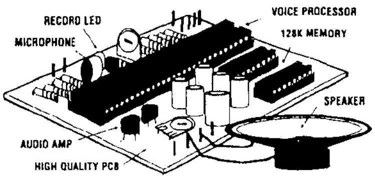


This simple to construct and even simpler to operate kit will record and playback short messages or tunes. It has many uses – seatbelt or lights reminder in the car, welcome messages to visitors at home or at work, warning messages in factories and public places, in fact anywhere where a spoken message is announced and which needs to be changed from time to time. Also suitable for toys – why not convert your daughter's £8 doll to an £80 talking doll!!

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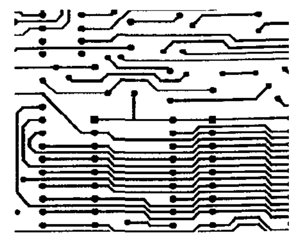

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# A DIGITAL COMPASS

**John Becker reveals how to sense magnetic fields.**

Following a number of readers' queries on the subject, this circuit has been designed to illustrate one way in which the Earth's magnetic field can be monitored electronically. The idea is to provide not only information on magnetic fields and Hall Effect devices, but also DC amplification and analogue to digital conversion (ADC).

## OPTIONS

Commercially, there are three main techniques available to produce an electronic compass: electro–mechanical, flux–gate and Hall Effect. The first directly or indirectly tracks the rotation of a magnetic compass with a servo or pulse counting sensors. The second uses a type of interferometry by sensing magnetically induced changes in a tuned circuit, from which the field direction is calculated. Hall Effect devices produce an analogue voltage output directly related to field strength and thus, by interpretation, to direction.

The compass described here makes use of the Hall Effect technique to directly evaluate the Earth's magnetic field strength. It can also be used as a type of electro–mechanical interface, in which the position of an ordinary compass needle is monitored by Hall Effect sensors. It is microprocessor controlled and produces a digital bearing on an LCD readout.

## HALL EFFECT

The Hall Effect was named after Edwin H. Hall (1855 to 1938). He discovered that when an electric current flows in a wire placed within a strong transverse magnetic field a potential difference is developed across the wire at right angles to both the magnetic field and the wire itself. The phenomenon is also observable in thin strips of metal and in some semiconductors. Fig.1 illustrates the concept.

The Hall Effect element has electrodes at either end which enable an electric current to flow down it. When the element is placed within a magnetic field and rotated relative to it, the resulting changes in voltage developed across the element can be observed on a sensitive meter connected across the sides of the element. The maximum voltage occurs when the element and the field are at right angles to each other. If the field is rotated through 180 degrees, the voltage will steadily decrease from maximum positive to maximum negative. The relative voltage polarity varies depending upon what the element is made from. For example, with zinc it is positive, whereas with gold it is negative.

Unfortunately, the Hall voltage is always feeble and requires considerable amplification to be of any practical use. The conducting qualities of the Hall element also affect the voltage level produced. With good conductors the voltage is very small since the charged particles move too fast to be deflected in substantial quantities, except in the presence of very large magnetic fields. However, particles move more slowly in semiconductors so they are capable of producing a larger voltage.

## SENSORS

There are a number of Hall Effect sensors available but most of them have been designed for use as magnetically controlled switches. Since their outputs are digital, producing voltages that are either high or low (on or off), they are not suitable for use in measuring relative field strengths across a wide range. Those which are suitable are of the linear type and there are three which are easily available, the 634SS2, Lohet I and Lohet II

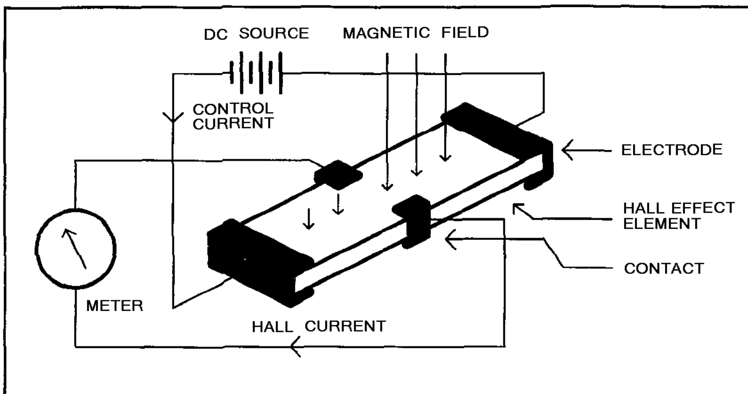



**Fig. 1. Hall Effect sensor**

Lohets I and II are analogue devices designed to produce an output voltage linear to the intensity of the magnetic field to which they are exposed. Of the two, the Lohet II has the best temperature stability and is used in this project.

Constructed on a thin ceramic substrate, the sensor has three in–line PCB terminals on standard 0.1 inch mounting centres. It has laser trimmed thick film resistors to minimise variations in sensitivity and to compensate for temperature variations. Lohet II utilises a special IC which provides increased stability and performance with a temperature drift almost ten times better than Lohet I. The quoted temperature errors for gain and null are both only ±0.02% per degree C.

Unfortunately, there are different supply voltage requirements for Lohet I and II. Whereas the former can operate on any DC supply between 8V and 16V, Lohet II has a range restricted to 7.6V and 8.4V DC. Both sensors have a magnetic span of –400 to +400 Gauss and the linearities are comparable, being 1.5% and 1% of span.

## THE EARTH'S FIELD

Confusingly, four units of measurement are used for expressing the values of magnetic fields: Gauss, Tesla, Maxwell/cm2 and Weber/metre2. The relationships are:

1 Gauss = 1 Maxwell.cm$^{-2}$
1 Tesla = 10000 Gauss = 1 Weber.metre$^{-2}$ (Wb/m2)
1 milli Tesla (mT) = 10 Gauss

The values for the strength of the Earth's magnetic field were obtained from the Open University book Understanding the Earth. It varies over the surface of the Earth from 2.5 x 10–5 to 7 x 10–5 Wb.m$^{-2}$

Expressed in the same units used for Hall sensor ratings, the field range is thus 0.025mT to 0.07mT, or 0.25mG to 0.7mG. Lohet II has a sensitivity of 5mV per Gauss. The 0.5mG change between –0.25mG and +0.25mG (from facing South to facing North), will thus, without amplification, only produce a sensor voltage change of 0.0025mV (0.005 x 0.5). Consequently, in order to use a Hall Effect device considerable amplification is needed before the readings are suitable for monitoring.

## CONSIDERATIONS

Although the sensor could be used to give the direction of the North Pole by looking for the highest voltage output, it is desirable to use it to assess the compass bearing of any direction. The system must therefore be able

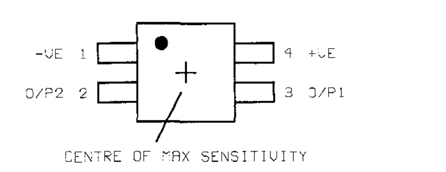



**Fig. 2. 634SS2 Sensor**

to differentiate between at least 180 separate values between the maximum for North and the minimum for South. Another design requirement is to be able to tell whether the bearing is to the West or East. In addition, allowance has to be made for the different magnetic field strengths around the globe. All of this can be best evaluated with a microcontroller.

## AMPLIFICATION

A microcontroller requires information to be fed to it in digital form. This means that the sensor's voltage has to be converted from analogue to digital. An ADC requires a reasonable amount of voltage change in order to swing reliably through its full digital output range. However, most are unlikely to operate successfully with a range as low as 0.0025mV. A swing of around 2.5V would be more realistic, requiring an amplification factor of 1000. Unfortunately, when amplifying a DC signal by this amount temperature drift can become a hazard. Although the Lohet II appears to have a very good temperature stability, of 0.02% per °C, multiplying this by a factor of 1000 gives a 20% shift per °C. A change of only 5°C could cause the voltage seen by the ADC to swing across the entire range allowed for directional readings. Additional temperature control must therefore be incorporated.

## DIGITAL CONVERSION

The above swing figure of 0.0025mV is the lowest likely to be encountered from the Earth's magnetic field. The highest could be around three times that. Therefore, even if there is perfect temperature stability, the ADC must be capable of handling full swings through any normal field range, irrespective of locality, and still produce a digital output that allows differentiation between at least 180 degrees. With a global field range of around 1:3, the ADC has to be capable of handling at least 3 x 180 = 540 steps, i.e. it should be at least a 10–bit device ($2^9$ = 512), preferably larger.

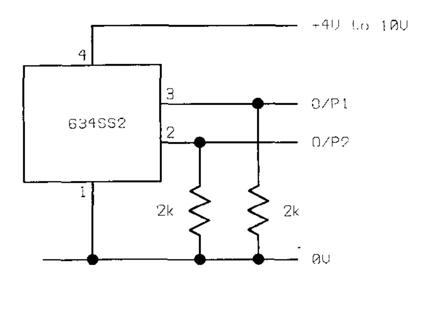



**Fig. 3. Test circuit**

Taking into account that ADCs of greater than eight bits are not cheap, and several other factors, such as the stability of high gain amplifiers, and of having to monitor two magnetic sensors (N–S and W–E) plus an ambient temperature sensor, an alternative technique is used: voltage to frequency conversion. The principle is simple: the sensor output voltage is amplified just enough to drive a voltage to frequency (V–F) converter and a computer is used to measure the frequencies. With suitable sampling rates, the sensor voltage can be chopped into as many discrete level steps as we want. The answers can easily be related to a base of 180 by straightforward calculations. This technique allows for widely differing output levels to be monitored without excess amplification and without the danger of over–running a standard ADC's bit–range. The same V–F converter is used for monitoring all three above functions using a simple multiplexing circuit, so ensuring relative consistency between source readings.

## PRACTICAL HALL EFFECT

Fig. 4 shows the block diagram of the complete compass. There are two Hall Effect devices, monitoring N–S and W–E field strengths, each feeding into their own amplifiers. A third sensor monitors ambient temperature providing data used to correct the direction sensor readings against temperature drift. All three outputs are fed through a multiplexer into a voltage to frequency converter, or more correctly, a voltage controlled oscillator (VCO).

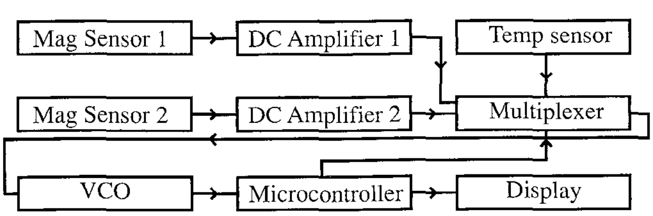



**Fig. 4.**

The VCO is monitored by a microcontroller principally consisting, in the conventional manner, of a microprocessor (MPU), a versatile interface adapter (VIA), an E(E)PROM and a memory. Having read the VCO data associated with each sensor, the MPU makes the necessary corrections and calculations, and sends the answer as a pulse chain to a display circuit comprising a frequency counter and LCD.

Details of the complete sensing and multiplexing circuits are shown in Fig. 5.

IC1 and IC2 are the Lohet II Hall Effect devices which monitor the N–S and W–E magnetic fields respectively. The two diodes inserted into the joint power lines are used to drop the main 9V power supply voltage to within the 7.6V to 8.4V range specified for the Lohet II. Each diode has a 0.6V drop across it, thus the nominal 9V power level is reduced by 1.2V to around 7.8V.

The sensors feed into two identical temperature–compensated DC–amplifier networks, IC3a–c and IC4a–c. IC1 has its output current set by R3 and its output voltage is fed into the non–inverting input of IC3b. The potential divider consisting of R1, VR1 and R2 sets the bias level required by the amplifier system. VR1 is adjusted to match the inherent bias voltage level from the output of IC1, so allowing the final output from IC3c to be set to a roughly–midway point.

IC3a and IC3b are cross–coupled with their gains initially set by R5 and R6 plus the total resistance of R4 plus VR2. Adjusting VR2 varies each opamp's gain by an equal amount. IC3a and IC3b then feed into the unity gain differential amplifier IC3c. The advantage of this type of DC amplifier is that it has built–in compensation for its own temperature drift. Since IC3a and IC3b have nominally identical gains, any temperature change will affect them identically. By inverting one output with respect to the other in the differential stage, any common drift is cancelled out. The network does not, however, compensate for any drift in the output of the sensor, which will probably have a different temperature coefficient to the amplifier components.

The output of IC3c is smoothed by the action R21 and C2 and taken to the multiplexed gate IC5, at pin 1. The second sensor, IC2, is treated similarly, its final amplified voltage being taken to IC5 pin 5.

## MULTIPLEXED VCO

IC5 is a dual 4–input analogue multiplexer of which only one half is used.Each of the inputs (1I0–1I3) can be individually fed to the common output (1OUT) at pin 3. The selected analogue voltage then sets the DC bias level of the VCO IC6, so varying its oscillation frequency. The basic frequency range is set by the combination of R23, R24 and C5 whose values have been chosen to set the range to a rate best suited to the microcontroller sampling rate. 18Hz is a typical figure, depending on the VCO input voltage.

Selection of the multiplexer channel is performed by the microcontroller which puts the required binary gating code on the A/B inputs of IC5: 00 = chan 0, 01 = chan 1, 10 = chan 2. Channel 3 (11) is not used.

## TEMPERATURE SENSING

Overall ambient temperature monitoring is carried out by using thermistor TH1 as the sensor. This decreases its resistance as its temperature increases. It is in series with R27 across the power lines and so the voltage seen at the junction of the two components will similarly decrease. The voltage is fed to the inverting amplifier IC4d, resulting in an increase in its output voltage as ambient temperature increases. VR5 sets the gain of this stage, allowing for correction of the volts per °C slope.

Individual Hall Effect sensors could drift upwards or downwards by the quoted 0.02% per °C. However, during its calculations, the microcontroller assumes that any drift is upwards. Once the circuit has been built it may be that this is not correct. If so, the monitored temperature gradient can be inverted by swapping over TH1 and R27.

## THE MICROCONTROLLER

The 65C02 MPU and 65C22 VIA used in the microcontroller are the CMOS versions of the standard 6502 and 6522 devices and have the benefit of lower power consumptions, faster speed and of not requiring external pull–up input resistors. The 65C02 also has more control commands than its standard counterpart, though they are not used in this application.

The addresses at which the microprocessor sees its system chips are: memory at (hex) \$0000–07FF, via at \$2000–20FF, e(e)prom at \$4000–47FF. Selection of the EPROM block address is performed by inverting A14 via IC5a, while the memory is selected by ANDing A13 and A14 via D1, D2 and R4.

Crystal controlled, the 1MHz clock rate is generated by the circuit around IC5b. Operation of the circuit is strongly time–dependent so using a lower–cost 1MHz ceramic resonator is inadvisable since its frequency is less–well stabilised.

At switch–on the system is held in reset mode by IC5d until C1 has, via R1, charged up sufficiently to trip the twin inverters IC5c and IC5d.

Although the VIA has two 8–bit output ports plus handshake lines, in this application only the PA0–7 port is used. PA0 and PA1 control the multiplexer channel routing and PA2 detects the VCO frequency output. PA7 is connected to the program–reset switch (S1 in Fig. 5), indicating to the program that it should reset the memory contents back to zero when required – PA6 is not used. PA3–PA5 control the display counter module – the circuit for this is in Fig.7. It consists of a dedicated counter/display control chip and a liquid crystal display.

Having made its calculations from the VCO data, the microcontroller sends out on PA5 the same number of pulses as there are degrees in the direction sensed. These are counted by the counter/driver chip IC4 though the data is only transferred to the display at the end of each count. The display continues to show the same data until updated at the end of the next count sequence. IC4's reset input is controlled by PA3, and its transfer latches (store) by PA4.

Fig. 8 shows the pin–outs for the counter/driver type ICM7224 and the LCD module.

## CONSTRUCTION

Component and track layouts for the PCBs are shown in Figs. 9–11.

The microcontroller and LCD boards need some precise soldering and the use of a fine–tipped soldering iron is recommended. Many of the tracks run between IC socket pins and there is the danger of allowing solder to bridge across them. Note that some wire links on the controller board should be inserted before the IC sockets are soldered in.

Two power supply voltages are required by the sensor board, 9V and 5V. Regulator chip IC6 steps the 9V down to 5V on the controller board. This 5V line also supplies power to the LCD module. Ultimately, a 9V battery could be used to power the unit, though for testing purposes it is best to use a regulated 9V supply from a mains operated power supply unit. Do not exceed 9V unless suitable precautions are taken to protect the Hall sensors.

## TESTING

It is important to note that, for reasons best known to the manufacturers, Lohet II devices are sensitive to light. Their output voltage can be considerably affected if even

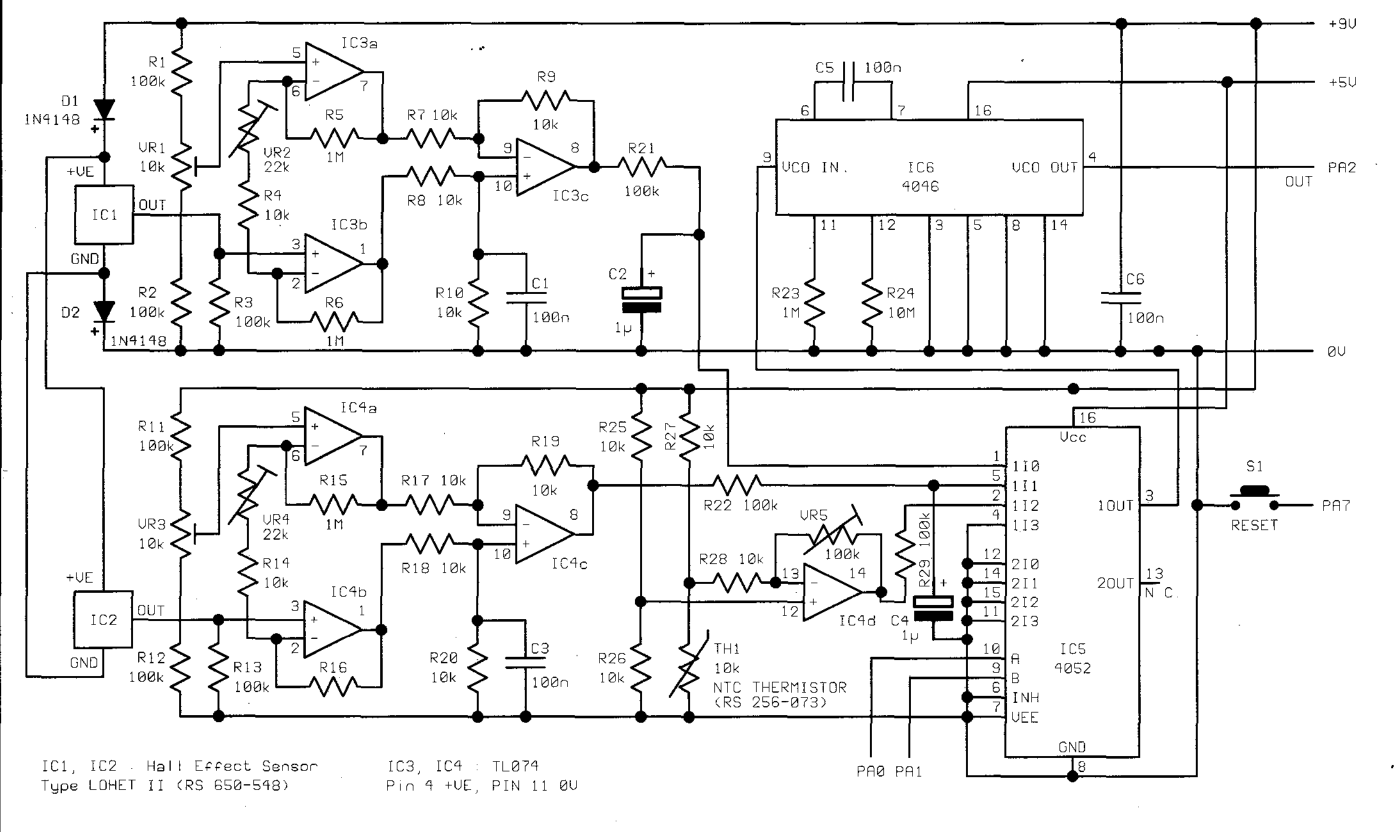



**Fig. 5. The main sensor/multiplexer circuits.**

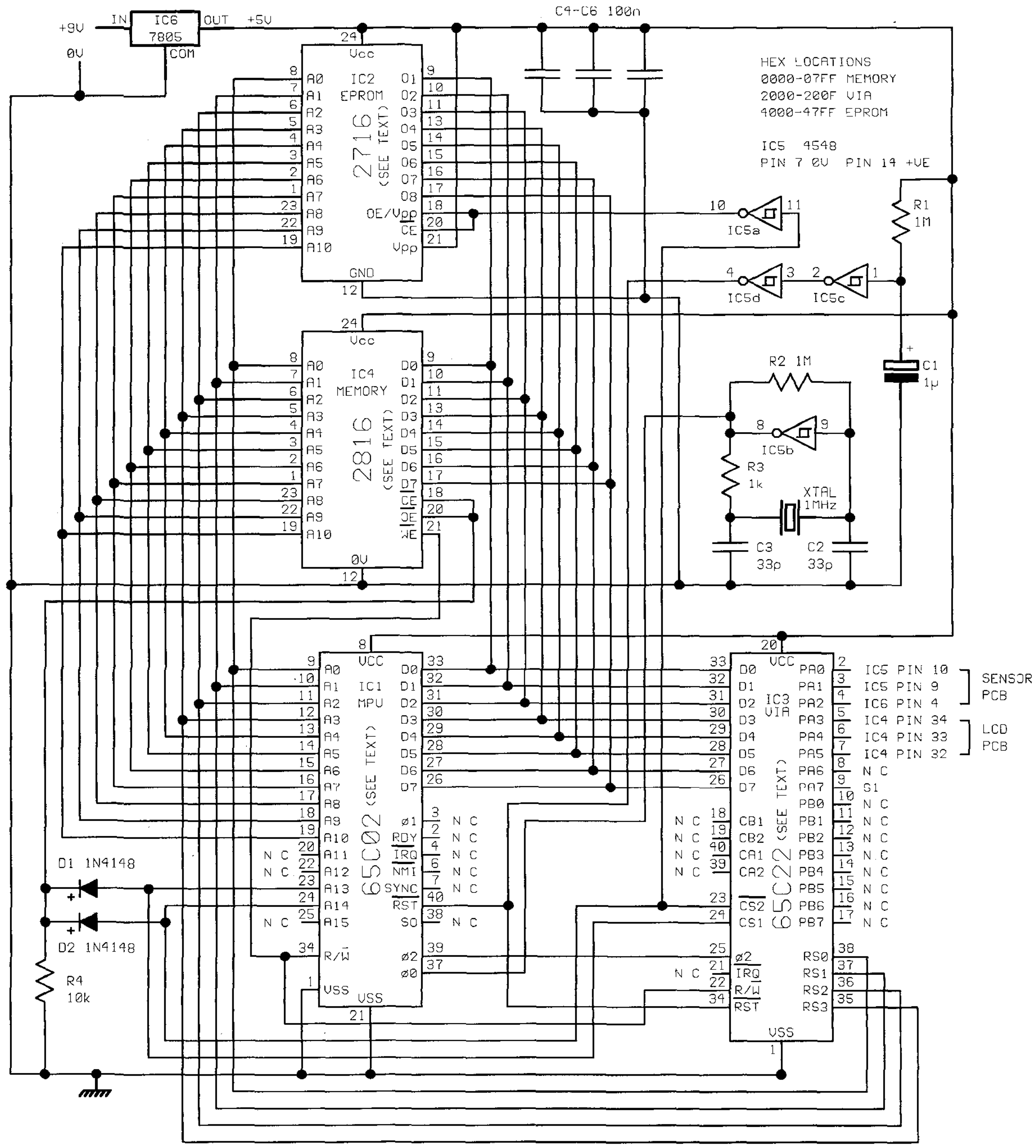



**Fig. 6. The Microcontroller circuit.**

low levels of light fall on the chips. Because of this it is a good idea to wrap them in black insulating tape before use.

For the initial testing of the sensor board the microcontroller and LCD module are not needed. The first step is to switch on the power and check that 9V and 5V appear at the correct points on the board. Check that the voltage across the positive and negative pins of the sensor is between 7.6V and 8.4V and then check that the voltage between the sensor's output and the 0V line is about 4.5V or so (half the power line level of 9V). Do this for both sensors. Now set the wipers of VR1 and VR3 to a voltage similar to that on the sensor outputs.

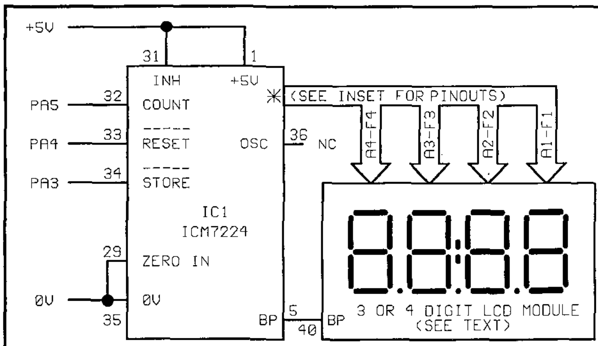



**Fig. 7. The display counter module.**

Set VR2 and VR4 for maximum resistance and check that the outputs of IC3a–IC3c and IC4a–IC4c all show fairly equal voltages of about half PSU level. If necessary, adjust the bias control pots VR1 and VR3 until the condition is met.

Next check the temperature sensor. Set VR5 for minimum resistance (least gain). Use a meter to monitor the voltage on the

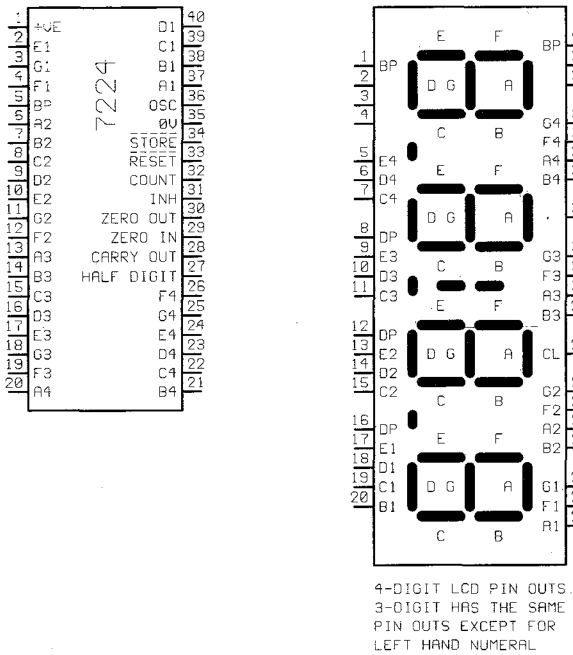


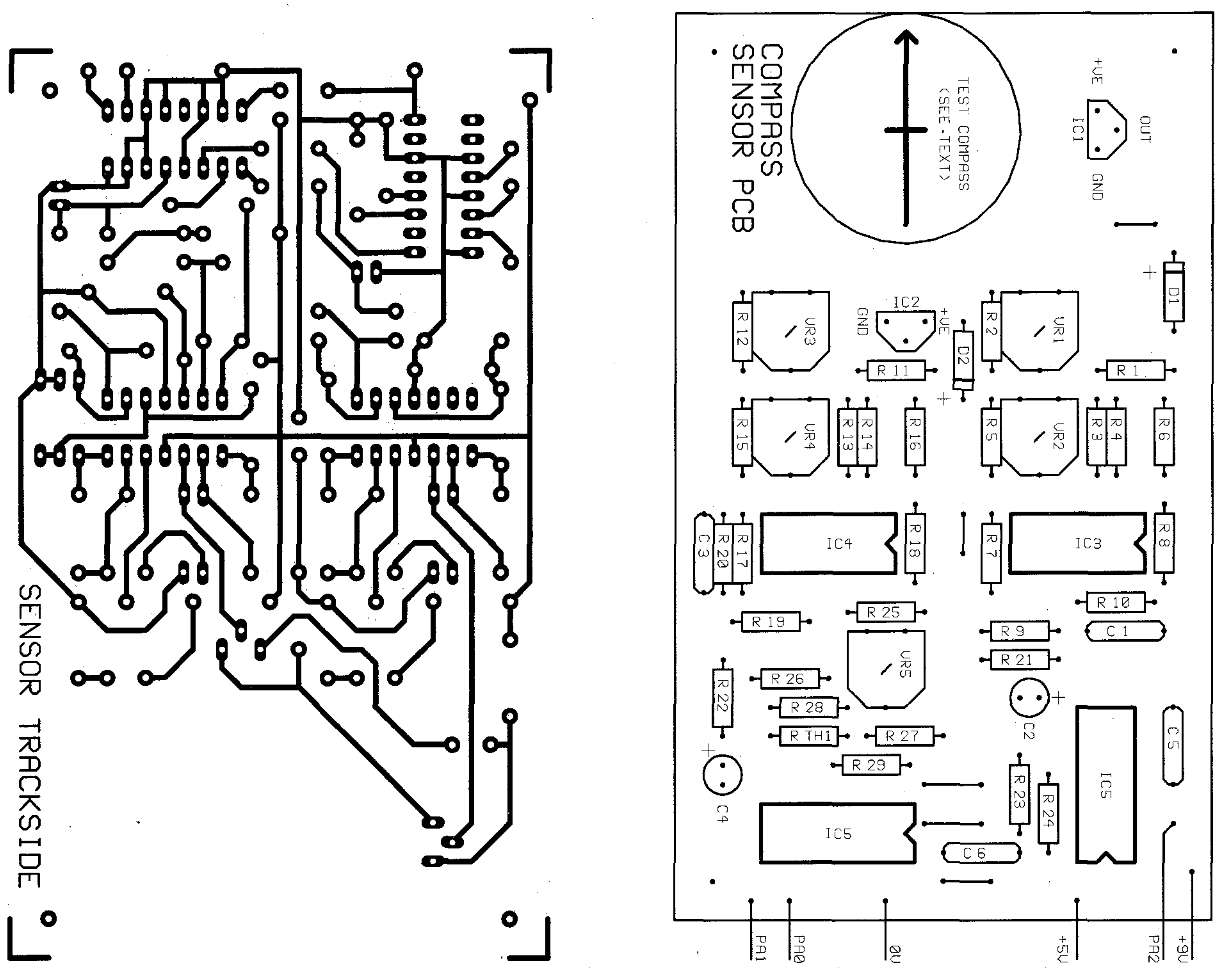

**Fig. 8. Pin-outs for ICM7224 and LCD module.**

output of IC4d and then warm the thermistor (place it between your fingers )while observing the meter. A small change in voltage reading should be visible. Increasing VR5 should increase the reading. The rate and direction of voltage change will depend on the heat applied to the device relative to room temperature (and how long the unit has been switched on before taking the readings – ideally allow a few minutes for the temperature to stabilise before monitoring).

Now connect a wire to each of the multiplexer control pins A and B. Connect them to the 5V and 0V lines in the binary sequence of 00, 01, 10 (B is the left hand digit, A is the right). With each combination check that the voltage passing through the multiplexer to the VCO at its pin 9 is the same as that originating from the respective input channel line. (also check that 0V is at the output if code 11 is applied.)

To check the circuit's response to magnetic fields, a small permanent magnet should be moved around the sensors while the voltage reading at the multiplexer inputs in monitored. After establishing that the sensors respond to different magnetic polarities and strengths, place an ordinary magnetic compass centrally between the two sensors. In effect, the compass behaves as an amplifier of the Earth's magnetic field – it reacts to the field, and the sensors then respond to its magnetised needle. While still monitoring the amplified sensor lines, rotate the PCB fully though 360° and note the voltages produced on the lines. If the voltages do not swing evenly it may be necessary to slighty change the settings of the bias and gain presets. Aim for a swing of around 0.5V to 1V while keeping the maximum level a little below 5V.

**Fig. 9. Sensor PCB component and track layouts**



## SOFTWARE

Either an EPROM or an EEPROM can be used to store the control program and data. A 2048x8–bit device is needed such as the 2716 or 27C16 EPROMs, or the 2816 or 2817 EEPROMs.

The software occupies the first 1024 bytes of the PROM with the remainder unused except for an initial set–up and jump instruction at $47F0/FF, directing the program proper to commence at $4000. See end for listing details.

## SYSTEM RESET

At power switch–on the system is reset, though the memory contents are not cleared. These are only set to zero immediately on pressing the reset switch. This allows experimentation with a non–volatile memory (NVM) in place of the volatile memory quoted in the parts list. In theory, an NVM should allow data stored prior to last switching off to be recalled for examination.

If using an ordinary volatile memory, the unit should be switched to reset mode following power–on to clear the memory of random data. This resetting to zero is only carried out during the first cycle upon detection of the reset switch being pressed on. The switch should continue to be held down to allow the unit to assess the magnetic field strength factors. This entails smoothly rotating the unit fully through a complete circle, taking about four or five seconds. During rotation the unit will look for the maximum and minimum readings from both magnetic sensors. It will also be constantly reading and storing the current temperature. When the reset is switched off the temperature value becomes fixed and is then used as the base against which any temperature changes are judged.

## DATA READING

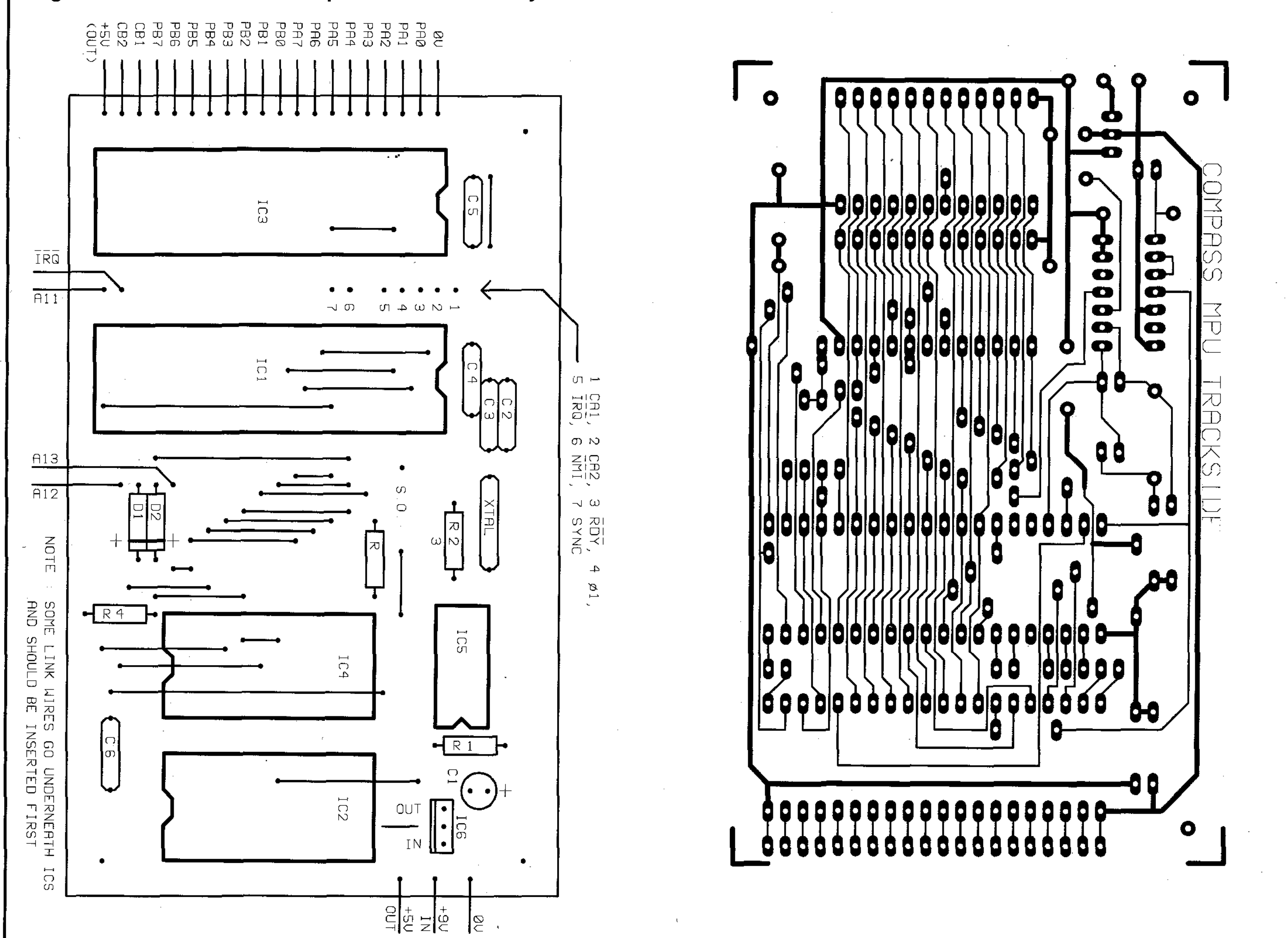
When reading the VCO, the program cycles through each multiplexer address in turn. Each time, a counter is reset, then started on receipt of the first available positive–going pulse from the VCO. The counter is then repeatedly incremented until the pulse goes negative. The counter value then holds a numeric representation of the oscillator's frequency, which, of course will vary with the sensor voltage.

The count value is first compared with the stored minimum and maximum values for the relevant sensor, updating the stores if appropriate. The calculations then relate the current reading to 180°. To establish the overall numerical range, between North and South or West and East, depending on the sensor accessed, the minimum value is subtracted from the maximum. The answer is multiplied by 180, and then divided by the present reading, to establish the relative angle of rotation. The West/East value is compared against a midway value, from which the correct rotation hemisphere is established. If the reading represents an Easterly bearing the N/S answer is sent to the LCD module as a value between 0 and 180. If it's a Westerly bearing, the N/S reading is corrected so that the value sent to the LCD is in the range of 180 to 360.

## VCO RATE

The VCO rate is set for about 18Hz, allowing the program to increment the counter several hundred times during each sample. The rate is chosen to be a compromise between sampling speed and pulse count totals. For the best resolution of direction the count needs a few hundred more than 180. The sampling rate is satisfactory for routine reading of the display, though it does require the initial circling during reset to be somewhat slower than ideal. Using a clock of greater than 1MHz would speed the rate, though it's conceivable that the memory counter could

**Fig. 10. Main Processor component and track layout.**



overflow, resulting in bad data. Anyone conversant with 6502 programming could experiment with this to modifying the software if necessary.

The ordinary compass can now be dispensed with. To increase the gain of the system the resistance of presets VR2 and VR4 must be decreased. It's possible that reduction of R4 and R14 may also be necessary. As the gain is increased any misalignment of the bias presets will be become increasingly significant, and more fiddly to re–adjust. The voltage swing at the outputs of IC3c and IC4c must stay below 5V as stated above.

## A BASIC SENSOR

For very simple measurements of steady magnetic fields, the microcontroller and LCD are not really needed. Simply connecting a voltmeter to the output of IC3c and observing the voltage change as the sensor is rotated or brought closer to the field gives some idea of the operation. Only one sensing amplifier need be constructed, the rest of the circuitry can be ignored. For measuring alternating (e.g. 50Hz) magnetic fields, a diode can be connected across R21 and C1 removed. If temperature drift is not important then Hall sensor type 634SS2 could be substituted for Lohet II – either of its outputs may be used.

## PROGRAM LISTING

A full hex dump listing of the software for this project can be obtained from the address below for £1.50.

Digital Compass
PE Software
Intra House
193 Uxbridge Road
London W12 9RA

PE

## COMPONENTS

### MAGNETIC SENSOR

RESISTORS
R1–R3, R11–R13, R21, R22, R29 100k (9 off)
R4, R7–R10, R14, R17–R20, R25–R28 10k (14 off)
R5, R6, R15, R16, R23 1M (5 off)
R24 10M
all 0.25W 5% carbon or better

CAPACITORS
C1, C3, C5, C6 100n polyester (4 off)
C2, C4 1µ 16V electrolytic

POTENTIOMETERS
VR1, VR3 10k horiz preset (2 off)
VR2, VR4 22k horiz preset (2 off)

SEMICONDUCTORS
D1–D2 1N4148 (2 off)
IC1, IC2 Lohet II Hall Effect ic (RS 650–548 or equivalent) (2 off)
IC3, IC4 TL074 (2 off)
IC5 4052
IC6 4046

MISCELLANEOUS
S1 single pole push–make switch.
TH1 10k NTC thermistor (RS 256–073 or similar).
14–pin DIL ic sockets (2 off), 16–pin DIL ic sockets (2 off), printed circuit board, test compass (see text).

### MICROCONTROLLER

RESISTORS
R1, R2 1M (2 off)
R3 1k
R4 10k
all 0.25W 5% carbon or better

CAPACITORS
C1 1µ 16V electrolytic
C2, C3 33p polystyrene (2 off)
C4–C6 100n polyester (3 off)

SEMICONDUCTORS
D1, D2 1N4148 (2 off)
IC1 65C02 microprocessor
IC2 2716 EPROM (see text)
IC3 65C22 via
IC4 2816 memory (see text)
IC5 4548 hex Schmitt trigger inverter

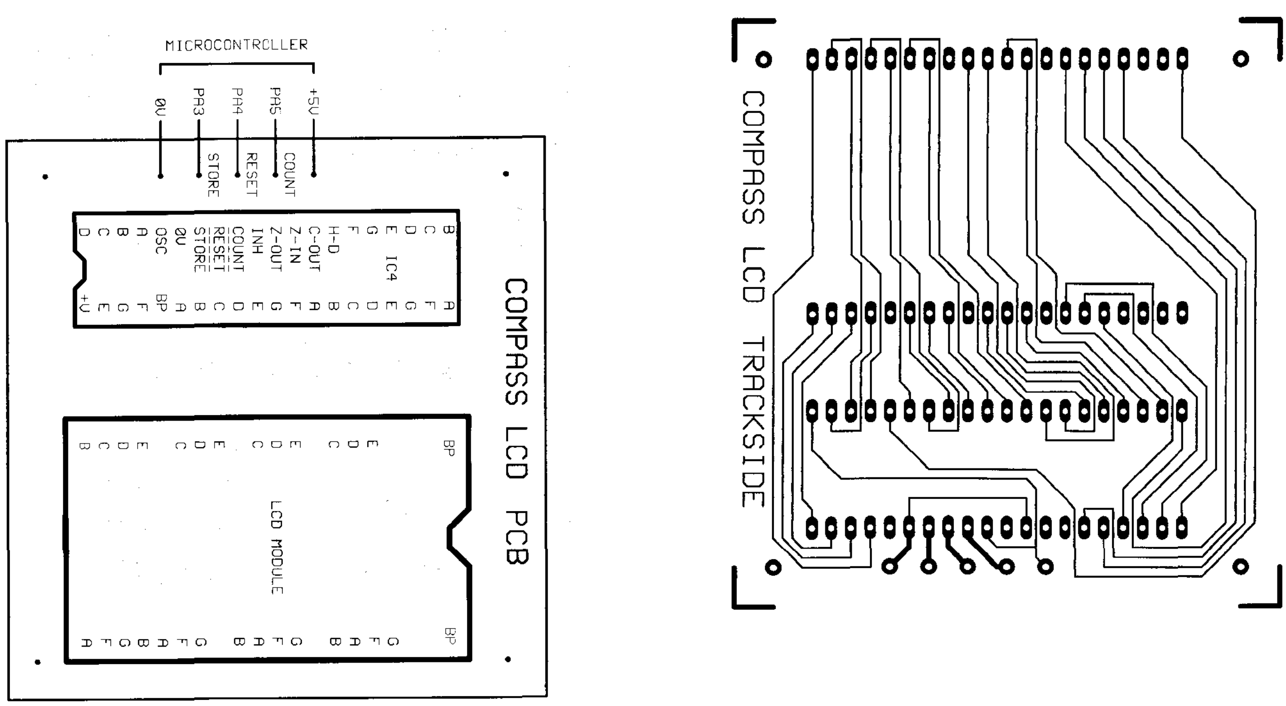
MISCELLANEOUS
DIL ic sockets: 14–pin, 24–pin (2 off), 40–pin (2 off).
Printed circuit board, 1MHz crystal.

### LCD DISPLAY

SEMICONDUCTORS
IC1 ICM7224 LCD driver/counter
LCD 3 1/2 digit LCD module (see text)

MISCELLANEOUS
40–pin DIL ic sockets (2 off – 1 to be cut vertically in half to fit LCD).
Printed circuit board.

**Fig. 11. Compass LCD component and track layouts.**



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## HIGHLIGHTS

### Hardware:

- IBM PC, XT, AT or 100% compatible.
- MSDOS 3.x.
- 640K bytes system memory.
- HGA, CGA, MCGA, EGA or VGA display.
- Microsoft or compatible mouse recommended.

### Capabilities :

- Integrated PCB and schematic editor.
- 8 tracking layers, 2 silk screen layers.
- Maximum board or schematic size - 17 x 17 inches.
- 2000 components per layout. Symbols can be moved, rotated, repeated and mirrored.
- User definable symbol and macro library facilities including a symbol library editor.
- Graphical library browse facility.
- Design rule checking (DRC)- checks the clearances between items on the board.
- Real-time DRC display - when placing tracks you can see a continuous graphical display of the design rules set.
- Placement grid - Separate visible and snap grid - 7 placement grids in the range 2 thou to 0.1 inch.
- Auto via - vias are automatically placed when you switch layers - layer pairs can be assigned by the user.
- Blocks - groups of tracks, pads, symbols and text can be block manipulated using repeat, move, rotate and mirroring commands. Connectivity can be maintained if required.
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- Circles - Arcs and circles up to the maximum board size can be drawn. These can be used to generate rounded track corners.
- Ground plane support - areas of copper can be filled to provide a ground plane or large copper area. This will automatically flow around any existing tracks and pads respecting design rules.

### Output drivers :

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- Compensated laser printer.
- PostScript output.
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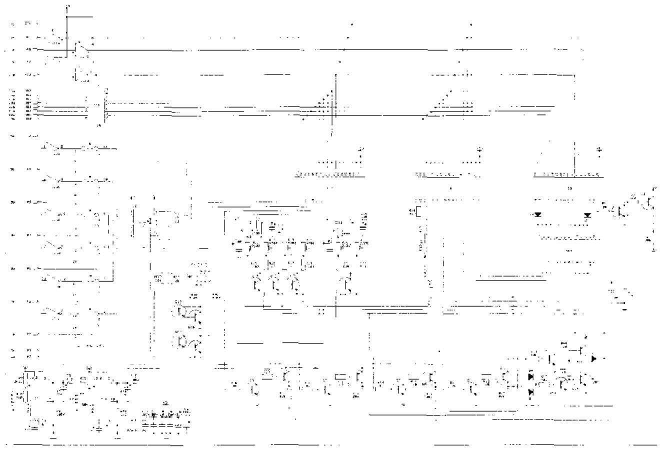
- Photoplot (Gerber) output.
- NC (ASCII Excellon) drill output.



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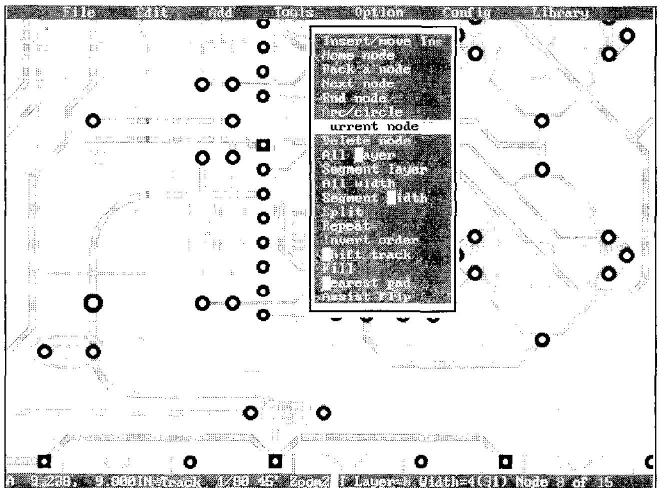


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# AN A TO Z OF DIGITAL DEVICES

**Chris Kelly reviews a range of chips and logic circuits.**

Digital devices have grown to dominate electronics over the past twenty years. The range of components is vast and some of the terms and jargon may be bewildering. This A-Z guide provides a brief look at many of the digital functions now available in the form of integrated circuits.

There are two main families of digital integrated circuit, denoted by prefix numbers. Chip code numbers starting with a 4 usually refer to the CMOS (Complementary Metal On Silicon) series of low power IC's, e.g. 4000 and 4042. The other main family begins with 74, e.g. 7400 or 7496. These are known as TTL (Transistor Transistor Logic) and use more power than the 4XXX (X can be any figure) series. However, there are variations such as the AC, HC and LS series which provide higher speeds and lower power.

## Analogue to Digital Converter

The conversion of 'real' signals e.g. analogue voltages that vary with time, such as recordings of speech or music, into digital form is performed by an Analogue to Digital Converter (ADC). This uses comparators to check the incoming analogue voltage against reference values and give a result that is a parallel digital number. This can then be used with other digital circuits and stored or altered for output with a Digital to Analogue Converter (DAC).

There are a number of ADC chips available from the 7109 which gives a 12 bit output (input voltages can be split into 4096 separate levels) to the ADC0820CCN which only converts to eight bits high speed but is quite fast (a conversion every 1.5µS). Another option is the Si520 which has eight channels, each of which can be switched into an eight bit ADC.

## Analogue Switches

While not truly digital, these devices can be used in digital systems to allow them to control analogue voltages. Similar to a demultiplexer, a single input voltage can be switched to any of a number of outputs. Standard sizes range from one pole eight way (4051), allowing one signal to be switched between eight outputs, to four pole one way giving four individual switches as in the 4066.

The technology used to manufacture the switches imposes some limitations on what voltages can be switched. Normally this means not exceeding the power supply and, where negative and positive going voltages must be switched, there must be a negative power supply.

## Arithmetic ICs

Full adder logic circuits (Fig. 1) add together two binary numbers presented to parallel inputs and generate a result with a carry bit. The TTL 7483, 74283 and CMOS 4008 are chips which add four bit numbers, with carry-in and carry-out lines so that the devices can be cascaded to add eight bits, 12 bits, and so on.

Arithmetic logic units (ALU) are ICs which perform a number of arithmetic operations on binary numbers. Which one is used depends on the code at the select inputs. The 74181 and CMOS 4581 are examples.

## Asynchronous

A digital circuit which responds to logic signals that do not occur at regular or clocked intervals.

A ripple counter is an asynchronous circuit because the bistables are clocked one after another, not simultaneously as with a synchronous counter.

UARTs (Universal Asynchronous Receiver Transmitter) are asynchronous (Fig. 2) because, although each bit within a character is timed for a given baud rate, the duration between each character sent or received is variable.

## Baud-rate or Bit-Rate Generator

A device which generates the usual baud rates (75, 1200, 9600 etc. bits/second) used for the transmission of serial data.

The 4702B can generate baud rates between 50 and 19200 baud depending on a four bit code applied to rate-select inputs.

## Bistables (flip-flops or latches)

These are logic circuits which remain in one of two stable states until switched to the other state by a change in the input signals. They are used as the basis of electronic memories, registers and counters.

There are a number of different bistable devices. All have a Q output and many have

Fig. 1. Two- by four-bit adder circuit giving eight-bit addition

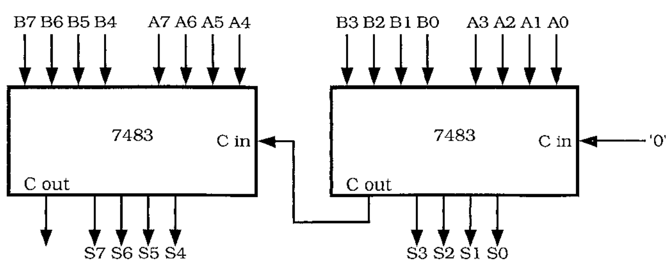
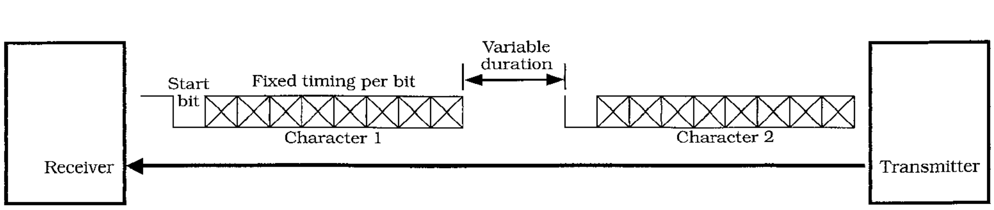



Fig. 2. An asynchronous transmitter receiver



an inverse output $\overline{Q}$.

The SET state is when Q = 1 and $\overline{Q}$ = 0.

The RESET state is when Q = 0 and $\overline{Q}$ = 1.

The S-R bistable (Fig. 3) is the simplest form having two inputs, one called SET (S) to trigger the set (on) state, the other called RESET (R) to trigger the reset (off) state. Typical chips are the CMOS 4043 and the TTL 74118.

The J-K bistable (Fig. 4) is the most commonly used because of its versatility for counters and registers. Its function is very similar to the S-R (the J is the SET input and K is the RESET) but differs when both inputs are high. When both J and K inputs are at logic 1 the J-K acts as a toggle or T-type bistable where the Q output changes or 'toggles' to its alternative state at every clock pulse. Typical chips are the 4027 and the 7476.

The D-type latch (Fig. 5) remembers the logic level present at its D input when a clock pulse occurs by switching the Q output to the same state as the D input. D-type bistables are often used for buffer storage such as the output or input ports of a microprocessor system. Typical chips are 4013 and 7474 (dual D-types) or 74273 and 74374 (octal D-types).

Clocked bistables respond to inputs when a clock or strobe input is active. There are two types of clock or strobe response (Fig. 6):

Level triggered where the bistable responds when the clock input is active (high or low depending on the type of bistable).

Edge triggered – where the bistable responds to inputs only on one edge of the clock pulse (rising or falling edge).

For edge – triggered bistables the set-up time (see Fig. 7) is the time required for the signals to be available at the inputs before the active edge of the clock pulse. The hold time is the period required for the input signals to remain at inputs after the active edge of the clock pulse to ensure proper response.

## Boolean Logic

When designing digital systems, a formal approach must be used to define the various operations. Boolean algebra has two values (on and off or 1 and 0) and offers three basic functions, AND, OR, NOT. The simplest is the latter since all it does is invert the value at its input – a 0 becomes a 1 and a 1 becomes a zero. The other two functions take two inputs and give one output as a result. AND gives an output of 1 only when both inputs are 1 i.e. 1 AND 1 = 1. The OR function outputs a 1 when either or both inputs are also 1.

The three basic Boolean logic functions form the basis of all digital logic devices since they can be combined to form more complex functions.

## Buffer Drivers

A logic buffer driver is an electronic circuit which takes its input from a low current source and provides a higher current output to drive other higher power circuits.

Many devices such as microprocessors send information onto a bus system but have insufficient output current to drive all of the other devices on the bus; memories and input/output devices, etc. In these circumstances, drivers would be used as boosters for the existing signals.

For example, the 74240 and 74241 are octal buffers with inverting and non-inverting outputs respectively.

## Bus Transceivers

Similar to buffers but able to allow data to flow in either direction, bus transceivers are also used in microprocessor systems. Control signals can switch the respective outputs into a high-impedance state (tri-state) which effectively disconnects the outputs from the bus allowing more than one transceiver to use it. The 74245 and 74640 are octal transceivers.

## CMOS

Complementary Metal Oxide Semiconductor is a chip manufacturing process used to build low power digital chips. These offer low noise immunity, a wide range of power supply levels – approx 3V to 15V – and high fan out as well as consuming from .2mW to 10mW per gate.

The noise immunity comes from the fact that the transistors don't switch on until well over the halfway stage from off (normally 0V) to on (the supply voltage, normally 5V) and vice versa. This means that any ripples in the logic signals have to be quite vigorous before they have any effect on the circuitry.

The fan out of a chip is related to the input impedance of the gates and defines the number of inputs that can be driven from one output. With CMOS chips this is in the range of 50+ making it very easy to create complex logic circuits without having to worry too much about power requirements..

Unfortunately, there are a couple of drawbacks with standard CMOS devices. The first is that they can easily be destroyed by high static voltages. Since these can easily be generated simply by walking across a nylon

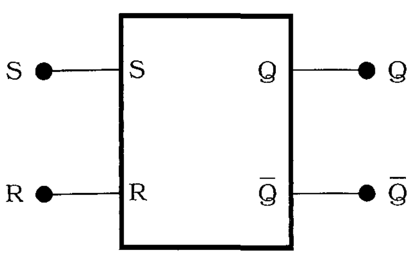



**Fig. 3. S-R Bistable**

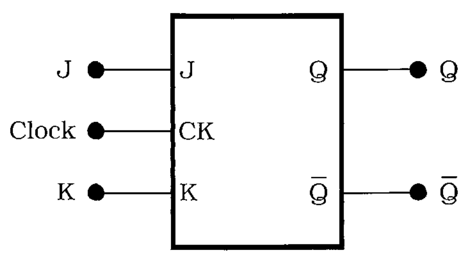



**Fig. 4. J-K Bistable**

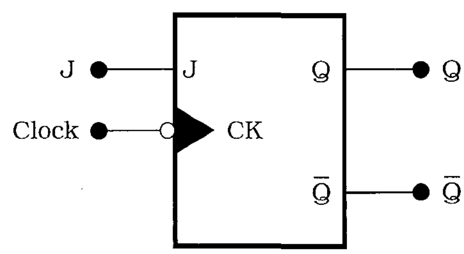



**Fig. 5. D-type Bistable**

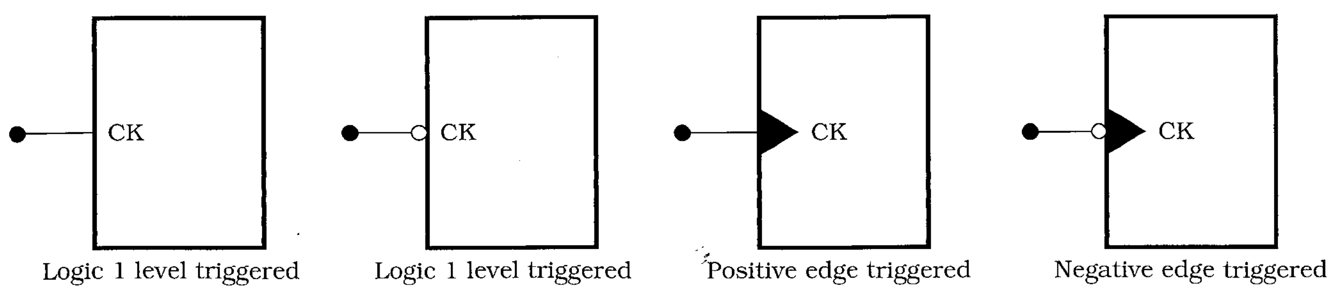



**Fig. 6. Bistable clock symbols**

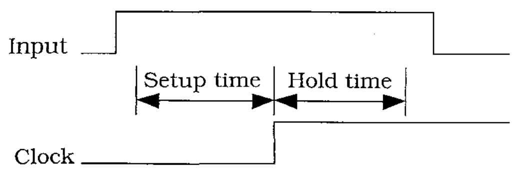



Fig. 7. Setup and Hold Time

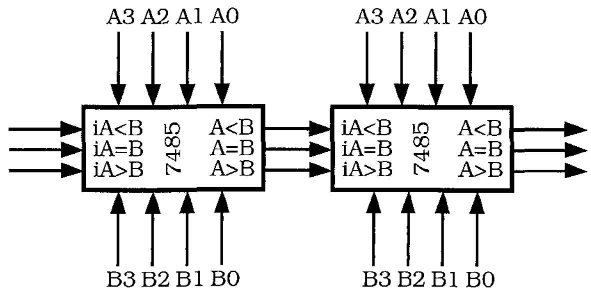
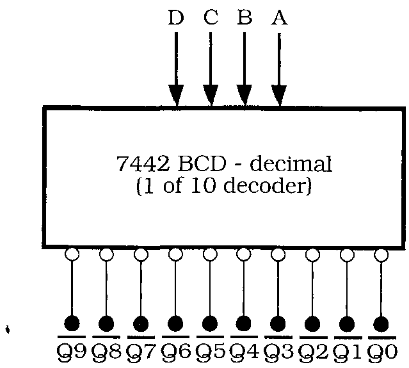



Fig. 9. 4-bit comparators cascaded




| Inputs D | C | B | A | Active output |
|---|---|---|---|---|
| L | L | L | L | $\overline{Q0}$ |
| L | L | L | H | $\overline{Q1}$ |
| L | L | H | L | $\overline{Q2}$ |
| L | L | H | H | $\overline{Q3}$ |
| L | H | L | L | $\overline{Q4}$ |
| L | H | L | H | $\overline{Q5}$ |
| L | H | H | L | $\overline{Q6}$ |
| L | H | H | H | $\overline{Q7}$ |
| H | L | L | L | $\overline{Q8}$ |
| H | L | L | H | $\overline{Q9}$ |
| H | L | H | L | None |
| H | L | H | H | None |
| H | H | L | L | None |
| H | H | L | H | None |
| H | H | H | L | None |
| H | H | H | H | None |

H=High voltage level
L=Low voltage level

Fig. 8. Code convertor and its output

carpet, care should always be taken to store them in conducting foam so that all of the pins are kept at the same potential. Fortunately, many modern CMOS designs have protecting diodes connected across their inputs to shunt high voltages out of harm's way. The most popular CMOS families are the 4000 and 74C series – the latter have the same pin connections as the industry standard 7400 series but are fabricated in CMOS rather than TTL.

## Code Converters

Sometimes known as decoders these are combinational logic circuits which translate values of one code to another (Fig. 8). For example, the 7442 converts BCD (four bit binary coded decimal) to decimal. The 7447 is a BCD to seven-segment decoder used for driving LED displays.

## Combinational Logic

This is the general name given to many gates which are connected together to make a system with any number of inputs and outputs. The outputs respond almost immediately to any change in the input logic states, any delay being due to the propagation of the signals through the circuitry.

Combinational logic is often used for control and decoding circuitry in more complex systems. Because it is used to link separate parts of a system it is sometimes referred to as glue logic. For many years standard gate chips were the only way to do this, but now gate arrays and programmable logic devices are becoming widely used.

## Comparators

These are devices which compare the magnitude of two binary numbers (A and B) presented to parallel inputs and give an indication of whether A is less than B (A<B), A is equal to B (A=B) or A is greater than B (A>B).

The 7485 (see Fig. 9) is a four-bit magnitude comparator which can be cascaded (the outputs of one fed to the inputs of another) to increase the size of binary numbers compared.

## Counters

Counters are based on bistables linked together to step through a pre-determined sequence when clock pulses are applied. The number of different states is called to modulo. For example, a four stage counter would be a modulo 16 or divide by 16 counter.

Asynchronous or ripple-through counters (Fig. 11) are made by using the output of one bistable to feed the clock input of the next. These are limited because of the cumulative propagation delays – the time taken for the input signal to be processed and appear at the output of a chip. The 7493 is a four-stage asynchronous counter with a reset path which permits modification to count values less than modulo 16.

Synchronous counters (Fig. 13) have all their bistables clocked simultaneously so they can operate at higher speeds. Logic gates between the bistables determine the count sequence. The 74161 is a synchronous counter with asynchronous clear, meaning that the clear is independent of the clock pulse.

## Demultiplexers

This selects one output to be active depending on the digital code presented to inputs (Fig. 12). For example, a two to four line decoder has a two input code to make one of the four outputs to go low or high depending on the type used. The 74139 causes the selected output to go low and the 4555 causes the selected output to go high.

There are also three to eight line and four to sixteen line decoders. Combinations of these devices are widely used in selecting blocks of memory in microprocessor systems.

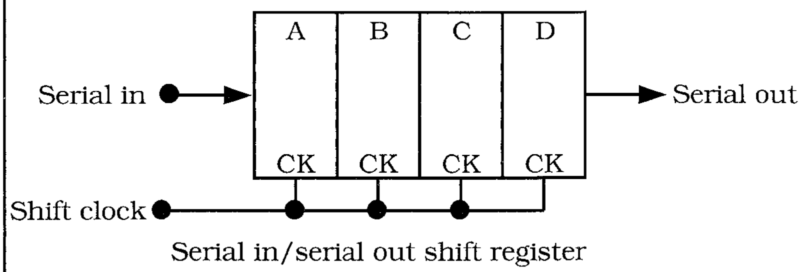
Demultiplexers are also used to separate chunks of serial data on one line into individual streams. This is done by connecting the output enable to the single serial line and taking the separated streams from the outputs. This is the opposite function to a multiplexer.

## Digital to Analogue Converter

Where digital numbers must be converted into analogue form, a Digital to Analogue Converter (DAC) is used. This is exactly the reverse of an ADC and normally uses a resistor network to provide a varying analogue current from the parallel digital number. This gives a voltage which can be amplified and used to drive any analogue system e.g. a loudspeaker. Examples of DACs are the DAC0801 and ZN425E.

## Encoders

Priority encoders generate a parallel binary code depending on the highest ranking input line which has a logic 1 applied to it. For



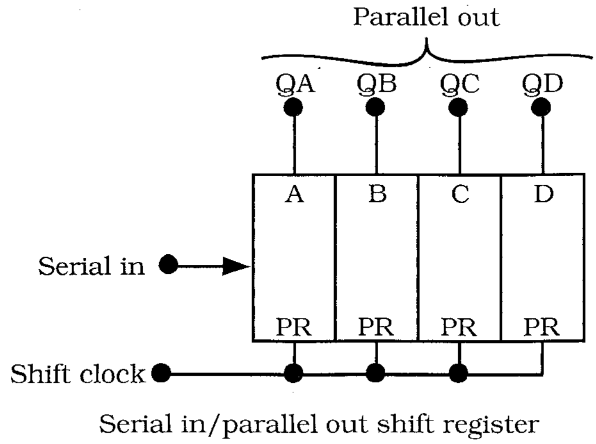




**Fig. 10. Various registers.**

example, the 4532 will generate a three-bit code of 101 if input five is at 1, irrespective of any of the lower ranking inputs at 1. However, if input six goes to 1, this will have priority and a code of 110 will be generated. Likewise input seven has priority over input six.

Keyboard encoders scan keyboard switches and generate a code for any key pressed. This can be a simple four-bit code for 16-key keypads or alphanumeric codes (such as ASCII) for larger keyboards.

## Gates

Logic gates are electronic circuits which control the flow of digital signals. They are the basic building blocks of all digital systems. When many gates are connected together they can perform the functions of bistables, counters, registers and memories. These in turn can be built into microprocessors and other complex digital systems.

The fundamental gate functions are given in Fig. 14.

## Interface Adapters

Microprocessors can communicate with the outside world in one of two ways, in serial mode or in parallel. The interface chips needed to perform this are USART Universal Asynchronous Receivers Transmitters (USARTs) and Interface Adapters (IAs) respectively. The latter come in two main formats depending on the type of microprocessor in use. Both give access to the outside world in the form of parallel ports to which values can be written and from which values can be read. Memory based systems such as the 6502, 68000 i.e. Motorola family chips, see the outside world as part of their memory area. Data can be transferred to and from the ports simply by storing and loading data directly from the memory. Examples of interface adapters of this type are the 6522 VIA (Versatile Interface Adapter) as used in the BBC Micro among other machines, and the 6521 PIA. In addition to simply supplying parallel ports, IAs generally include some sort of independent clocks, handshaking, and interrupt facilities allowing the microprocessor to get on with other jobs while the IA handles the communications.

The other main type of IA is used with the Intel family of chips. These have special In and Out commands which allow them to transfer data to and from the IAs leaving all of the memory available for programs and storage. This type of chip is used in Z80/8080/8086 type systems e.g. the 8255 Peripheral Interface Adapter.

## Microprocessors

Probably the most complex logic circuit available is the microprocessor. Its ability to follow a series of instructions and perform complex functions makes it a very versatile circuit.

Examples of microprocessors range from the relatively simple low power 65C02 to the complex 68030 used in high performance computers such as the Apple Macintosh II.

## Memories

Built around bistable circuits, memory chips are used to store large arrays of binary numbers. The two main types are RAM

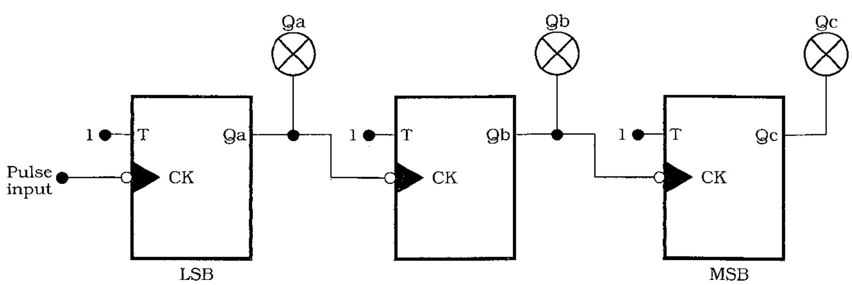



**Fig. 10. Ripple-through counter**

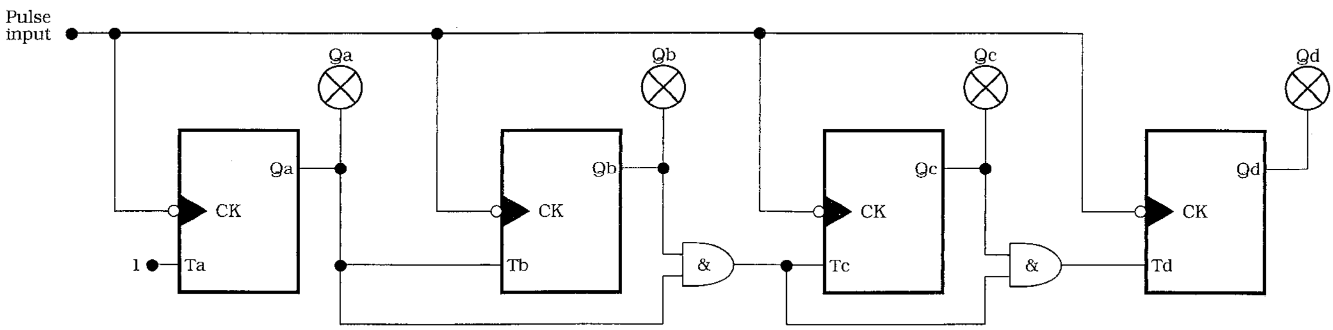



**Fig. 11. Synchronous counter**

(Read And write Memory) and ROM (Read Only Memory). The first is volatile – it loses it contents when the power is removed – and the second has its values 'burned' in when it is manufactured. EPROMS (Erasable Programmable ROMS) and EEPROMS (Electrically EPROMS) fall in between the two types since they allow data to be changed but not lost when the power goes.

Memory capacities range from the 128 bytes of the MC6810 to the 1M bits in a 511000.

## Multiplexers

A digital multiplexer routes information from a number of input channels to a single serial line. A binary code applied to the channel select determines which input channel is routed to the output.

Multiplexers are often used in data logging or data communications applications where it is more economical to use a single data line rather than many in parallel.

The 74153 is a dual four line to one line multiplexer. The 74150 is sixteen line to one line.

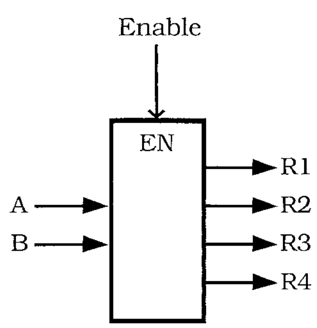
## Prescalers

A prescaler is a special IC used for dividing square wave signals by pre-determined amounts. They are widely used for counters, frequency meters and waveform synthesizers. The SP8629 is a 100 prescaler operating up to a maximum of 150 MHz.

The AY-1-5050 is a seven stage divider giving a wide choice of divider values.

## Registers

Registers (see Fig. 10) are n-bit stores made up of bistables which can accept input data in serial or parallel and output in parallel or serial. Shift registers move the stored bits to the right or left and can be used as parallel to serial converters or for arithmetic operations. Examples are the 4035, 7495 and the 74194 which has a asynchronous master reset.




| A | B | R0 | R1 | R2 | R3 |
|---|---|---|---|---|---|
| L | L | H | H | H | L |
| L | H | H | H | L | H |
| H | L | H | L | H | H |
| H | H | L | H | H | H |

Fig. 12. 2 to 4 (1 of 4) decoder

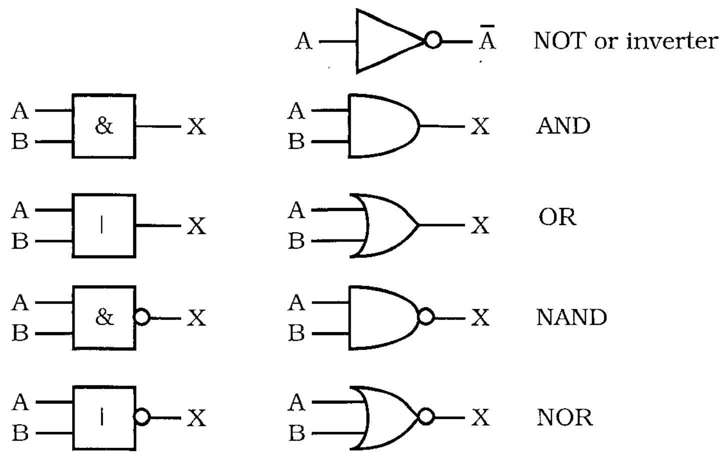



Fig. 14. Basic logic gates

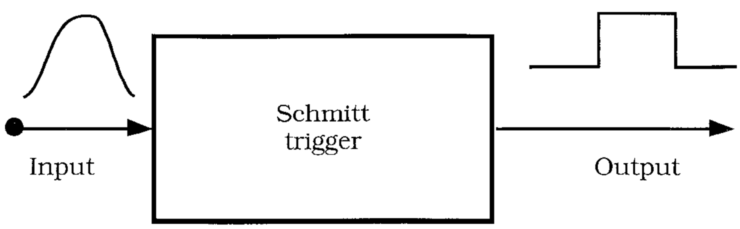



Fig. 17. Schmitt trigger

The 40105 is a First In First Out (FIFO) register that can store up to sixteen four-bit words.

## Schmitt Triggers

The quality of digital signals can be degraded by stray capacitance and inductive effects of circuits. Many digital devices require their inputs to have very short rise and fall times and may not function correctly with distorted signals.

Schmitt triggers (see Fig. 15) clean up distorted digital signals by triggering the output when the input exceeds a threshold level and then switching quickly back to its previous state when the input falls below a lower threshold.

Schmitt triggers were originally made of discrete components but are now available as functions in logic ICs. For example, the 74132 and the 4093B are quad 2-input NANDs with Schmitt triggers. The 7414 and 40106B are hex inverters.

## Timers

These are ICs which can be programmed to generate pulses at accurately timed intervals.

The standard method of timing has circuits which utilise the charge/discharge properties of series resistor/capacitor circuits. The most popular of these is the NE555 timer IC which can be wired as a monostable (single pulse generator of a given duration, sometimes called a one shot) or as a free running astable square wave generator.

Other types of timers are programmable, where a digital code is loaded into internal registers and this value is counted down to zero under the control of an accurate clock, often crystal controlled. The timer output gives a pulse or state change to show when the timed period has elapsed.

Timers are sometimes combined with counters in the same package and are thus known as counter-timers. The ZN1034E is a precision counter-timer which can generate time periods from 16ms to several days.

## TTL

Transistor–transistor logic or $T^2L$ (T squared L) is a chip fabrication method that has, until recently, been the industry standard for logic chips. The method of manufacture is cheap and reliable and devices built using this process are widely available and still quite popular. The industry standard 7400 series of logic chips were originally developed using this process but they are now being superseded by the 74LS, HC and AC ranges which offer identical functions e.g. NAND, NOR, etc. in the same packages but give improved performance with lower power consumption, higher speed, and greater fan out. PE

# RESISTANCE CALCULATOR

## S R A Stopford reveals a novel way of working out parallel resistances

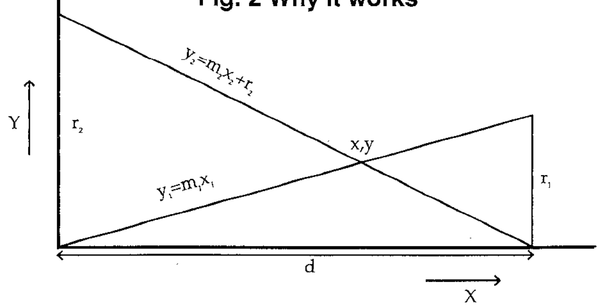
I found Joe Chamberlain's cleverly constructed tables (Jan 90 PE) for determining the value of resistors in parallel especially useful when high accuracy was required - such as for meter shunts. However, for some years I have been using a less accurate but very satisfactory home made 'calculator' which is particularly quick and easy to use and simple to make.

As can be seen in Fig. 1 the calculator consists of two cursors which can rotate around the points A and B. The values of the two resistors in parallel are set, using these cursors, on the scales R1 and R2. Their combined resistance is then read off the linear scale R. If this is not quite the value required, other combinations can quickly be tested or a third resistor added to the parallel resistance of the first two.

The calculator is easy to make since the geometry is simple. The distance AB is not critical but 12cm results in a calculator which can be held in one hand. Using graph paper, the central scale (R) is drawn so that it runs from 0 to 10 units - using 1 unit per cm. Two arcs are then drawn with a radius AB and centres at A and B giving the cardinal's hat shape. Two construction lines are then used to scale the calculator, drawn vertically up from A and B and marked with preferred values on the same scale of 1 unit per cm. The scale for R1 can then be drawn by placing a ruler on point B and each preferred value in turn, marking off the intersections with the arc. The process is repeated for the R2 scale. The outer profile is then drawn, the construction lines rubbed out and the figures over-written in ink. The graph paper can then be pasted on a piece of hardboard cut to the outer cardinal's hat profile. To protect the device when in use, a layer of clear lacquer should be sprayed on.

Holes are drilled at A and B and screws used to form the pivots for the cursors. These are made from clear stiff plastic drilled and scribed along their length. A red wax pencil rubbed into the scribed lines provides a good contrast against the scales. PE

**Fig. 2 Why it works**




**Proof**

With reference to Fig. 2.

$y_1=m_1x_1$ since the y intercept is at zero
$y_2=m_2x_2+r_2$ y intercept is $r_2$
$m_1=r_1/d$ and $m_2=-r_2/d$

Substituting the gradients gives:
$y_1=r_1x_1/d$ and $y_2=-(r_2x_2/d)+r_2$

At x,y $x=x_1=x_2$ and $y=y_1=y_2$ so
$y=r_1x/d$ and $y=-(r_2x/d)+r_2$

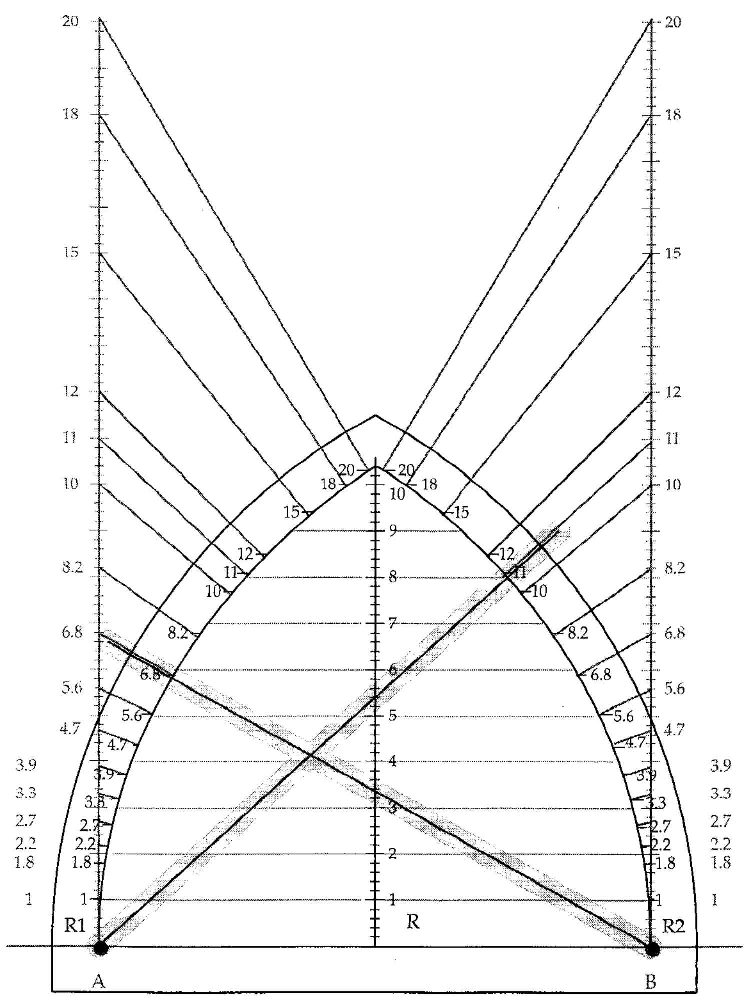
Re-arranging gives:
$x=yd/r_1$ and $y=-(r_2y/r_1)+r_2$ the d's cancelling out

Re-arranging the second of these to isolate y gives:
$y(1+r_2/r1)=r_2$ i.e. $y=r_2/(1+r_2/r_1)$
multiplying bottom and top of this by $r_1$ gives:
$y=r_2r_1/(r_2+r_1)$

The rule for working out the resistance of two resistors in parallel is:
$1/R=(1/r_1)+(1/r_2)$

which using similar manipulations as above is the same as:
$R=r_1r_2/(r_1+r_2)$
Therefore R is the same as y abovewhich is why the graphical method works.

**Fig. 1 The resistor calculator and how to construct it**



# SYNCHRONOUS LOGIC DESIGN

**Disciplined techniques are the key to successful circuits. By Tim Watson.**

The purpose of this article is to describe a formal technique for designing synchronous logic circuits. The aim is to be able to start with a specification, pencil, paper (and rubber) and to finish by soldering together some chips to form a piece of well designed synchronous logic. It will take a while to reach our goal – and it may not always seem the easiest route. However, the reward will be with an interesting and useful design technique.

## FORMAL DESIGN

Before we talk about synchronous logic, let us consider what formal design is and why it is needed. For example, ask yourself this question, "How do I solve problems?", any problem, not just circuit design. For example, find the value of A in the equation Ax6=138. Probably you will solve this using the rules of algebra, in this case dividing each side of the '=' by 6 to find that A=23. The equation has been solved using a formal method, that of applying the rules of algebra. The second method of problem solving is that of 'think of an answer'. In this method, you chew over the problem until the answer suddenly appears from nowhere. How you arrive at the answer is largely unknown as is the time to find it.

The 'think of an answer' method has a number of disadvantages. It is difficult to teach to someone else or instruct them as to how the answers are arrived at. Also, should the answer not prove to work exactly as intended, it is more difficult to trace what has gone wrong and why. With regard to logic circuit design, the more complex a circuit, the more error prone the 'think of an answer' solution becomes.

## SYNCHRONOUS LOGIC STATE MACHINES

Asynchronous logic circuits are limited to an operational speed defined by the propagational delays of the logic devices in use. Outputs change as soon as possible after the inputs arrive. Purely combinational logic circuits, those consisting of gates only with no memory elements, are asynchronous in operation and present no great design problems. After a new set of input conditions are applied the output will be valid after the worst case propagation delay. In the case of Fig. 1, if all the gates have a propagation delay of 10nS, then the worst case delay is 30nS – the path from A to Y. In reality, the propagation delays of gates are not all the same or even predictable. However, as long as the worst case is used there should be no problems.

Adding an edge triggered clocked D type flip flop to the circuit as in Fig. 2 produces something that, although it may look fine, has the makings of a disaster. If input A is low and B goes high at the same time as C goes low then the D type data input will change at about the same time the clock changes. It is difficult to know the logic level that will be clocked into the flip flop and the overall circuit operation becomes erratic. We can't simply wait for the worst case propagation delay time and expect the results to be valid. We need to consider the exact timing of the signals relative to each other. When only one flip flop is involved, this is not too bad and can be done relatively easily. As more flip flops are added, however, more possible conditions exist and the circuit soon becomes impossible to predict. Should such a circuit be built it would work unreliably, it may do partly what it was intended to do, then again it may not. The only good point about this type of circuit is that it should be fast in operation since the speed limits are imposed by the propagation delays. The bad points are that circuits such as these are difficult to design, difficult to observe in operation and thus difficult to debug.

So, how do we go about designing a logic circuit that involves memory elements? The answer is to use synchronous logic. These type of circuits have their operations timed by a master clock so that all signals are guaranteed to be valid before the data is clocked into the flip flops. The circuit's operational speed is no longer directly determined by the propagation delays, it is defined by a master clock.

A circuit with memory is known as a state machine. Its current state depends on past conditions, not just the present inputs. The state machine forms the heart of a circuit and controls the sequence of operations. A block diagram of a synchronous logic state machine is given in Fig. 3. Some of the combinational logic outputs are fed back to the data inputs of the flip flops whose outputs go back to the main logic block. The output of the master clock is connected to all of the flip flop clock inputs and controls when new data is moved into them

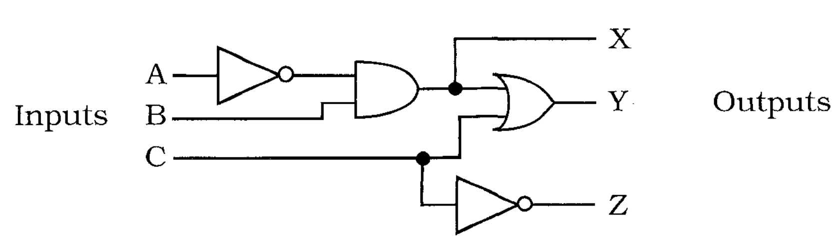



**Fig. 1. Pure combinational logic.**

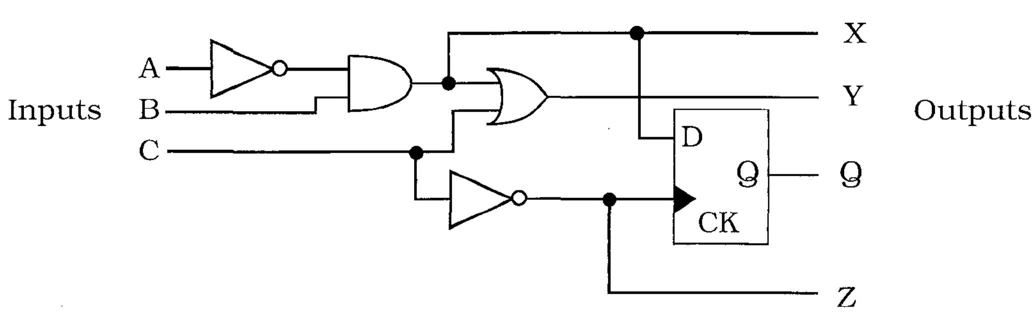



**Fig. 2. Combinational Logic with Memory.**

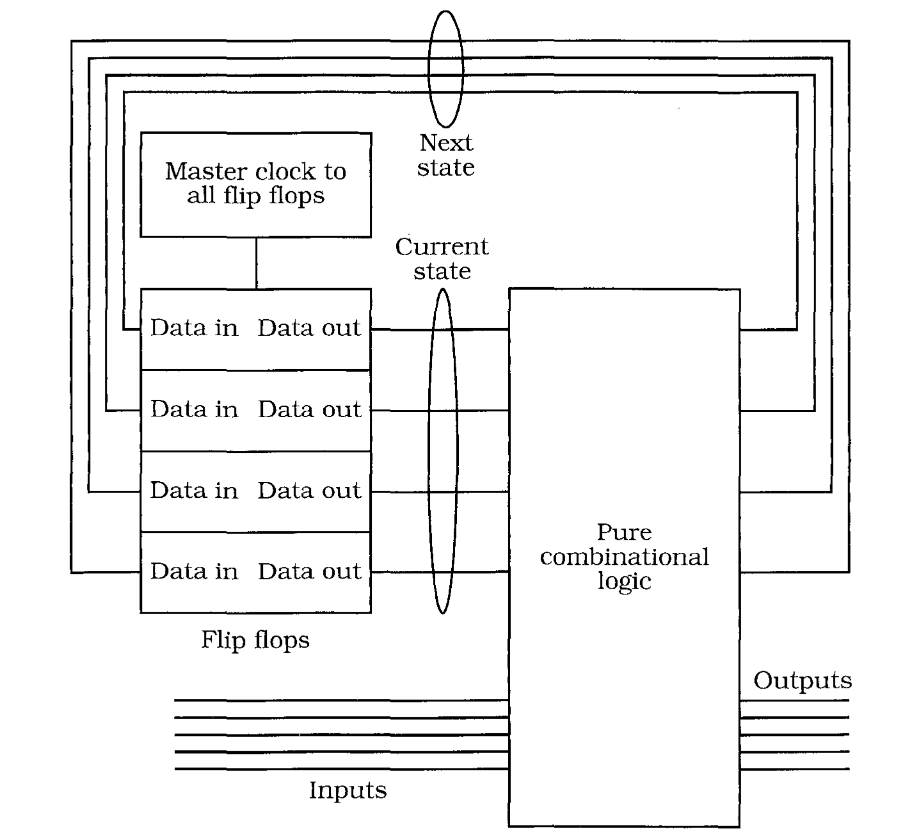



**Fig. 3. The state machine.**

making sure that all are written at the same time. The diagram is called a state machine because flip flops remember a state, the current state. At the next clock edge the circuit will advance to the next state, which is determined by the inputs of the current state. A circuit with n flip flops will have $2^n$ different states.

For the moment, ignore the exact logic function of the combinational section and treat it as a black box that has been designed and proven to work. At power up time assume that all of the flip flops are reset (to zero) and, for ease of reference, the state of the flip flops are defined as a binary word whose number of bits is determined by the number of flip flops i.e. one bit per flip flop.

For the four logic gates in Fig. 3, the current state is 0000. The combinational logic combines the current state with the inputs to produce the outputs and the next state. Assume that this is 0110. At the next clock the next state is clocked into the flip flops and becomes the current state. Now the current state is 0110 and the inputs (which may or may not have changed) are combined to produce a new next state, say 0111. At the following clock the current state becomes 0111 and a new next state will be produced and so on.

The reason why the flip flops must be edge triggered is that if the flip flops are transparent, so that the input passes straight to the output when the clock is sent high, then the data will race round and round the circuit until the clock goes low. Edge triggering moves things only at the edge of the clock signal so everything can only happen at one set time.

The maximum frequency for the master clock is determined by the worst case propagation delay in the combinational logic so the next state cannot be clocked in until it is valid. The state machine does not have to be operated at its maximum frequency, in fact when debugging a circuit it can be useful to slow the clock down to observe the system moving from state to state.

One of the most common state machines around at the moment is the microprocessor. Although these are highly complex, the basic theory is the same. There is a master clock to which all events are synchronised and the logic internal to the chip moves from state to state as determined by combinational logic and external inputs – mainly from the data bus signals. It is worth mentioning at this point that microprocessors can be used to perform the tasks of most synchronous logic circuits. However, there are times when they just aren't fast enough or are complete overkill and a synchronous logic circuit is a far better solution.

## ALOGARYTHMIC STATE MACHINES

In the previous description of a state machine, no real thought was given to the combinational logic block other than that it existed and did the right thing. Nor was any thought given to what states were needed. To sort these things out the design of the state machine must be worked out and written on paper, starting from a formal specification. The design can then be done using ASM charts, leaving the final implementation of the hardware until last.

ASM charts were developed by Hewlett-Packard and anyone who is familiar with flow charts will immediately recognize them as being very similar. There are subtle differences, however, and caution should be used since ASM charts are much more strictly defined.

A rectangular box is used to define a particular state (see Fig. 4). A box is entered from the previous state at the top and exited to the next state at the bottom. Inside the box is written a list of all the active (high or '1') outputs during this state. If there are no active outputs then the box is left empty. To the left of the box is written a description of the state and what it is for. This will help with understanding the workings of the system at a later date. A state box has a time slot and is entered under control of the master clock. At the end of the clock period, the box is exited and the process moves on to the next state.

To illustrate an ASM chart, two bit Gray code is used. This is a binary numbering system where only one bit of the code changes with each state, and was originally developed to allow logic circuits to monitor rotating objects. Fig. 5 shows the sequence for the Gray code count and forms the functional specification for the design. Positive logic conventions are assumed where the active level is a logic 1. There are no inputs required except for the clock and there are two outputs A and B. The ASM chart is very simple and is

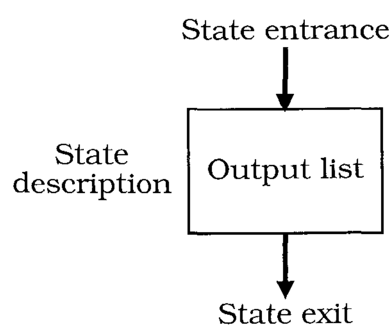



**Fig. 4. State box.**

| Count of | Gray code A | Gray code B |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 0 | 1 |
| 3 | 1 | 1 |
| 4 | 1 | 0 |

**Fig. 5. 2-bit Gray code.**

shown in Fig. 6. Consider that the current state is *count of 2* then the output will be A=0 and B=1. At the next clock edge the *count of 3* state will be entered and the output will change to A=1, B=1. When the *count of 4* state is exited the ASM chart shows that the *count of 1* state is entered. Once running the counter will continue to cycle around in the way most binary counters do. If the circuit was required to stop at *count of 4* then the ASM chart would loop back to the input of the *count of 4* box as in Fig. 7. However, the functional specification doesn't define what is to happen - slapped wrists for an incomplete specification! Another piece of information that is missing from Fig. 5 is the state that should be entered at power up.

The ASM charts in Figs. 6 and 7 are fine but a bit boring and don't seem particularly clever. Very few real life problems can be solved with such simple state machines since real life involves making decisions. To do this in a state machine, the outputs must depend on the inputs. ASM charts provide a method for organising decisions with the shape shown in Fig. 8 - the decision box. This is entered at the top from a previous state and has two exits, an active exit and an inactive exit. Inside the box is a condition which determines which of the two exits should be used. The condition is a Boolean expression and a result of 1 defines the active and 0 the inactive exit. The Gray counter can now be modified to include an input called RESTART. When this is active the state machine should move to the count of 1 state after count of 3, rather than continuing to count of 4. The modified ASM chart is shown in Fig. 9. When exiting the count of 3 state the count of 1 state will be entered if RESTART is 1 or the count of 4 state if RESTART=0.

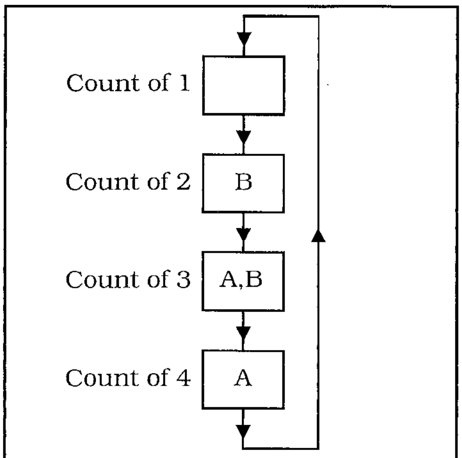



**Fig. 6. Chart for 2 bit Gray counter.**

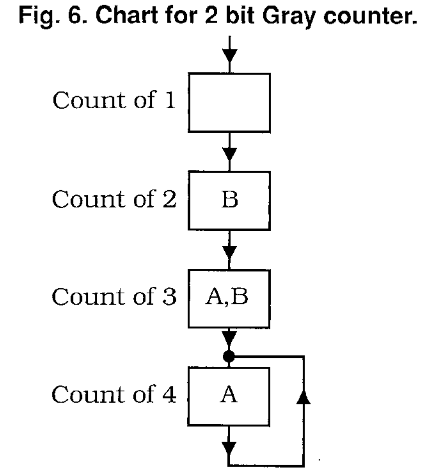



**Fig. 7. Chart for non-cycling Gray counter.**

Unlike state boxes, decision boxes do not have a time slot. They are merely passed through on the way between state boxes and because of this cannot feed back into themselves. To cause a wait, a state box must be used in conjunction with a decision box as in Fig. 11.

The final ASM chart operation is shown in Fig. 10. The conditional output box is similar to the standard decision box in that it has no time slot. It holds a list of outputs and is used in conjunction with decision boxes to alter an output as soon as the latter becomes true (or false). The ASM chart in Figs. 11 illustrates the use of a conditional output box. Starting in the wait until *Ready* state the *Ready* condition is continually evaluated. As soon as it goes to '1'. *Cont* will also go to '1' without waiting for the next clock edge. Should *Ready* go to '0' again before the next clock edge then *Cont* will also go to '0'. Assuming *Ready* remains active then the *operation continues* state will be entered at the next clock edge.

## THE TRANSITION TABLE

The next step on the way to implementing an ASM chart as a piece of hardware is the transition table. This lists what the start and output signals should be at the next clock edge, given the existing state and input signals.

Continuing with the Gray code counter and taking into account that $2^n$ states requires n flip flops, the four states shown in Fig. 6 define two flip flops for the circuit. The four state values that can be stored are represented by the flip flop outputs of 00, 01, 10, and 11. The final piece of information to add to the ASM chart is the assignment of state values to state boxes. This process is totally arbitrary, any box can be give any state value. However, the complexity of the combinational logic will be affected by the assignment. The value assigned to a state is written on the top right of the state box. Figs. 12 and 14 show two perfectly valid assignments for the Gray code counter. Fig. 12 is used since it will reduce the complexity of the combinational logic, a fact divined from hindsight.

The final consideration of most state machines is what happens on power up. Since most flip flops have a reset input it is easy to ensure that the state value of all zeros if entered at power up so this is the value assigned to the state to be used at power up.

The transition table for the Gray code counter is shown in Fig. 13. The order of the rows is totally arbitrary; in Fig. 13 they have been ordered so that the current state increases the normal binary counting sequence. The advantage of this is that it is more difficult to miss a state from the table and that unused states are included. The far left column shows the current state; the bits of

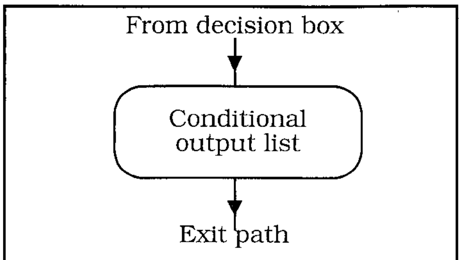



**Fig. 10. Conditional output box**

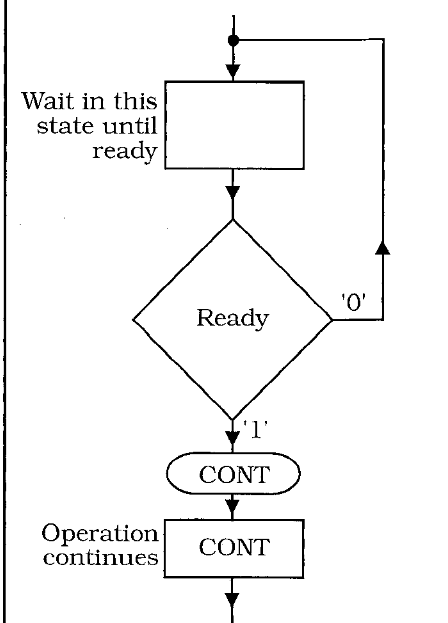



**Fig. 11. Combining elements**

the state value have been called S0 and S1. The next column shows inputs to the combinational logic of which there are none in this example. The next column shows the next state, given the current state and inputs shown in that particular row. The value to enter in the next state column is easily determined from the ASM chart. After the next state column comes the transition column. This shows how the state bits must change in order to move from the current state to the next state. The values listed in this column are not logic levels. A 0 means the state bit stays at logic '0' and a 1 means that the state bit stays at logic '1'. An $\alpha$ means that the state bit makes a transition from '0' to '1' and a $\beta$ means a transition from '1' to '0'. After the transition column come the combinational logic outputs, in this example A and B. The values for the outputs are taken from the ASM chart state boxes, the appropriate box being picked according to the current state listed in the particular row.

A brief mention was made earlier about unused states. Consider an ASM chart with six states. To implement it would require a minimum of three flip flops. These will produce eight possible states, however, leaving two unused. Normally it would be possible to ignore these, but if the circuit accidentally jumps into one of them it could cause the whole thing to hang up. It is good practice, therefore, to put them into the transition table with their next states being that at power up. In a worst case of corruption, all that can happen to the circuit is that it resets itself.

The next step is to produce a transition table that involves decisions and inputs. A convenient example is the Gray code counter shown in Fig. 9. Firstly assign state values as in Fig. 14, the state values having been assigned to the states as for the normal grey code counter. Because of this the transition table is similar to that shown in Fig. 13, the only difference being in the row for the current state of S0=1, S1=1, count of 3. The next state after count of 3 depends on the restart input. The new transition table is shown in Fig. 15. In the input column, X's have been used to indicate that it doesn't matter whether the signal is '1' or '0' (don't care). From the ASM chart in Fig. 14 it can be seen that for the current states of *count of 1*, *count of 2* and *count of 4*, the next state is not dependent on the *Restart* input, so the transition table X's have been entered in the inputs column for these rows. The current state *count of 3* now appears twice in the table, once when *Restart* is '0' and once when it is '1'. As can be seen from the ASM chart, when *Restart* is '0' the next state after *count of 3* is *count of 4*, as is the case of the normal Gray code counter. This is entered in the next state column and the transition is the same as before. When *Restart* is '1' the next state after *count of 3* is *count of 1*. So, in the next state column the *count of 1* state has been entered instead of *count of 4* and the transitions go from *count of 3* to *count of 1* are shown. The output column remains unchanged by any of this.

Now that a transition table which represents the state machine has been defined, the hardware design can be started.

| Current state S1 S0 | Inputs None | Next state S1 S0 | Transition S1 S0 | Outputs A B |
|---|---|---|---|---|
| 0 0 | - | 0 1 | 0 α | 0 0 |
| 0 1 | - | 1 1 | α 1 | 0 1 |
| 1 0 | - | 0 0 | β 0 | 1 0 |
| 1 1 | - | 1 0 | 1 β | 1 1 |

**Fig. 13. Gray code counter transition table.**

| Current state S1 S0 | Inputs Restart | Next state S1 S0 | Transition S1 S0 | Outputs A B |
|---|---|---|---|---|
| 0 0 | X | 0 1 | 0 α | 0 0 |
| 0 1 | X | 1 1 | α 1 | 0 1 |
| 1 0 | X | 0 0 | β 0 | 1 0 |
| 1 1 | 0 | 1 0 | 1 β | 1 1 |
| 1 1 | 1 | 0 0 | β β | 1 1 |

**Fig. 15. Restarting Gray code counter transitions.**

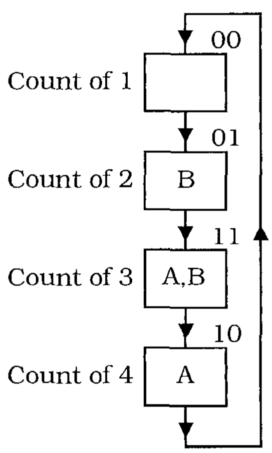



**Fig. 12. State assignments.**

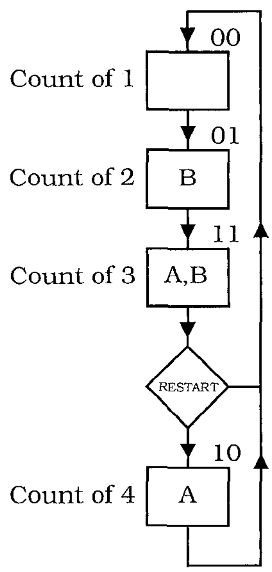



**Fig. 14. Restarting states.**

## HARDWARE IMPLEMENTATION

Designing the hardware mainly involves determining the combinational logic that will cause the transitions as listed in the transition table. The method used is to draw Karnaugh maps for the combinational logic outputs given the current state and inputs.

Fig. 16 shows the state machine for a two bit Gray code counter. The combinational logic has two inputs S0 and S1 (the current state) and four outputs, the counter output A and B and the two outputs connected to the D type data inputs Ds0 and Ds1. Four Karnaugh maps must therefore be created from the transition table, one for each output. These maps are shown in Figs. 17 to 20. The data for Ds0 is taken from the transition S0 column and similarly for Ds1. The data for A is taken from the output A column, similarly for B. Fortunately, the outputs A and B turn out to be identical to the current state. This good fortune came from the way in which the states values were assigned, a touch of the 'think of an answer' methodology. Only two outputs are now required, Ds0 and Ds1.

The values in the Karnaugh maps are not logic levels but transitions. The question is, what value should be clocked into the flip flop to cause the correct output? The answer depends on the type of flip flop and with D-types the values shown in Fig. 21 are used. To produce the Karnaugh maps for the D-type inputs the transitions in the Karnaugh maps of Figs. 17 and 18 are substituted into the table of Fig. 21 to give the Karnaugh maps in Fig. 22 providing expressions for the D inputs. Now the circuit can be drawn using a 4013 dual D-type positive edge flip flop CMOS logic chip with inverted outputs. The complete circuit is shown in Fig. 25 and a de-bounced push switch is used to generate the master clock. This is based around the 4093 Schmitt trigger NAND gate. The set and reset inputs of the 4013 have been tied 0 volts meaning that the power up state of the circuit is unknown. It would be possible to modify the circuit so that at power up it enters the *count of 1* state by pulsing both reset inputs to '1' at power up. The circuit is advanced to the next state by pressing the switch. This makes it easy to observe what is happening in the circuit since it can be stepped along at human speeds.

At this point it may seem that the amount of effort involved in the design of such a simple circuit suggests that ASM charts are a waste of time. However, it should be borne in mind that as familiarity with the method

| Transition | D type input |
|---|---|
| 0 | 0 |
| α | 1 |
| 1 | 1 |
| β | 0 |

**Fig. 21. D-type conversion table.**

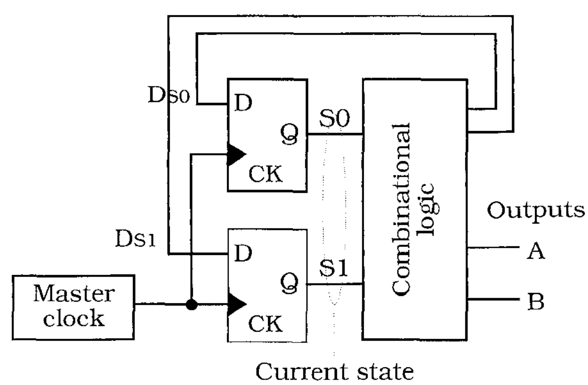



**Fig. 16. State machine for Gray code counter.**

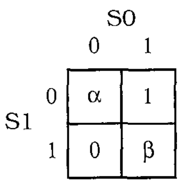



Fig. 17. Karnaugh map for Ds0.

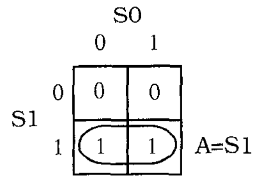



Fig. 19. Karnaugh map for A.


Fig. 22. Karnaugh maps for Ds0 and Ds1

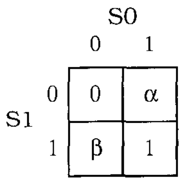



Fig. 18. Karnaugh map for Ds1

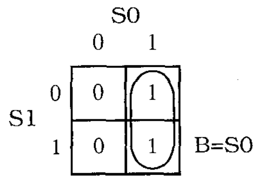



Fig. 20. Karnaugh map for B

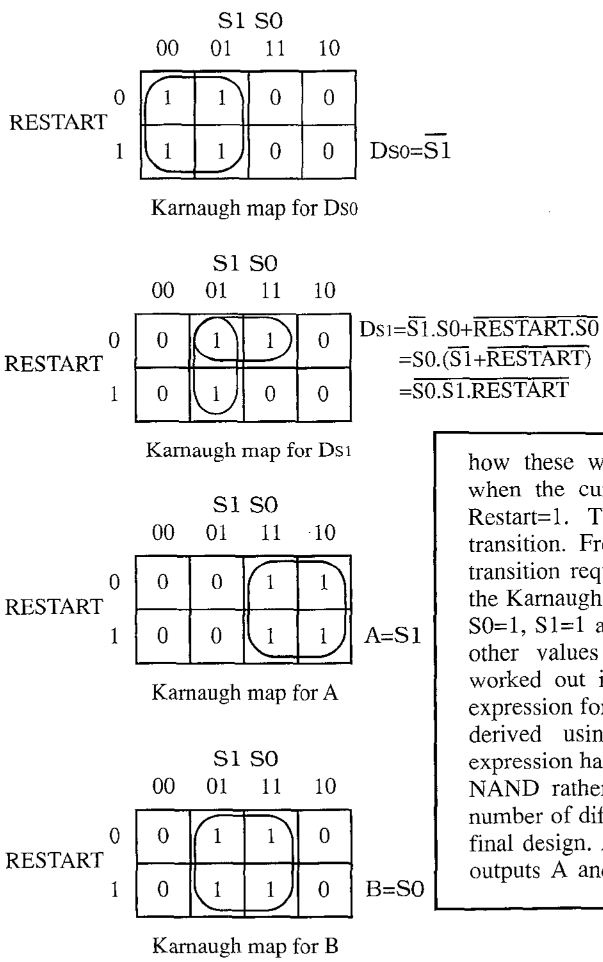



Fig. 23. Restarting Karnaugh maps

grows it becomes faster and a lot easier to use. In addition, the returns are better with more complex circuits.

The final implementation of a restarting Gray code counter requires the transition table in Fig. 15. Remembering the table in Fig. 21 showing the D type input levels for all possible output transitions, the Karnaugh maps for the counter can be written as in Fig. 23. As an example of how these will be used, consider the case when the current state is S0=1, S1=1 and Restart=1. The transition for S1 is a β transition. From the table in Fig. 21 the β transition requires an input of '0', hence for the Karnaugh map for Ds1 with the condition S0=1, S1=1 and Restart=1 we write a 0. The other values for the Karnaugh maps are worked out in the same way and the final expression for Ds1 shown in Fig. 23 has been derived using Boolean logic rules. The expression has been worked into a form using NAND rather than OR gates to reduce the number of different types of chips used in the final design. As in the previous example, the outputs A and B are the same as S1 and S0 respectively.

The circuit diagram is shown in Fig. 26. The Restart signal is generated using an SPST switch such that when the switch is closed, Restart is '1' and the counter will restart at *count of 1* after the *count of 3* state, as per the original specification.

## GENERAL STATE MACHINES

All that remains is a couple of important points about state machines in general. There is no reason why the master clock should be run at full speed. If a slower speed makes timing easier then this should be used. The minimum allowable clock frequency can be worked out by specifying the maximum time that can be allowed for the worst case path through the state machine. This is done simply by counting the number of state boxes passed through and dividing the specified maximum time by this value to give the clock period.

When designing state machines do not ignore ready made modules such as counters, shift registers and so on, as these can all be incorporated into a design to save time and money. Finally, for those who are really keen, it should be noted that several state machines can be run in parallel to provide more processing (parallel processing) power.

PE

For more information see Designing Logic Systems using State Machines by C. Clare. McGraw-Hill, New York, 1973.

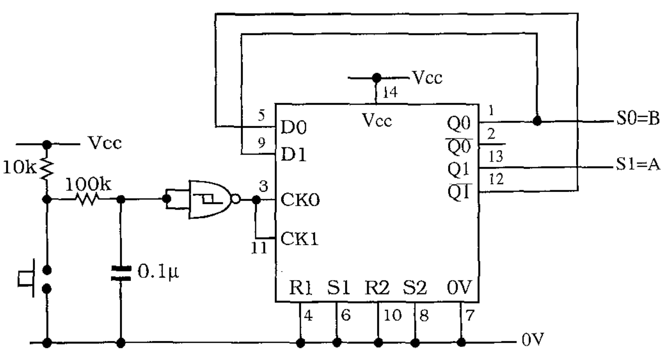



Fig. 24. Two bit Gray code counter.

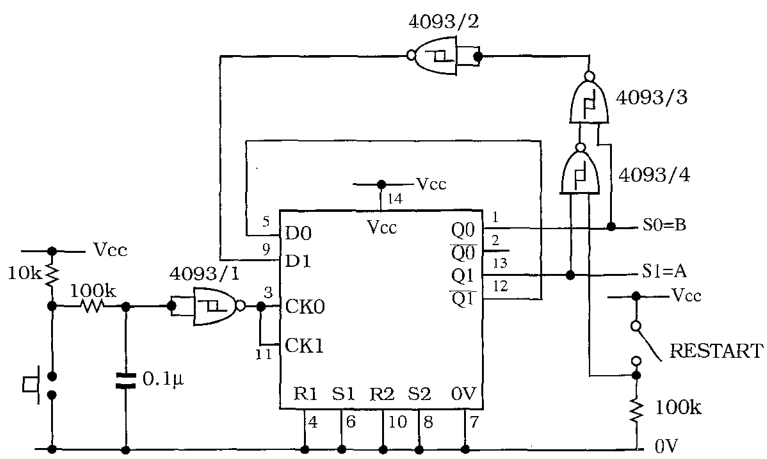



Fig. 25. Restarting Gray code counter.

# A COMPUTER CONTROLLED SERIAL MULTIPLEXER

**A soft solution to a hardware problem. Sort out your computer connections thanks to Ron Goudling of Heriot-Watt University**

It is quite common these days to have a number of computers connected to the single serial input of a printer. Switching between machines is usually performed by means of a manual switch on a switching box. Another way of looking at this would be to use the switching box to connect one computer to a number of other serial devices, say a modem, a printer and even other computers. The drawback with this is the use of a manual switch to divert the data flow from place to place. The obvious improvement to the scheme is to use an output from the computer to operate an electronic switch to send the data to the appropriate destination.

Practical details are given here mainly for the BBC Micro, allowing it to communicate with several peripheral devices or other computers in an intelligent manner. The software on the central computer may switch in peripherals periodically and then send, or receive data, perhaps transferring it to and from its local disc drive with or without processing. The system now becomes a slow network which is ideal for many activities that proceed over a long period of time. It is important to realise that slow as well as fast processes are amenable to, and enhanced by, computerisation. The practical version of the MUX-system employs a BBC Micro as the central controller and the multiplexer box in place of the switch in Fig. 1.

The user port, port B of the 6522 VIA chip at base address &FE60 (the '&' symbol is used to denote hexadecimal numbers on computers running BBC Basic) or &FCB0 for the expanded Electron, provides the control functions. Refs. 1 gives hardware details for the range of Acorn 6502-based machines.

## COMMUNICATIONS

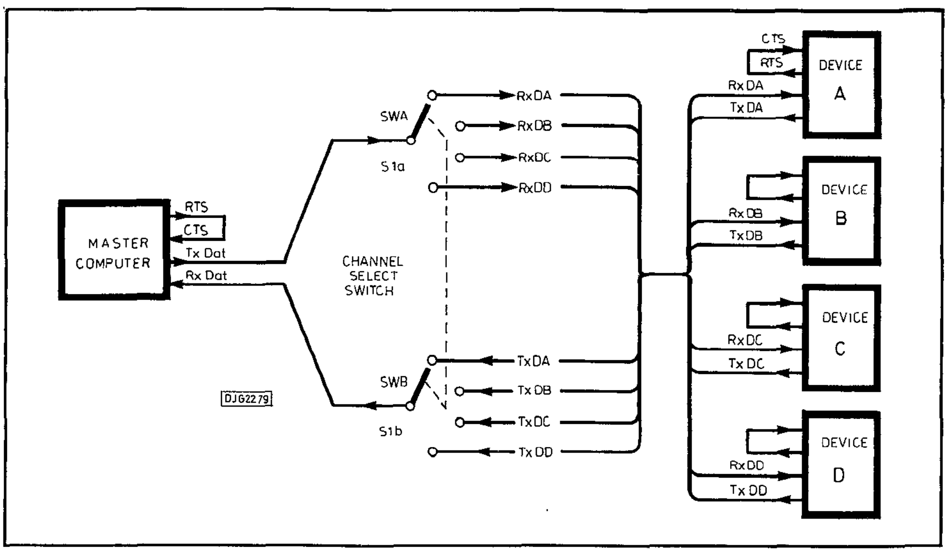
The general principle of operation is that once a device is connected, communication proceeds until messages are complete, leaving the system available for other devices. To minimise the number of lines that have to be switched, it is convenient to 'loop back' RTS to CTS locally. Many serial devices do not use handshake lines, or use the software xon/xoff (Ctrl+Q, Ctrl+S) protocol to stop and start data transmissions.

Fig. 2 gives the circuit diagram and wiring details for a four-way switching system. Two of the VIA data lines (PB0, PB1) are used to select the transmit station and two more (PB4, PB5) the receive station. This situation corresponds to Fig. 1 except for the additional possibility of being able to receive from one station and send to another at the same time. The actual multiplexing is performed by a dual four-way demultiplexer (LS153, receive) and a dual four-way multiplexer (LS139, send). Since both chips have a dual configuration, both the data and the handshake lines will be switched in unison. It should be noted that the two halves of this TTL-version of the switch are definitely unidirectional since the LS153 and LS139 are themselves unidirectional, as they have input and output terminals. Therefore, the electronic version does, in fact, differ from a simple mechanical four-way switch.

The PCB for a four-way MUX is shown in Figs. 3 and 4. To aid the initial setting-up and subsequent monitoring of its functioning, both address and serial data lines are monitored by LEDs. This circuitry results in a lot of cross-wiring regardless of any arrangement tried for the six chips on the board.

A double-sided PCB was avoided mainly because of the cost, although the final design does involve quite a few link wires including some under the chips. This is not a problem as long as they are not forgotten until the chips/sockets are soldered in, and suitable sockets are chosen (no bare 'platework' underneath). Having the tracks wholly accessible on a single-sided PCB is a definite advantage if servicing is needed. Employing the widest tracks possible minimises track lifting if (or when!) desoldering is required. However, inter-track shorting caused by whisker-formation on aging can still be a problem – unfortunately the green 'varnish' used on commercial PCBs is not generally available outside the trade.

**Fig. 1 Mechanical serial MUX**




## CONSTRUCTION

First all wire links (bare tinned copper wire produced by stripping PVC-coated 1/0.6 mm wire, for example) are inserted, followed by the DIL sockets. Resistors, capacitors, diodes and transistors are then soldered in. The decoupling capacitors should have 0.2 inch pitch leads and be of very small physical size. Electrolytics are of the tantalum bead type. Be sure to check the polarity for the electrolytics, diodes and LEDs.

Next, the three 10-pin PCB headers are soldered in plus two 1mm Veropins (optional). For off-board connections, ribbon-cable (Figs. 5e/f) is used. The end furthest from the Insulation Displacement Connector (IDC) is spread out and the individual wires soldered to the D25 connector following the wiring schedule of Fig. 2. The 'remote' lead is more complex (and starts with a greater length) since three of the separated ribbon wires are connected to the 5-pin DIN socket (power connector). Finally a separate wire link must be made from the DIN pin 3 to the D25 pin 7 (system ground). Note that the DINs and D25s carry the number of each pin on their plastic moldings, which helps to avoid wiring errors. Alternatively you can use direct wire links, however, the header-method gives uniformity between units, especially if several are put to use on one site.

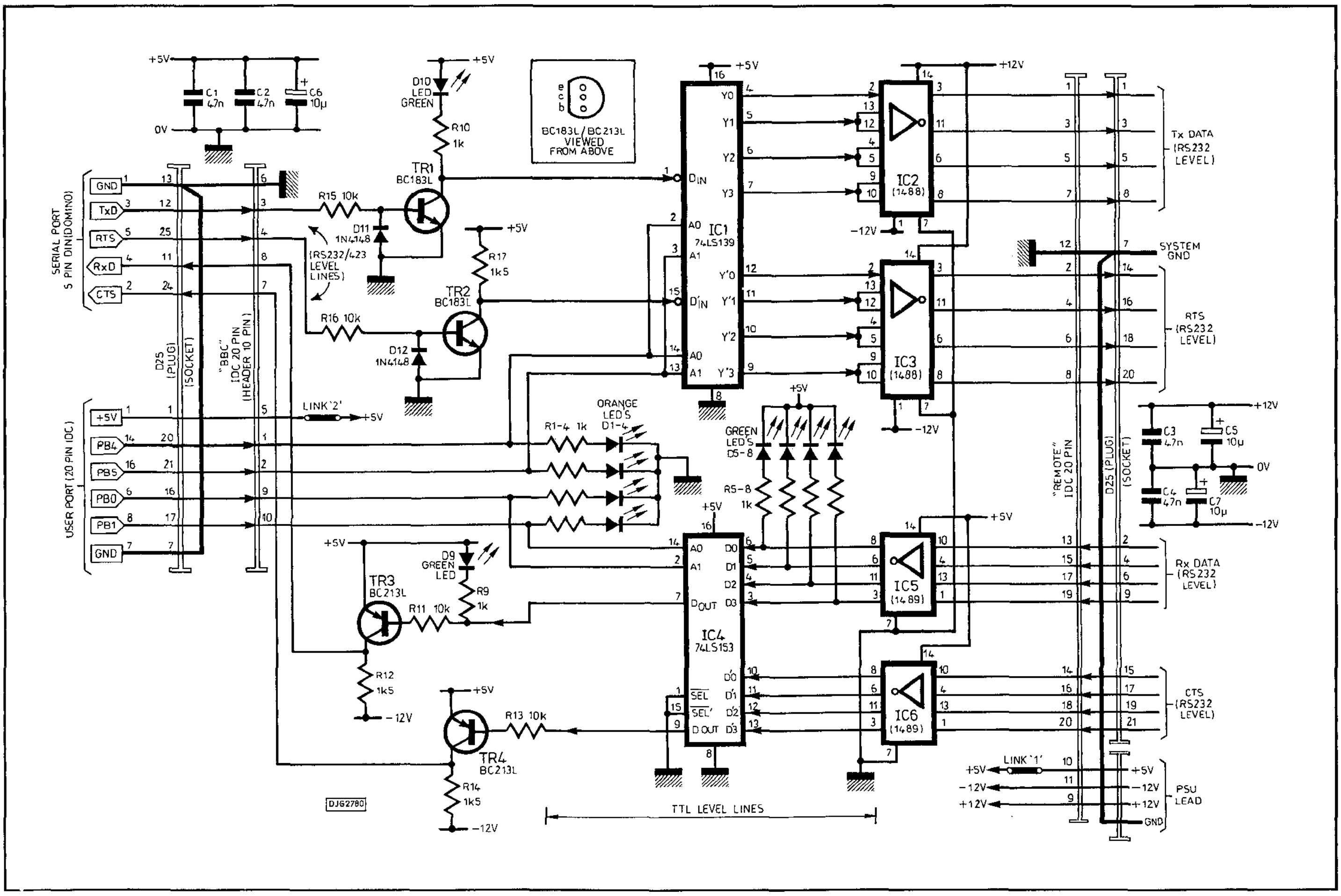



**Fig. 2 Circuit diagram – make one link only out of links 1 and 2.**

After completing the soldering, it is a good idea to remove all flux residues. For this job a small amount of methylated spirits, isopropanol or chlorinated solvent, is scrubbed on with an old toothbrush and finally cleaned with some cotton rag.

Finally the chips are inserted and after making all conceivable checks the unit is ready for a power-on test. A continuity tester that does not turn on PN-junctions is essential for tests made in the presence of chips or transistors. The two Veropins are to allow a logic probe to be connected to the board. Make up a lead to connect to a suitable power supply; use a PCB socket or solder to the under side of the PCB to the relevant pins of the 20-way header. Power-up the unit and quickly test for over-heating ICs (finger test) and then for the correct rail voltages. In case of trouble switch off quickly and double-check the construction. Ideally, a current-limiting power supply should be used during testing.

## SETTING UP

Most of the setting up can be done away from the computer. Deal with the transmit (TXD, RTS) sections first. Arrange switches to apply logic 0/1 as required to PB0/PB1, TXD and RTS inputs and monitor the four peripheral TXD outputs with a logic probe or meter. Fig. 5(a-d) shows the type of input and output test circuits to employ. The output of the selected channel should follow the applied serial logic level whereas other channels should be held permanently low. The on-board green TX LED should glow whenever data is present at the common input.

Repeat the process for the receive side. Apply the logic probe to the common rxd/CTS and show that only the selected (by PB4/PB5) peripheral rxd/CTS input will affect the common output. The on-board green LEDs will also be active as follows: each of the four LEDs that monitor the peripheral inputs will light up whenever any data is received on the particular input. The fifth rx LED only lights when a channel is selected, and receiving data. The two pairs of orange LEDs show the rx and TX channel selected in two-bit binary format.

## PLATFORM ADAPTATION

When all tests are completed successfully the temporary connections are removed, the permanent IDC-D25 cabling installed and the unit is fitted into a suitable case. If this construction and testing sequence is followed and all cabling is made up without wiring errors, the MUX should work first time with the BBC or other computer. The initial link should be one machine (a) connected to the common D25, labelled 'BBC' on the PCB, and another (b) attached to the 'remote' D25 connection. RTS/CTS should be looped-back locally at each machine.

For a BBC Micro/Master, type in ?&FE62=&FF <CR> (make port B 'output'), ?&FE60=0 <cr> (all outputs off), on the controller (a), followed by *FX8,3 <cr> (transmit speed to 300 bits per sec (BPS)), *FX3,5 <cr> (send output to the serial port). Type in *FX7,3 <CR> (receive speed to 300 BPS) *FX2,1 <cr> (input from the serial port rather than the keyboard), on the peripheral machine (b). Now characters typed on (a) will be 'echoed' (appear on the screen) of (b). Repeat for the reverse direction – press <break> on each machine and type ?&FE62=&FF <cr> ?&FE60=0 <cr> *FX7,3 <cr> *FX2,1 <cr> on (a), *FX8,3 <cr> *FX3,5 <cr> on (b). At this stage it is a good idea to read chapter 38 of the Model B User Guide (the serial port) or any advanced user guide you may have. For non-Acorn machines the manuals will have to be consulted for how to access the serial and user ports. The methods required are well documented for the Microsoft-80 Basic supplied with CP/M and IBM-PC compatible machines. BBC Basic language systems are available for the IBM-PC compatibles, Atari ST, Amiga, and Mac machines and these have good documentation of the commands required to operate the serial port.

## CONNECTIONS

Connection to the BBC (serial and user ports) is through a single D25-connector (Fig.6). All of the bi-directional peripheral lines (each two conductors plus screen) are brought into a second D25. The multiplexer

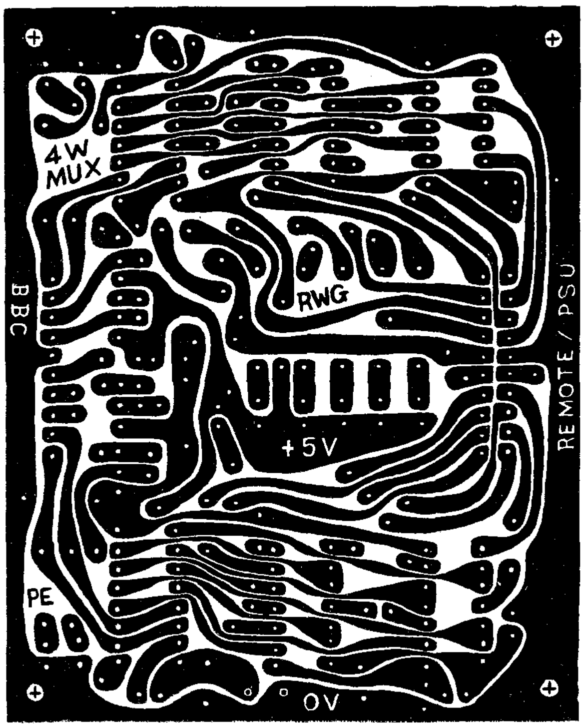



Fig. 3 PCB copper tracks.

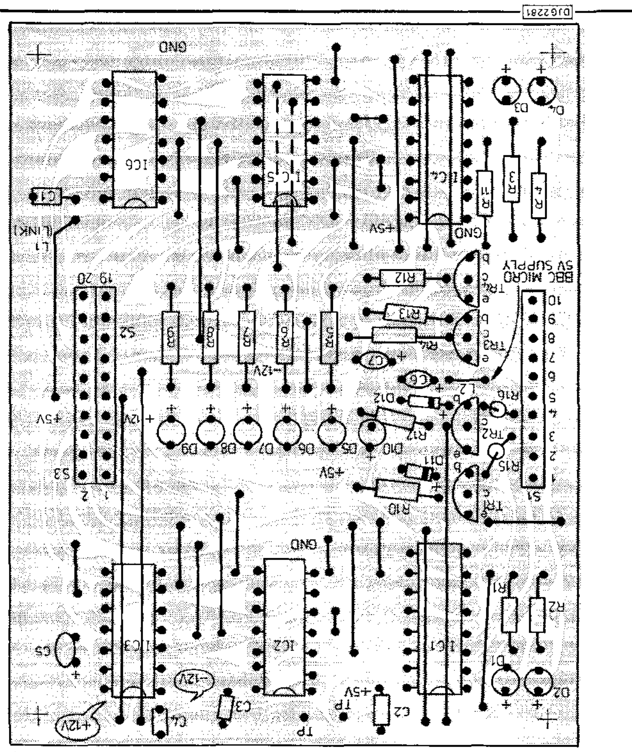



Fig. 4 PCB components

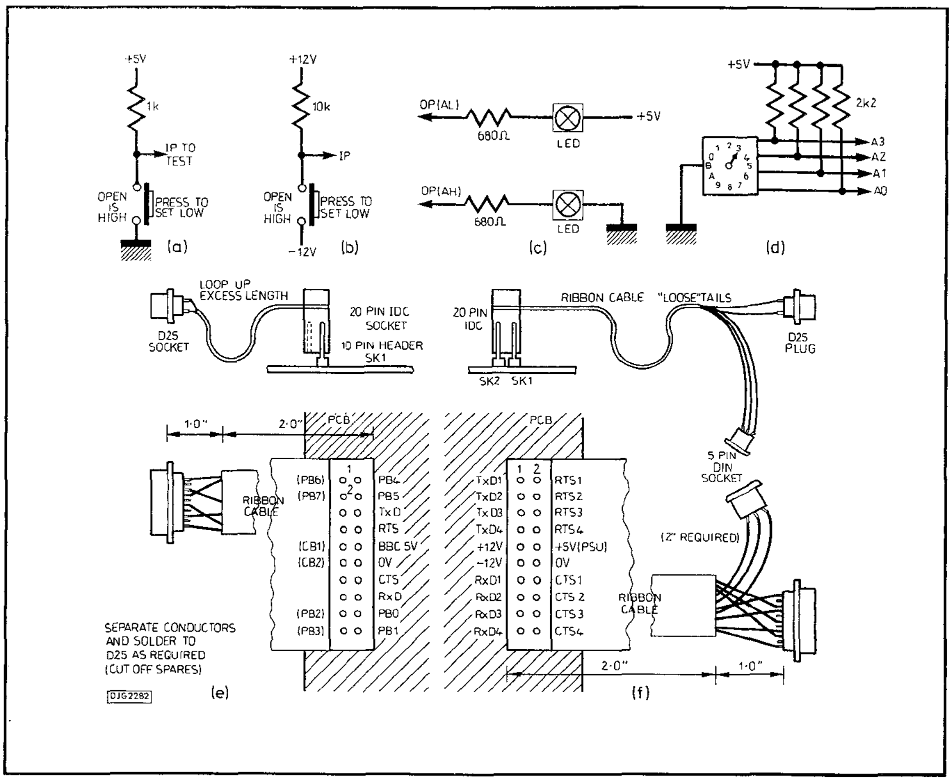
could be powered from the BBC micro, but a DC-DC invertor chip would be required to produce the −12V supply. A better solution is to use a small +5V, ±12V PSU. The PCB has two links (L1 and L2) allowing selection of either the BBC +5V supply (L2) from the user port lead, or the PSU +5V supply (L1). Whatever you do DO NOT insert both links. The unused pins in the peripheral D25 are a deliberate feature.

This MUX hardware will also work satisfactorily with an expanded Acorn Electron with Plus 3 (Acorn original or PRES re-work), Acorn or PRES Plus 1 and the Andyk serial cartridge (ref. 2). The MUX can be controlled either from the printer port (a simple write to address &FC71) or alternatively from the user port of a VIA expansion cartridge (Project Expansions, a 6821 PIA at base address &FCB0). Please note that certain combinations of hardware listed above are incompatible since a Plus 1 only has two cartridge connectors.

The Master Compact needs two additional items of hardware, the serial port upgrade (two chips) and the 'Companion' that contains, amongst other items, the missing full-spec user port (refs 1, 2b). The Archimedes has the serial port, but requires a 'podule' card to gain the user port. It is possible that readers of PE would probably prefer the Apec prototyping card (ref 2c). CP/M machines have serial and printer ports as standard and sometimes a parallel port (e.g. the RML 480Z/Nimbus series often found in Education). The IBM-PC standard is equipped with very similar I/O arrangements. PE discussed peripheral cards for the PC in April 1990.

A BBC format disc is available for £5 from the author. It contains long listings not suitable for incorporation into the text. Please state machine, filing system and disc drive details (and your address!). Write to Dept Building, BBC Software Offer, Heriot-Watt University, Riccarton, Edinburgh, EH14 4AS.

Fig. 5 Test circuits and permanent connections to the PCB.




## REFERENCES

1 BBC New Advanced User Guide (BBC), Adder, 1988

1a The Master Advanced Reference Manual, Watford Electronics, 1989

1b Electron Advanced User Guide, Adder, 1985. (Also useful for BBC Micro owners).

2a Electron serial Card and manual from Andyk (possibly no longer available). Electron user port card from Project Expansions, Electron New Plus 3 disc interface, PRES Ltd, Lightwater, GU19 5PW. BBC/Electron 6502 second processor bare PCB, Jafa systems, Caerphilly.

2b Master Compact 'Companion', Mertec, Swansea, SA1 3QN

2c 'Apec' Archimedes prototyping card, Atomwide, Orpington, Kent.

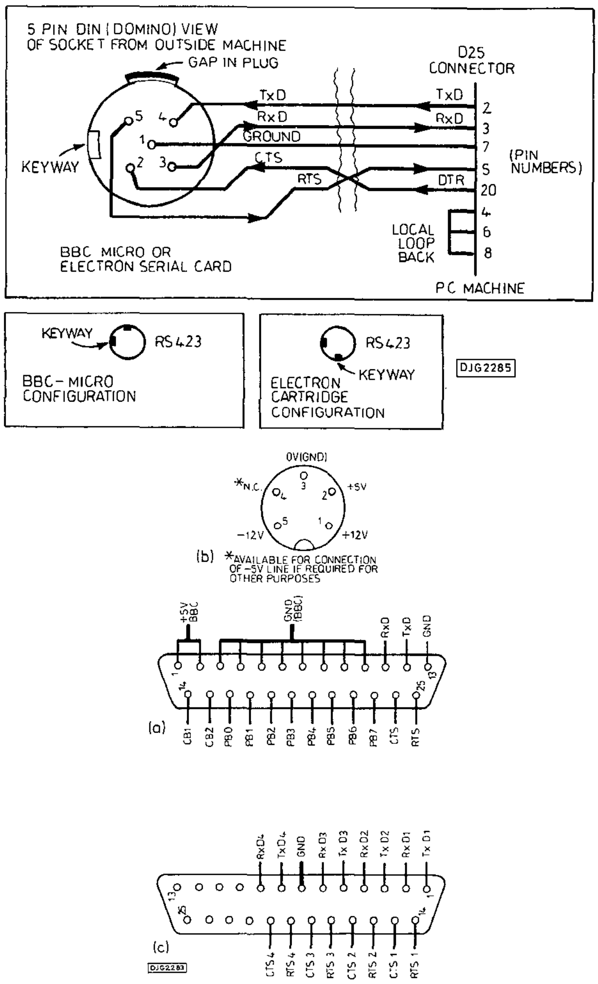



**Fig. 6. D25 connectors and keyways.**

## COMPONENTS

### RESISTORS

R1-R10 1k (10 off)
R11, R13, R15, R16 10k
R12, R14, R1 1k5
All resistors 0.1W 5%

### CAPACITORS

C1-C4 47n see text
C5-C7 10μ 16V tantalum bead

### SEMICONDUCTORS

| | |
|---|---|
| D1-D4 | orange micro-LED (2mA, 3mm) |
| D5-D10 | green micro-LED (2mA, 3mm) |
| D11, D12 | 1N4148 |
| TR1, TR2 | BC183L or similar |
| TR3, TR4 | BC213L or similar |
| IC1 | 74LS139 |
| IC2, IC3 | 1488 (or 75188) |
| IC4 | 74LS153 |
| IC5, IC6 | 1489 (or 75189) |

### SOCKETS

14-pin DIL 4 off
16-pin DIL 2 off
10-pin PCB header (e.g. RS 467 - 582) 3 off
10-pin PCB socket (e.g. RS 467 - 677. Optional for testing unit) (2 off
D25 socket-solder type 2 off
D25 plug-solder type 2 off
20-pin IDC socket 3 off
5-pin, 270 degree DIN plug and socket
5-pin domino DIN plug (one per BBC micro/expanded Electron to be used)

### MISCELLANEOUS

1mm Vero-pins (optional) 2 off
Metal or ABS box to suit
20way ribbon cable 2 metres
4-way screened cable 7/0.2 mm as required for serial links
6BA nuts, bolts & washers as required to fix connectors, etc.

## SERIAL COMMUNICATION

One of the standard ways to connect one computer to another, or to printers or to other reasonably intelligent devices, is to use a serial link. This takes the parallel data used by the computer, normally eight bits wide, and converts it into a form that can be sent down a single wire. Each of the bits in the data byte is sent one after the other as pulses which are picked up by the receiving machine and converted back into parallel format. The protocols used in the RS232 and similar standards involve a number of parameters which have to be the same for both the transmitting and receiving machines to communicate.

Start bits – used to tell the receiver that the following bits are data. In most cases there is only one of these.

Data bits – normally eight but seven are sometimes used.

Stop bits – tell the receiver that the data is at an end. There can be one, one and a half or two depending on the system. With an eight bit system there is usually only one.

Parity – used for simple error checking. The number of '1' bits in the data is counted and if even parity is being used, the parity bit is set (to '1') or cleared (to '0') to make the total number of '1' bits (including the parity) even. For example, 10110011 has an odd number of bits so even parity would cause the parity bit to be '1', odd parity would make it '0'. At the receiving end, a parity check will reveal any errors in the transmission and the data can be sent again.

Transmit and receive speed – usually defined in bits per second (bps), the standard speeds range from 50 through 300 and 1200 to 9600. The transmit and receive speeds can be different as in the 1200/75 (receive/transmit) used in Viewdata systems.

In practice the RS232 standard doesn't actually specify any of the above protocols, it is really only used to define the physical connection, i.e. the wires and voltages. Normally these are 25 way D type plugs and sockets with up to 20 connections. Unfortunately, non–standard plugs and wiring are quite common. For example the BBC micro uses a five pin domino DIN with five wires. The minimum connection is actually three wires, transmit, receive and ground. The other two are used for handshaking and are called RTS for Request To Send and CTS for Clear To Send. The first signals to the transmitting machine that data is ready to be sent and a reply comes over the CTS line to get things underway. The voltage level used on these lines is specified in the standard as being from ±3V to ±12V with the -ve voltage representing a '1' bit and the +ve voltage a '0'. By loping back the RTS line to the CTS line at each end of the connection, each machine can tell itself to send and receive and hence cut down the number of wires needed between the machines. However, since the data is usually placed into a buffer in the receiving computer and the buffer has a finite size, some form of handshaking is still required. The Xon, Xoff method uses the ASCII character numbers 19 and 17 (control S and Q respectively) to stop and start the transmissions – on some machines this also works with the keyboard and screen in that Ctrl+S will stop the print out and Ctrl+Q will start it again.

When connecting two computers up the transmit, receive, RTS and CTS line must all be crossed. For the first two it is obvious that connecting the transmit wire on one machine to the transmit wire on the other would cause problems. To make the handshaking work properly, the RTS of one machine is connected to the CTS of the other and vice versa so that inputs go to outputs.

Unfortunately, there are times when this crossing over is not necessary i.e. when connecting up to a modem which may already have its wires crossed or when using a cabnle which has built in crossovers. When setting up a communications system, always check in the manuals of the machines and cables to make sure things are the right way around.

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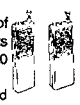

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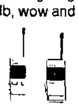

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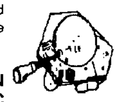

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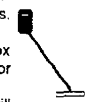

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# OPTICAL FIBRES TECHNOLOGY

**Mike Saunders describes how messages can be sent across the Altantic with some semiconductors and a piece of glass**

Compared to lasers, which zap us from every science fiction cinema screen, the average person gets very little exposure to optical fibre technology. Yet they form a multi-million pound business since they are replacing copper cables in underground communications networks in almost every country of the world.

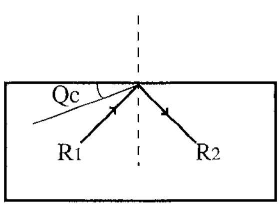
There are many reasons for this change:

- Optical fibres provide a much larger bandwidth.
- They are immune to electrical noise and corrosion.
- They are much cheaper since they do not depend on the world prices of copper.
- Optical fibres are thinner and therefore occupy less space.

The large bandwidth comes from the fact that light waves have a high frequency and hence can be modulated at relatively high speeds. The saving in underground space is a big bonus since cities usually have a heavy demand for underground services like sewers, trains, gas, electricity and water.

## PROPAGATION

Optical fibres are made from pure glass and light propagating down them will therefore obey the laws of refraction and reflection. With reference to Fig.1, a ray of light within the fibre striking the edge will either escape to the outside or be reflected back in. Whether it escapes or not depends on the angle at which the ray strikes the edge. Above a critical angle the light is reflected back into the fibre.




$R_1$ incident ray
$R_2$ reflected ray
Qc critical angle

**Fig. 1. Reflection without cladding.**

The critical angle can be made smaller if the fibre is covered with a coating of glass with a lower refractive index – around 1.5% less. This will cause most of the energy to remain within the fibre as shown in Fig.2 since the rays striking the edge do so at a shallower angle.

## FIBRE TYPES

There are three types of fibre in existence, multimode, graded index and monomode (Fig. 3). In the multimode fibre the core is about 50 µm in diameter and the rays of light are reflected off the boundary between core and cladding, hence the term multimode propagation.

In the graded index fibre, the refractive index changes gradually between core and cladding. By altering the type and amount of impurities in the glass (known as doping), there is a gradual change from core to cladding instead of a defined step.

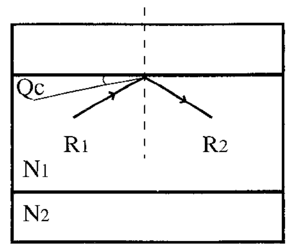
Compared to the 50µm core of a multimode fibre, the monomode fibre has a core of about 6µm. The small core means that manufacturing tolerances have to be good enough to make the core concentric with the cladding. If the tolerance is poor then when the fibre is joined to another, the cores will not line up and power will be lost. An additional problem is that a small core requires an intense source of light such as a laser in order to launch sufficient power down the fibre. The small core allows only one transverse mode, the fundamental.

The attenuation of a fibre at different wavelengths is shown in Fig. 4. It can be seen that at 1.6µm the attenuation is at its lowest. However, at this wavelength, the beam is dispersed causing a broadening of the ray. The amount of dispersion is stated in picoseconds per nanometre per kilometer of fibre.

The picoseconds refers to the amount of broadening of a transmitted pulse for deviations in wavelength (nanometres) from the operating wavelength. This can be seen in Fig. 5 for a kilometre of fibre operating at different wavelengths.

At 1.3µm the dispersion is zero and, although the attenuation is higher than that at 1.6µm, current fibre systems operate at 1.3µm. When ways are found of overcoming the dispersion problem, future fibre systems will operate at 1.6µm in order to exploit the lower attenuation. Presently, fibres operating at 1.3µm employ gallium arsenide indium phosphide (GaAsInP) lasers.

Because of the attenuation, amplifiers must be used at certain intervals in order to amplify the signals. Strictly speaking, the signals are not amplified by an amplifier. Instead a regenerator is used which replaces every pulse by a new one as shown in Fig.6. The distance between regenerators depends on the bandwidth being transmitted and in general, the narrower the bandwidth, the further the transmission without the necessity for regeneration.

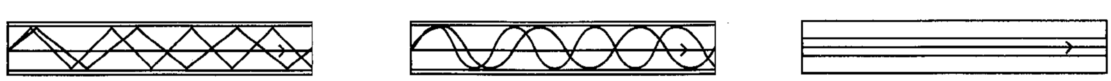



$R_1$ incident ray
$R_2$ reflected ray
Qc critical angle now reduced
$N_1$ refractive index of core
$N_2$ refractive index of cladding

**Fig. 2. Reflection with cladding.**

For instance, a gallium arsenide laser working with a multimode fibre could transmit a bandwidth of roughly 1 Gbit/s over one kilometre between repeaters. This means that if the bandwidth is reduced to 100Mbit/s the distance can be increased to 10km.

But to return to dispersion, a slightly more detailed explanation may be beneficial. There are two types of dispersion, modal and



Multimode Graded index Monomode

**Fig. 3. Fibre modes.**

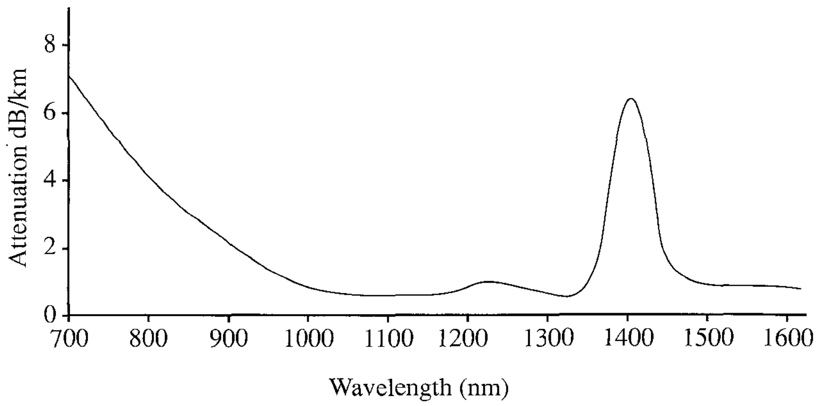



**Fig. 4. Attenuation of a fibre.**

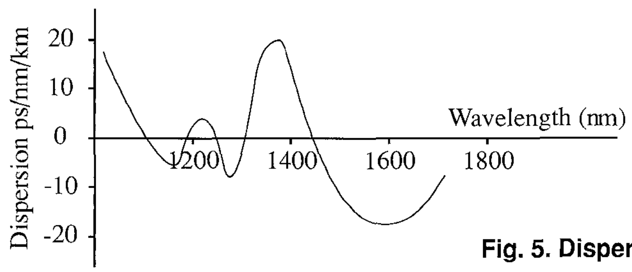



**Fig. 5. Dispersion in a fibre.**

chromatic.

A multimode fibre can support several transverse modes and the zig-zag paths which the higher transverse modes take is greater than the path of the fundamental mode which travels down the axis. This is called modal dispersion, (Fig.7).

So, although the rays left the source at the same time, they arrive at the detector or regenerator at different times, broadening the beam and hence the binary digits transmitted down the line.

The other type of dispersion, chromatic dispersion, is due to the different wavelengths emitted by the laser (Fig.8). These travel through the fibre at different speeds and also cause pulse broadening. The term chromatic is used because colour depends on wavelength.

Since the core of a multimode is large compared to that of a monomode fibre, a light emitting diode (LED) can launch sufficient power into it. However, at a wavelength of 0.8µm or 0.9µm the attenuation is about 2dB per kilometre and with the two types of dispersion, the signal requires regenerators every 10 to 15 kilometres.

Instead of using an LED, a laser could be substituted and 1Gbit/s/km achieved as mentioned earlier. If a monomode fibre is used with a laser, the bandwidth-distance product becomes 100Gbit/s per kilometre. This is an increase of a hundred times and is the reason for all large capacity international cables operating in monomode.

## FIBRE MANUFACTURE

There are many methods of manufacturing optical fibres. One is to use a starting rod with molten glass deposited on the end. As the rod is pulled from the melt a fibre is produced. Another method uses a rotating mandrel on which the core glass is deposited, followed by the cladding.

In order to achieve a higher refractive index in the core, the glass is doped with germanium, titanium, aluminium or phosphorus oxide. With graded index fibres these oxides diffuse through both core and cladding.

The two most common production methods are the Corning and the Double Crucible. In the first method (Fig.9) a hollow tube has a layer of glass deposited on the inside surface by means of an oxygen flame. This forms the cladding. Next the core, consisting of doped glass, is deposited by the flame and the two layers are collapsed to form a fibre.

In the Double Crucible method, two concentric crucibles are used as shown in Fig. 10. The doped glass of higher refractive index placed in the inner crucible and pure glass is placed in the outer crucible to form the cladding. The molten fibre is then pulled from the bottom of the assembly.

A platinum crucible was originally used but the glass was found to be contaminated. A silica crucible proved to be better but could not withstand the high temperatures involved. In order to drop the temperature of the molten glass to 1300°C and yet maintain the glass in its molten state a 5MHz RF field is coupled with the melt. This permits the use of a silica crucible and avoids the contamination of the platinum.

## LOSSES IN OPTICAL FIBRE

Loss of light, and hence signal strength, in optical fibre is due to two causes: absorption and scattering. The first is due to chemical impurities in the glass, mainly metal oxides. These reflect their characteristic colours and absorb all others. Hence, sapphires appear blue because of titanium, rubies are red because of chrome and green is caused by iron oxide. Because of this it is necessary to be as clean as an operating theatre when cooking glass. Not only must the chemical impurities be removed but nothing else must be picked up from the vessels.

The other source of loss, scatter, also called Rayleigh scatter, is due to physical deformities in the fibre. These are not only discontinuity and change in density of the glass but also things like water bubbles and bubbles of air. Most of the scatter losses are in the 0.85µm to 0.95µm window and there is nothing that can be done to remove them once the fibre has been produced. The bubbles of water and air are removed by boiling the raw glass and then if an application process, such as Corning is employed, even layers are applied. If a pulling process such as the Double Crucible is used, an even pull is applied so that the fibre has a uniform density.

## JOINING FIBRES

Lasers can be joined to fibres by pressing them on to the end of the fibre – a butt joint. Alternatively, they can be coupled via two lenses as in Fig.11. Alternatively, a 50µm well is etched into a Burrus Diode so that the end of a 50µm multimode fibre fits snugly .

In both instances, the object is to couple as much power as possible from the laser into the fibre. Ideally all the power must be

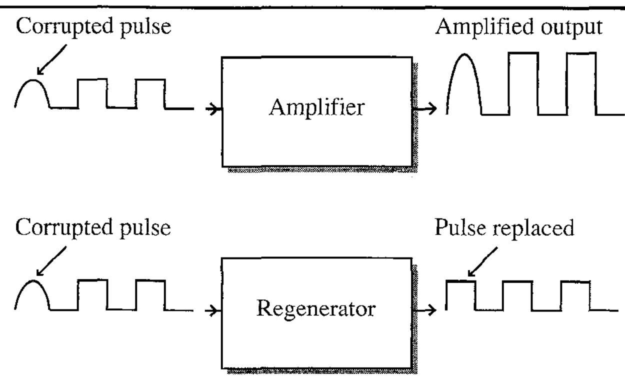



**Fig. 6. Comparison of amplifier and regenerator.**

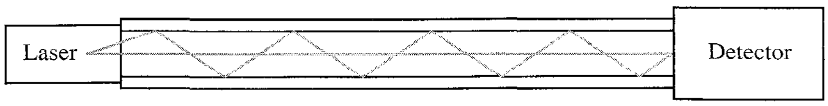



**Fig. 7. Modal dispersion**

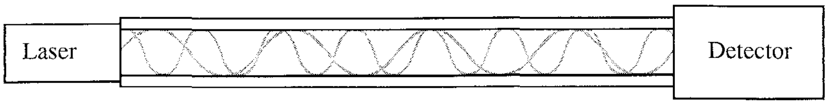



**Fig. 8. Chromatic dispersion**

launched into the core of the fibre. If some is lost, the regenerators must be placed closer together.

In practice, all the power can't be coupled into the fibre but of the two methods, the lens joint is more efficient as can be seen from the curves of Fig. 12. Lens joints are manufactured in two halves in the factory and each lens is located in its optimum position in a threaded cylinder. Then all that needs to be done in the field is to screw the two halves together.

Lens joints can also be used on fibre to fibre connections. This may be suitable for short lengths or where the lengths are known in advance. But more often than not it is necessary to cut the required lengths in the field. If this is the case, then suitable jointing procedures must be devised. The normal method used is to butt the cut surfaces up against each other and then cement or fuse them together.

One method of cementing uses gems, e.g. ruby. The fibre is cemented into a jewel mounted in a steel ferrule (Fig. 13). The surface of the fibre is therefore level with the surface of the jewel and when the ferrules are screwed together, the fibres are butted up tightly. The gems are cheap and holes can be drilled in them more accurately than in other materials.

When fibres need to be cut for butt joints, the cut must be clean and smooth, vertical and without steps. This ensures that the new surfaces are as close together as possible. A glass sleeve can be used which is heat shrunk to grip one of the fibres (Fig. 14). The other fibre is then cemented in at the other end.

With an increasing number of monomode fibres it is important that the core is perfectly aligned. Since it is only about 6μm in diameter, even a slight misalignment would waste considerable power. The fibres can initially be butted up with the use of micrometer screw gauges operating on the outer diameters, i.e. the cladding. Next, a beam of light is passed through the joint and the coupling efficiency checked. If one or both cores are not concentric with the cladding, there is scope for moving one of the fibres. When the coupling is satisfactory, the fibres are finally fused by discharging a spark across the joint. All the requirements for a fused joint, the micrometer gauge, the optical alignment devices and the spark discharge are housed in one instrument no larger than a briefcase.

The biggest application of optical fibres is in communications, as can be seen by the expenditure on recent and future optical cables spanning the Atlantic Ocean, the English Channel and the North Sea.

## DETECTING THE SIGNAL

A basic transmission system consists of a fibre linking a transmitter and receiver. The transmitter is usually an LED or laser and the receiver an APD (avalanche photodiode) or PIN (positive intrinsic negative) semiconductor.

The regenerators are effectively a transmitter and receiver back to back where the optical signal is converted to an electrical signal for pulse regeneration. Future systems will aim for optical amplifiers instead of regenerators which save time and hence enable larger bandwidths to be transmitted. This saving in time will only be of the order of a few microseconds but will take transmission from the Mbit/s range well into the Gbit/s range.

The receiver or detector follows the opposite process of the transmitter. The photons of light are absorbed and electrons flow in the external circuit. For this to happen, the band gap of the receiver must be the same as that of the transmitter, i.e. the receiver must be in sympathy with the wavelength being transmitted.

Two devices currently in use, PIN and APD, have gains of 100 and 1000 respectively. However, the PIN has a faster response than the APD and a gain of 100 is suitable for most applications. If the gain is too low, FET amplifiers can be used after the PIN detector to improve the signal to noise ratio. Efficiency is given as a ratio of number of electrons released to the number of photons received. The percentage efficiency is therefore:

(number of electrons/number of photons)x100

A minimum of 21 photons are required to give a good chance of detecting a signal, i.e. a

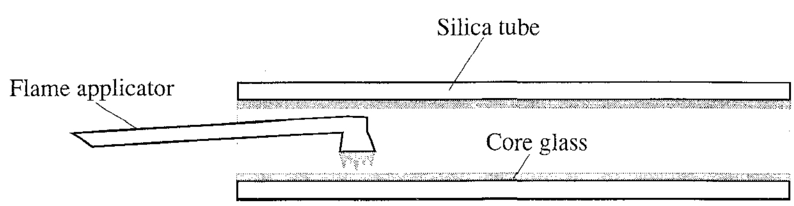



**Fig. 9. Corning method of fibre production.**

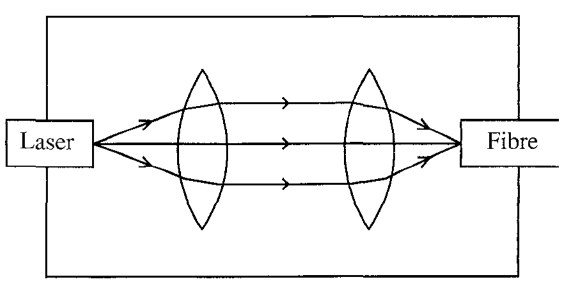



**Fig. 11. Laser fibre lens join.**

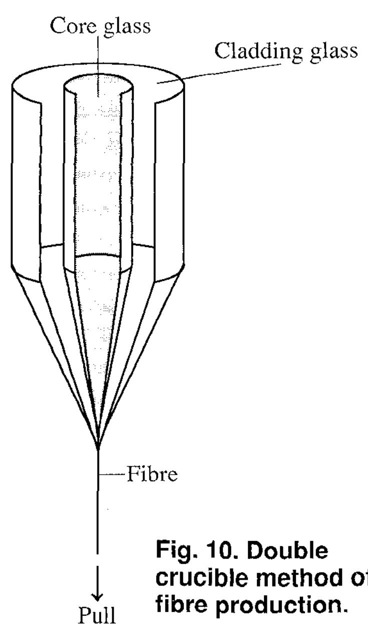



**Fig. 10. Double crucible method of fibre production.**

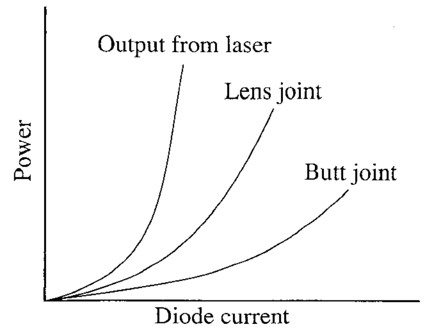



**Fig. 12. Laser power coupling.**

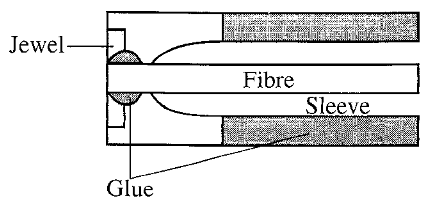



**Fig. 13. Using ruby joins to join fibres.**

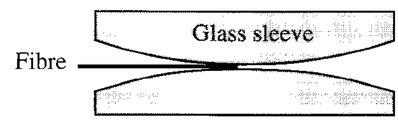



**Fig. 14. Glass sleeve for butt joints.**

digital 1 and if 85 electrons are released for every 100 photons received then the efficiency is 85%.

Photodiodes normally have areas of around one square centimetre, producing high sensitivity but increased capacitance and noise. Because of this the active areas are kept below 0.01 square centimetres. The response of small area devices is usually stated as output current per unit irradiance in Watts/cm2. A typical figure is 1mA/W/cm2.

Most of the noise in photodiodes is known as shot noise and results from holes and electrons bunching up or crossing the depletion region in a random manner. The short wavelength response of photodiodes can be improved by placing the junction closer to the surface but then the overall response is reduced.

In order to improve the response of a diode at all the wavelengths within its spectral range, an intrinsic layer is placed between the N type and P type semiconductor. This is a lightly doped region of N type impurity which improves the efficiency by providing a larger depletion region. This decreases the junction capacitance and, therefore, increases the speed of response.

In P type material, holes are the majority carriers and electrons the minority carriers. For N type material the opposite is true. When a reverse bias is applied to the junction, the minority carriers flow across the junction to the majority side creating a depletion region. This is known as the reach through effect since any signal now appearing at the device will be swept across the junction quite swiftly.

PIN chip sizes are about 400μm$^2$ which is the same as for lasers. The intrinsic layer is about 100μm thick and making it any thicker increases the leakage current.

## NEW DETECTORS

The other type of detector, the avalanche photodiode (APD), has different characteristics depending upon whether it is being exposed to light or not. The region of operation is the slope of the reverse characteristic with the diode illuminated. The main disadvantage of the APD is the high reverse voltage required – in the region of 100 volts.

APDs are manufactured with the junction close to the surface. To prevent damage to the junction from a strong electric field a guard ring surrounds it. The avalanche is started by electrons in the N+ region.

In addition to low capacitance and fast response, detector diodes must have a low dark current. This is a leakage current and therefore any signals below this threshold will not be detected.

Silicon APDs have lower dark currents than germanium APDs but they are suitable for detecting signals only at the lowest wavelengths. The main operational windows are around 0.8μm, 1.3μm and 1.5μm. The silicon APD is suitable at 0.8μm but the germanium APD is required for the others.

Research is continuing into new materials like indium gallium arsenide (InGaAs) which is not only sensitive to weak signals but can detect modulation rates from near DC to around 30 GHz. The technique used to grow the crystal is metal organic vapour phase epitaxy (MOVPE).

The growth technique has become a fine art with chemists building films of 20 to 80 atomic layers. With indium phosphide as the substrate, epitaxial growth is possible when the layer that is deposited has the same crystal as the substrate. This ensures that the layers are free from strain.

The MOVPE process is shown in Fig. 15 and is suitable for large scale production. It can produce very abrupt heterojunctions and the process is ideal for materials based on aluminium arsenide and gallium arsenide.

Metallo-organic compounds are used as volatile precursors and they are carried in hydrogen. A single crystal is used as a substrate and when the precursor vapours decompose over it, the required layers are deposited.

The indium gallium arsenide diode is an improvement on the PIN. If the intrinsic layer is thought of as a dielectric in a parallel plate capacitor, then this capacitance must be kept low for high speed. The capacitance is kept low by decreasing the thickness as well as reducing the area.

As the device gets smaller than 50μm in width, the problem of how to attach a wire to it arises. One design uses an electrically isolated remote pillar which is linked to the active device by air bridges.

The electrical isolation is obtained by using a semi-insulating indium phosphide substrate with the whole device being about 30μm wide and the intrinsic layer only 2μm thick. The air bridges are made from layers of titanium and gold and are 50μm long, 0.5μm thick and 5μm wide.

In spite of these dimensions the bridges are strong and the whole device can be mass produced quite easily. Unfortunately, it is one thing being able to manufacture a magnificent device in a laboratory but if it is going to be of widespread use, the process must lend itself to bulk reproduction. The tolerances must be adheared to and the packaging must be specially designed to keep any stray signals to the absolute minimum – it must also provide pin-outs for practical applications. PE

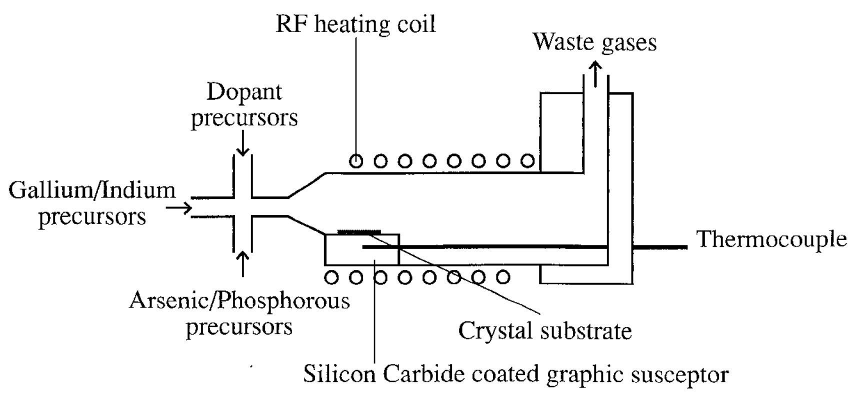



**Fig. 15. Metal oxide vapour phase epitaxy.**

There are probably hundreds of ways in which temperature conditions within any range can be monitored electronically. All electronic components change their characteristics with temperature and many of them can be used as sensors in electronic thermometers. Two in particular are especially suitable, diodes and thermistors. For example, the 1N4148 silicon diode can be used as a temperature sensor by taking advantage of its 1.8mV/°C change in forward voltage drop when reversed biased. Instead of feeding the outputs of the sensor into a microcontroller, the circuit is tailored to suit human monitoring, by adding sound and light. Although intended as a frost alarm, the circuit can be set to monitor the approach of other temperature levels, up or down.

**John Becker's answer to frost hazards is an audio temperature alarm.**

# THERMAL WARNING

## THERMISTORS

Thermistors are basically resistors whose impedences change with respect to temperature. They are manufactured with negative (NTC) and positive (PTC) temperature coefficients. NTC thermistors decrease their resistance with a rise in temperature, PTC thermistors do the opposite. Of the two, the NTC is probably more widely available to the hobbyist. The type used here is a general purpose disc thermistor having a nominal value of 10k ohms, ±10% at 25°C.

## THE CIRCUIT

The circuit has been designed to control a light emitting diode and an audible warning device (buzzer). With temperatures above a preset range neither the LED nor the sounder is active. As the temperature falls towards the preset level, the LED begins to flash and the buzzer bleeps at the same rate.

Below the preset level, both devices are turned fully on. The preset level can be set for any reasonable temperature above or below 0°C. It could, for example if, be set the at 20°C to give warning of the onset of nightfall.

Fig.1 shows the complete circuit diagram. It consists of three parts: amplifier, oscillator, and output driver.

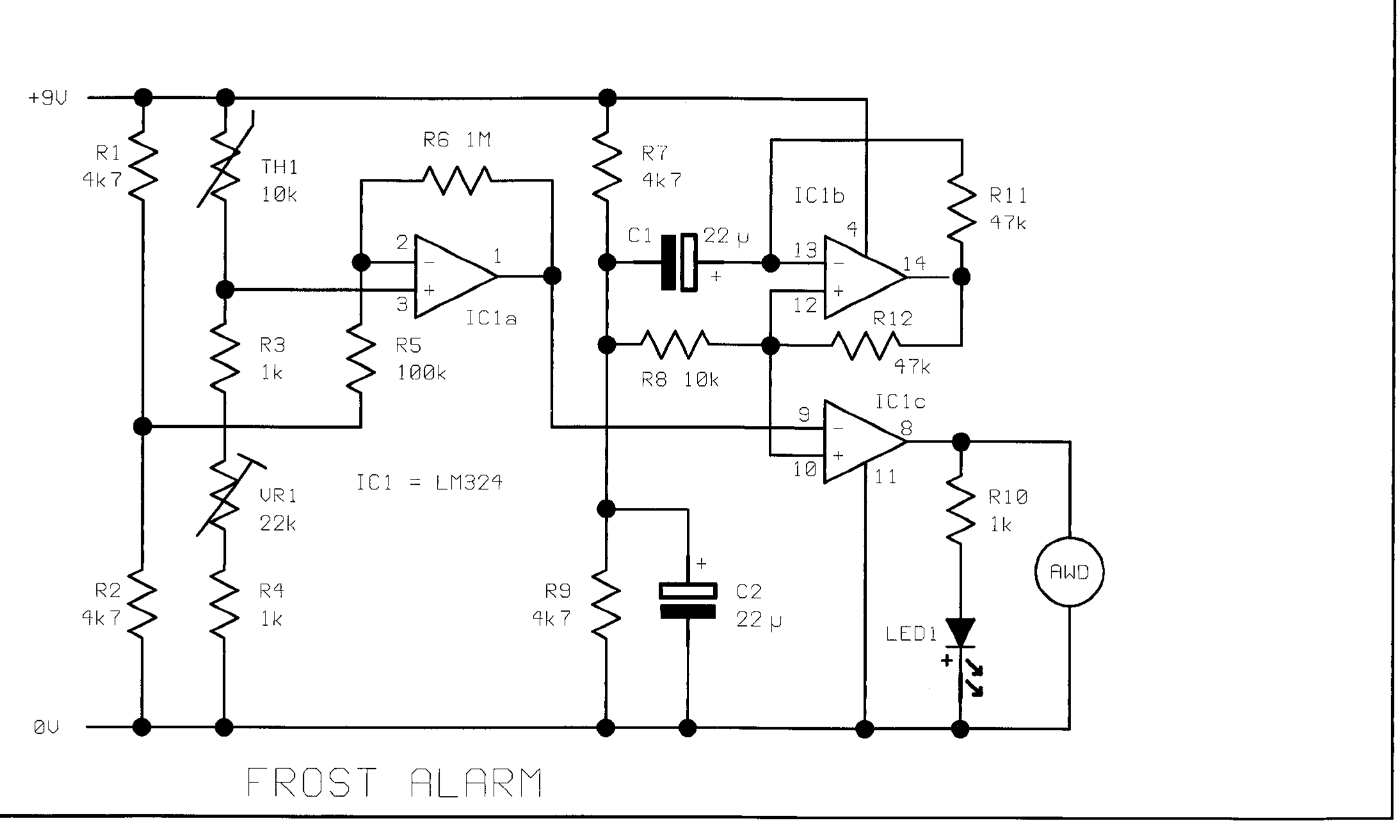
Thermistor TH1 is in series with R2, VR1 and R4, which form a potential divider across the 9V power line. The basic tapped voltage at the junction of TH1 and R2 can be adjusted by varying the resistance across VR1. As the ambient temperature changes, TH1's resistance changes in sympathy, resulting in a change in the tapped voltage level. IC1a amplifies the voltage change by about ten, as set by R5 and R6. The output voltage from IC1a is fed to the comparator stage around IC1c, setting its trip threshold level.

IC1b and associated components form a square wave oscillator, the basic frequency of which is set by C1, at around 1Hz. Normally with an oscillator of this type we would take the signal directly from the opamp's output, at pin 14. On this occasion it is taken from the junction of R8 and R12. The peak to peak swing here is much smaller than that at the opamp's output and is ideal for sending to the comparator as the second input signal.

## SETTING UP

With temperatures well above the level being detected, the output voltage from IC1a sets the comparator's threshold point too high for the small square wave signal from IC1b to cross it. Consequently, IC1c's output remains too low to drive the LED or the sounder. As the temperature drops towards the preset level, the comparison voltage seen by IC1c also falls, eventually to within the range at which the square wave can cross the threshold. Now each square wave is effectively amplified, triggering IC1c's output fully high and low. Each time the output is high, both the LED and the sounder are turned on, then off again when the drive voltage

**Fig. 1. The circuit.**



falls. In other words, the LED flashes, and the buzzer bleeps.

Eventually, when the temperature falls below the preset level, the comparison voltage seen by IC1c becomes too low to be crossed by the small square wave. The comparator now remains fully tripped, producing a constantly high output. Thus the LED and the sounder remain fully on. This condition continues until the temperature rises sufficiently to take the trip sequence in the opposite direction, from constantly on, through flashing, and eventually to fully off.

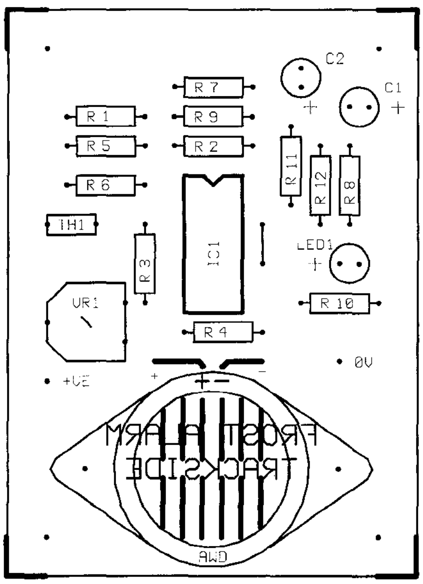
## TRIP CONTROL

By connecting the LED and the buzzer to the 9V line instead of 0V, the circuit could be used to warn you of temperatures getting too high. You would need to reverse the polarities of the LED and sounder. (The PCB does not allow for this, so you would need to hard–wire both devices to the correct lines.)

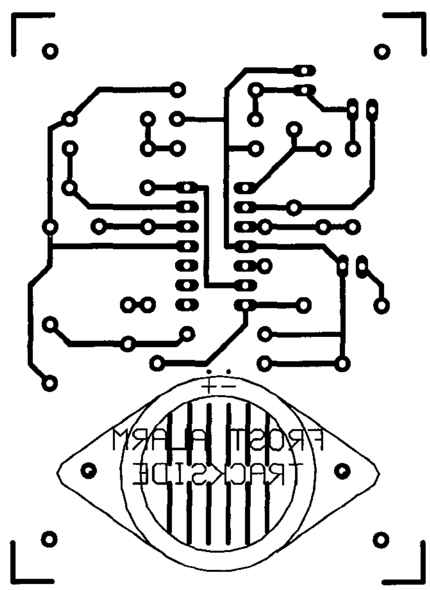
VR1 needs to be set by experimentation and in conjunction with a thermometer. If VR1 cannot be set to a high enough resistance to suit the thermistor used, increase the value of R4. For convenient panel selection of other temperature trip points, an ordinary rotary pot may be substituted for the preset variety if preferred. Its scale may be calibrated on the front panel.

To change the flash/bleep rate, substitute a different value for C1, larger for slower.

Bias levels for IC1a and IC1b are set by the divider chains R1/R2 and R7/R9 respectively, with C2 providing a bit of smoothing for the latter. The unit can be run from a 9V battery, drawing around 23mA when both LED and sounder are active. Either the LED or the buzzer could be omitted to suit the requirements of the final design; they draw about 10mA each. Note that the sounder is the active type, i.e. it buzzes when connected across a suitable power supply and does not need to be driven by a separate oscillator. PE




**Frost alarm components.**



**Frost alarm PCB tracks.**

## COMPONENTS

| | |
|---|---|
| **RESISTORS** | |
| R1, R2, R7, R9 | 4k7 (4 off) |
| R3, R4, R10 | 1k (3 off) |
| R5 | 100k |
| R6 | 1M |
| R8 | 10k |
| R11, R12 | 47k (2 off) |
| all 0.25W 5% or better | |
| **CAPACITORS** | |
| C1, C2 | 22u 16V electrolytic (2 off) |
| **SEMICONDUCTOR** | |
| IC1 | LM324 |
| **MISCELLANEOUS** | |
| VR1 | 22k preset potentiometer |
| TH1 | 10k ntc thermistor disc |
| LED1 | light emitting diode |
| AWD | active audible warning device (9V) |
| 14–pin dil ic socket | |
| Printed circuit board | |

# ALESSANDRO VOLTA

**By Ian Poole. Galvanic experiments with frogs' legs led to the invention of the electric battery.**

Photograph by courtesy of the Institution of Electrical Engineers.

The Volt is probably the most often used unit of electricity yet the life of the man who gave his name to it is now quite obscure. Most people involved in electronics today would be hard pressed to be able to say much about him at all.

Alessandro Volta was born on 18th February 1745 in Como, a town in northern Italy. He was the youngest son of a devout Catholic family and his uncles were all connected with the Church in one way or another. Alessandro's faith was dear to him and an integral part of his life.

Although his childhood had been very happy it was not without problems, as his father died when he was just seven years old. From then on his family received a lot of support from his father's brothers, one of them taking on the responsibility of Alessandro's education. Because of this Volta was sent to a Jesuit College at 12 years of age – quite young for the time.

A wealthy family friend also helped with his education by providing books, equipment and encouragement. This was probably one of the factors which sparked off Volta's interest in electricity and physical sciences. Unfortunately, Volta's uncles felt that his best career prospects lay with the legal profession and in most cases this would have been the most sensible direction – science was still very much in its infancy and there were comparatively few good career openings. Nevertheless, Volta somehow managed to continue his studies in electricity and showed his determination to stay in the field by corresponding with a number of the leading scientists and repeating their experiments.

Eventually Volta convinced his uncles that he must follow a scientific career and, with his best interests at heart, they agreed. So from the age of about 20 he studied science more formally with a particular interest in electricity. Such was his success that in 1774 he was appointed as a lecturer at the Royal School in Como. A year later he became the Professor of Physics at the school, making discoveries that were to form some of the basic ideas of modern physics and chemistry.

His first discovery was of the existence of methane gas, his second the invention of the electrophorus. This device allowed him to generate and experiment with static electricity. Of the two the electrophorus was probably the more significant event, but it was the discovery of methane which gave Volta renown in the scientific community. In fact he became known world wide and received a travel grant allowing him to meet other leading scientists.

With the rise of Volta's fame came the offer of a university chair. In 1779 he took up the post of Professor of Experimental Physics at the University of Pavia. Here he continued his work amidst a very changeable political climate when northern Italy came under French occupation during the Revolutionary Wars. Even though Volta naturally met the different heads of state he managed to keep himself out of the politics and make headway in his researches.

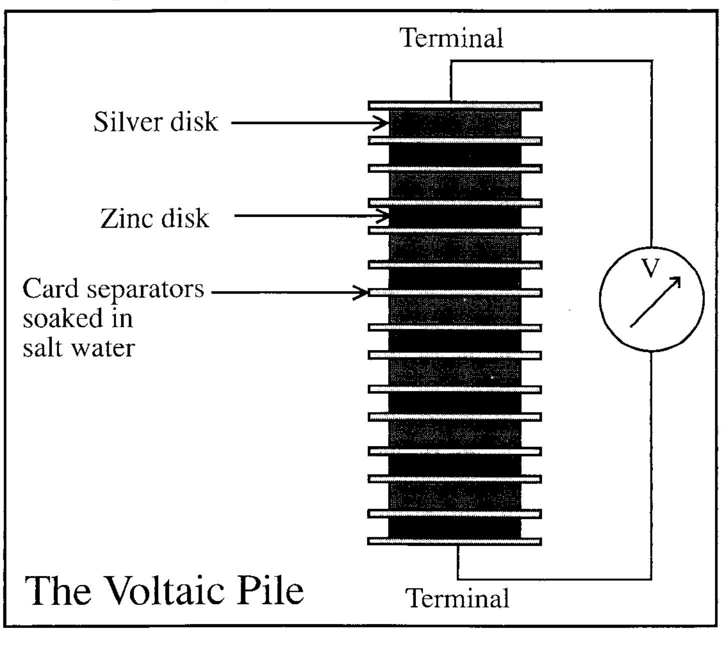
In 1780 a fellow Italian and friend of Volta discovered that the contact of two dissimilar metals on a frog's leg produced a small but measurable electric current. Volta also looked into this phenomenon and performed some further experiments. He came to the conclusion that the electrical current did not come from the frog's leg, it came instead from the fact that there were two dissimilar metals separated by brine or other solution containing a salt.

Volta managed to refine his experiments further and discovered that the pair of metals which produced the best effect were zinc and silver. At first he made individual cells out of wine goblets with brine in them. The two electrodes were dipped into this solution to produce the electrical cell. He also put a number of cells together in series to produce a larger voltage, but soon found that this approach became quite cumbersome. As an alternative, he made a cell out of two discs of dissimilar metal with cardboard soaked in brine between them. By stacking several of these cells on top of one another a pile of cells was made up quite easily. The limit of the number of cells in any pile was reached when the weight of the whole battery started to squeeze the brine out of the bottom cells. Even so it was possible to build up voltages large enough to give an electric shock.

Volta eventually became quite famous as a result of his discoveries. He gave many demonstrations throughout Europe, even to Napoleon himself who was fascinated by these new discoveries. In fact he was so impressed that he gave Volta a substantial salary to carry on with his experiments.

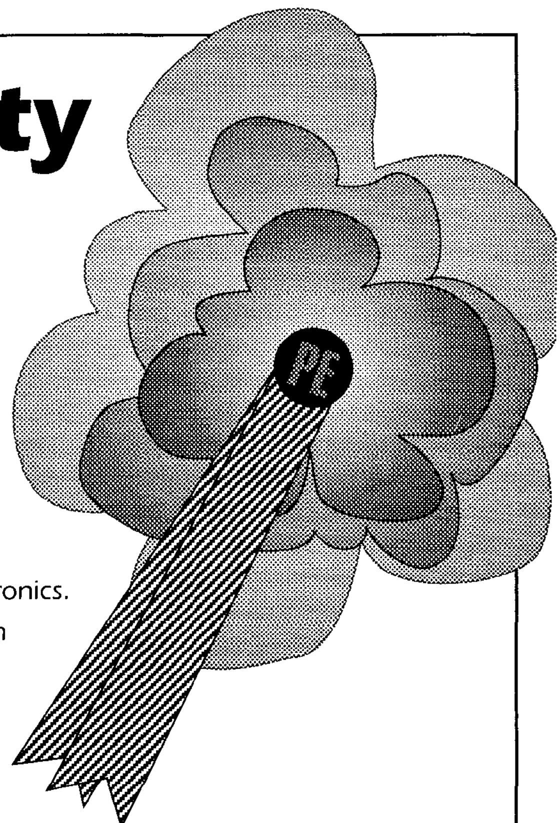
Volta received other recognition for his work when he was made a senator of the Kingdom of Lombardy, which increased his wealth still further. He received international recognition and many scientific institutions around Europe honoured him and asked him to give lectures.

With his fame and recognition came great wealth which enabled Volta to maintain a very high standard of living. He lived his last years in great luxury and died in Como on the 5th May 1827 at the age of 82. PE




The Voltaic Pile

# Rewarding Loyalty




## We've hit the popularity jackpot with our Reader Loyalty Bonus scheme.

## What an amazing response!

The five loyal readers who hit the jackpot this month are:

**D. R. Anderson** of Nottingham who has his £154.96 refunded for his purchase from Number One Systems.

**I. J. McNair** of Crewe receives £39.99 for buying goods from B. K. Electronics.

**S. Gale** of Bognor Regis who bought £24.23 worth of components from Maplin.

**M. L. Peake** of Bilston also traded with Maplin and has £17.91 refunded.

**G. T. Edwards** of Weymouth has the £13.50 he spent with Greenweld refunded.

## You too could be loyally rewarded – see page 61!

# BASIC ELECTRONICS

## Part 14. Owen Bishop continues his series for beginners.

Last month's tutorial finished off by describing low and high pass filters and how they react to various frequencies. It also defined the term decibel as the ratio between the input and output voltages at a given frequency. A special characteristic of low pass filters is the point at which the output voltage is 70% of the input voltage. In terms of decibels this is -3dB and is known as the half power point. Beyond the half-power point, the output voltage continues to drop, a doubling of frequency (i.e. a frequency one musical octave higher) halves the reactance of the capacitor and thus reduces output voltage to half. Since power is proportional to the square of the voltage, the power is reduced to a quarter, or by -6dB per octave.

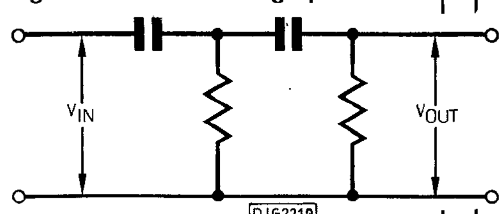
The filter described here is a first-order filter with only one stage of filtering. A second-order filter (Fig. 1) gives an enhanced effect. The reduction of power beyond the half-power point is -12dB per octave. For a bigger effect we can use even more stages, giving power reductions of -18dB, -24dB and so on. The only problem is that increasing the number of stages has little effect on the shape of the output curve between full power and the half-power point. The 'knee' of the curve remains unchanged. For many purposes this is not important but, if we wish for really sharp cut-off at a particular frequency, we need a filter with a sharper 'knee'. Ways of achieving this are described later.

What has been said for the low-pass filter also applies, though in reverse, to the high-pass filter. The half-power point is given by $f = 1/2\pi RC$, as before.

## INDUCTORS

Another component that possesses reactance is the inductor. An inductor consists of a coil of wire wound on a core of ferromagnetic material such as soft iron or ferrite. Any change in the current flowing through the coil acts to alter the strength of the magnetic field in the coil. However, the property of the inductor is to oppose such changes by developing a voltage (known as back e.m.f.) which acts to keep the current through the coil constant. Those who have studied Physics at school, will recognise that this action is a result of Lenz' Law. Not only does the inductor oppose changes in current flowing through it but, the more rapid the change, the greater the opposition.

**Fig. 1. Second-order high-pass filter.**




Consequently, the reactance $X_L$ of an inductor to an alternating current (caused by an applied alternating voltage) is greater when the frequency is higher. The equation is:

$$X_L = 2\pi fL$$

where L is the inductance, in henries.

Since reactance varies with frequency, it follows that we can build a filter using a resistance and an inductor.

***Investigation 3 - LR filter***

Fig. 2 shows an example of an LR filter. You need a suitable inductive component such as a relay or transformer. Connect its coil as in Fig. 3. Connect the flying lead either to R2 or to L1. R2 is to reduce the volume of the unfiltered signal to make it more readily comparable with the filtered signal obtained when the flying lead is connected to L1.

What type of LR filter is this? Explain its action.

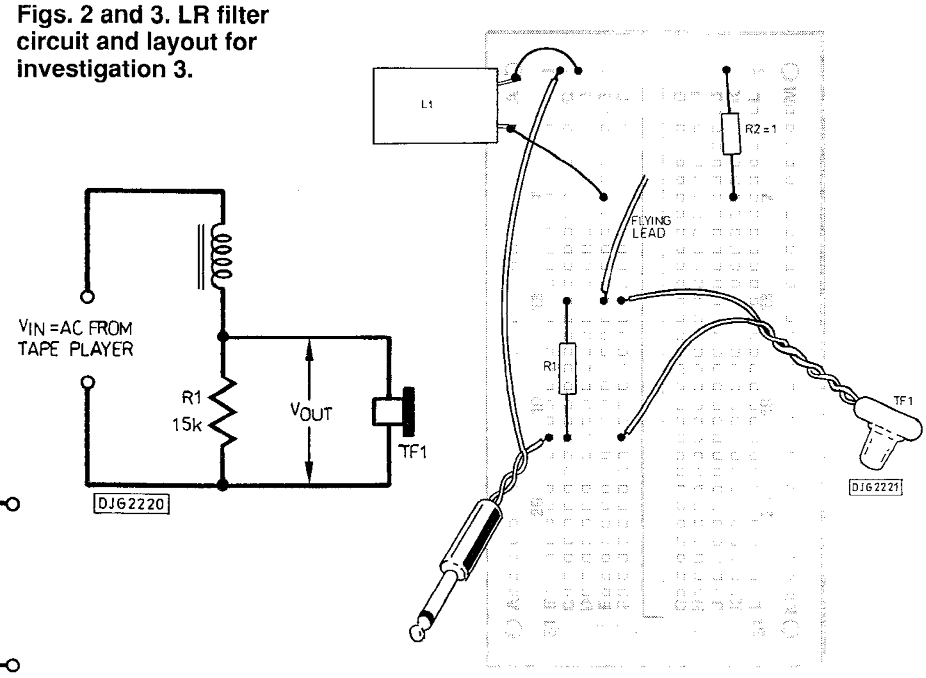
Inductors can be used in combination with capacitors to build filters with sharper cut-off, making The 'knee' of the output curve more angular. But filters incorporating inductors are less often used than formerly, as they have several disadvantages, one of the main ones being that the coil and core of the inductor are relatively large and massive so they are unsuited to today's compact and portable equipment. Another drawback is that it is not easy to produce an inductor with a specified inductance. There is also the problem that, unless they are protected by special mu-metal screening, they readily pick up electromagnetic interference from nearby circuitry, introducing hums and the possibility of oscillation into the circuit. Nowadays we have a much better and cheaper way of obtaining sharper cut-off. We use an active filter, as will be explained later.

An interesting configuration is shown in Fig. 4, which has a capacitor and inductor connected in parallel. At low frequencies, output is low because the reactance of the inductor is low. At high frequencies, output is low because the reactance of the capacitor is low. But at a given intermediate frequency, the reactances are both high and output is high. This kind of filter which removes both very low and very high frequencies, is known as a band-pass filter.

## CAPACITOR COUPLING

The use of capacitors for coupling parts of circuits that are at different DC voltage levels was described in Part 3 (PE, March 1990). Fig.5 shows a typical example of a stage in an amplifier, with capacitors C1 and C2 coupling it to previous and following stages. Taking our new view of capacitors as constituents of filters, we see that C1 and the two resistors R1 and R2 form a high-pass filter. The high-pass filter configuration is just incidental, as originally C1 is there for coupling, and the resistors are there to bias the base of the transistor. However, they are now acting as a high-pass filter and we must check that this

**Figs. 2 and 3. LR filter circuit and layout for investigation 3.**



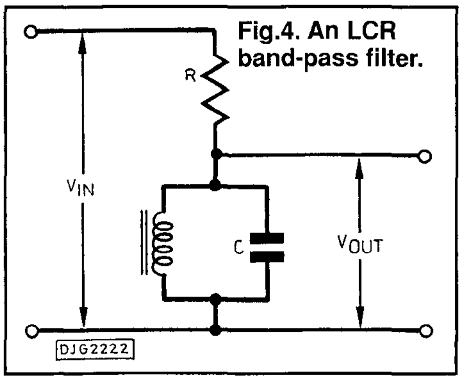



**Fig.4. An LCR band-pass filter.**

does not have any unwanted effect on the operation of the circuit.

In calculations involving the half-power point we consider the resistance of the filter to consist of R1 and R2 in parallel. This gives (in kilohms) R = (16 + 62)(16 x 62) = 12.7k. We will suppose that a high-pass filter with a half-power point of 30Hz is considered satisfactory. This passes all audible frequencies. We calculate the required capacitance, using a version of the half-power equation:

$C = 1/2\pi Rf = 1/2\pi(12.7\times10^3\times30) = 4.2\times10^{-7}$F.

The nearest preferred value is 470nF.

On the output side of Fig.5. the resistance involved is R3. A suitable value for C is given by:

$C = 1/2\pi(3.9\times10^3\times30) = 1.4\times10^{-6}$F

The nearest preferred value is 1µF.

This example shows how suitable values of coupling capacitors are chosen so as to pass all required frequencies. In other types of circuit, we may make use the capacitative coupling deliberately to filter out unwanted low frequencies, such as those caused by mains hum and low-frequency variations in input. An example would be in the amplifier of a passive infra-red intruder detector. Low frequency changes, such as caused by slow heating or cooling of objects in the room, would be filtered out and be ignored, while rapid high-frequency changes, such as caused by the movement of an intruder, would be passed through to the alarm-triggering section of the circuit.

## ACTIVE FILTERS

Filters using the varying reactance of capacitors or inductors are known as passive filters. With the introduction of inexpensive operational amplifier ics, it becomes more feasible to use amplification and feedback to achieve the same effect as the more expensive and bulky inductor of the RLC filters. Such filters are known as active filters, because of the active component, the amplifier.

***Investigation 4–an active high-pass filter***

Fig.6 shows the filter circuit consisting of a second-order RC high-pass filter feeding its output to a non-inverting amplifier (see last month's issue). Part of the output of this is fed back to the bottom end of the first RC filter.

Connect the circuit as in Fig. 7, using 22µF capacitors. The battery is tapped half-way along to give -3V, 0V and +3V. The frequency at the -3dB point is given by $1/2\pi RC$. In this case, the frequency is 21Hz, so the filter is not likely to make any appreciable difference to the quality of the sound. After listening to the sound for a while, replace the 22µF capacitors with 100nF capacitors. What is the cut-off frequency now? What effect does the filter have on the sound now? Listen during the silent period between tape tracks - what do you hear?

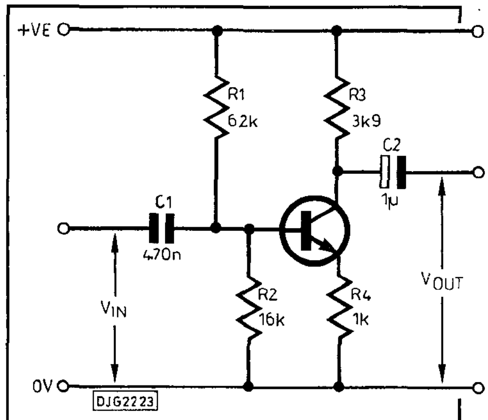
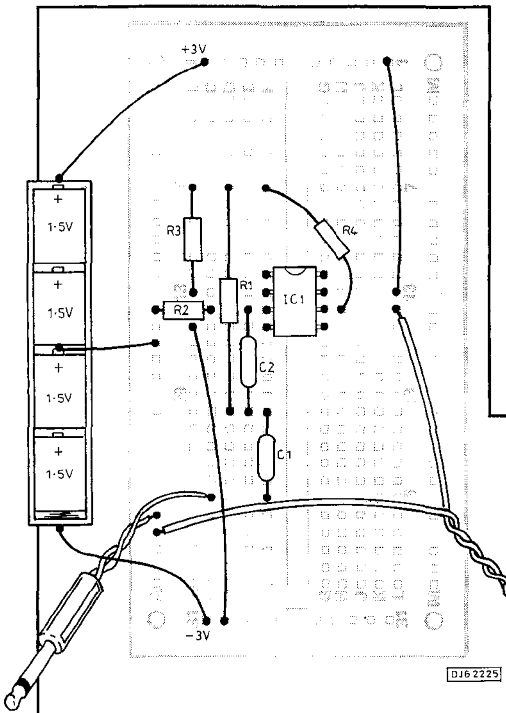


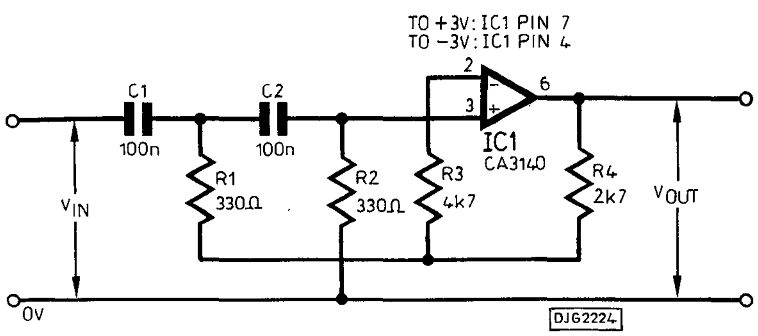

**Fig. 5. Common-emitter amplifier.**

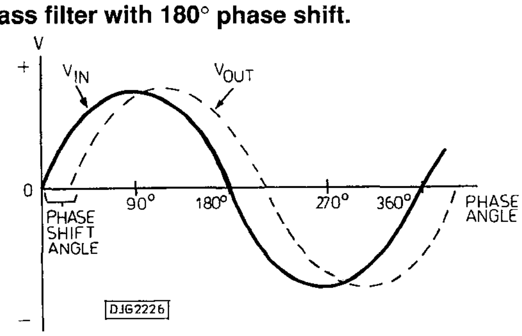
## PHASE SHIFT

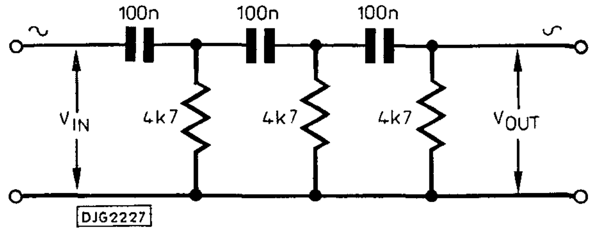
So far we have ignored an important characteristic of the RC network, that the output voltage is not in phase with the input voltage. There is a frequency-dependent phase shift between input and output. We usually express the phase shift as an angle, as in Fig.8. One complete oscillation is taken to correspond to 360°, a complete circular rotation. In the figure, Vout is shifted approximately 40° with respect to Vin.

The amount of phase depends on the relative values of the resistance R and the impedence of C and the latter depends on frequency , so the phase shift is frequency dependent. Usually the amount of phase shift is small, for example, only about 45° for a first-order filter operating at the -3dB frequency. However, a second-order or third-order filter may have a total shift of 180° at a given frequency, so that the output signal is the inverse of the input signal. One such

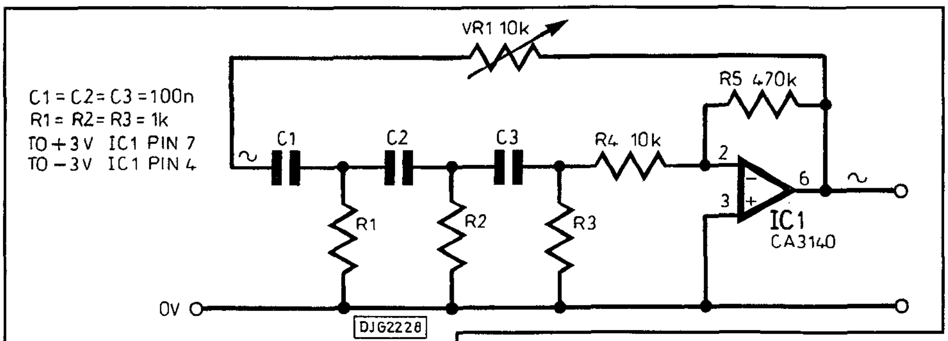


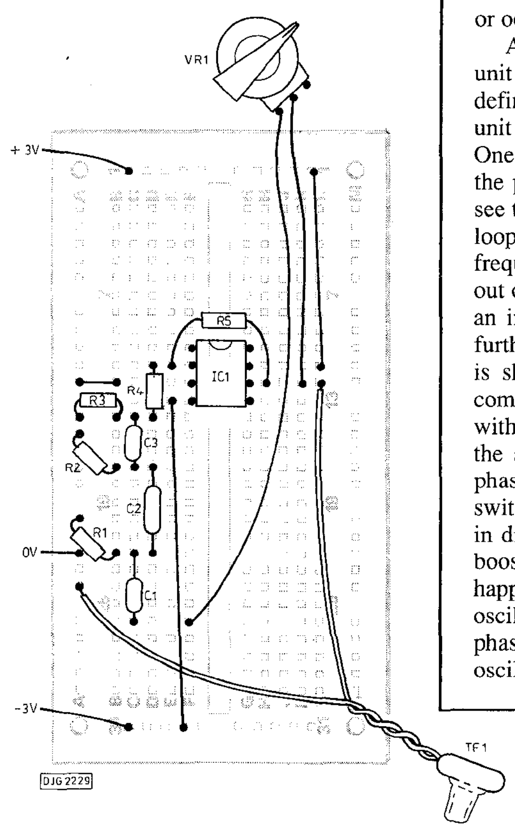




**Figs. 6 and 7. (left, bottom left). Active high-pass filter circuit and layout for investigation 4.**
**Fig. 8 (right). Phase shift in an RC filter.**
**Fig. 9 (bottom right). High-pass filter with 180° phase shift.**




**Figs.10 and 11. Phase shift oscillator circuit and layout for investigation 5. Battery connection is as in Fig.6.**

example is shown in Fig. 9, where the frequency for 180o shift is given by:

f= 1/(2 6RC)

This assumes that all resistors have the same resistance and all capacitors have the same capacitance. With the values given, the frequency is 138Hz. We make use of phase sift network in Investigation 5, below.

## OSCILLATORS

Another use for the time-dependent characteristics of capacitors and inductors is in the building of oscillators. Oscillators are of two basic types, relaxation oscillators and harmonic oscillators.

In a relaxation oscillator we usually have a gradual building up of a voltage, perhaps while a capacitor is being charged, ending in a sudden reduction (or relaxation). Often a switching action in the circuit discharges the capacitor rapidly, ready to begin the next cycle. One example of a relaxation oscillator is the UJT oscillator, described in Part 10 (October 1990). Tables based on the 555 timer IC and on various logic gates are other examples of this type. The output of a relaxation oscillator is usually a square wave, or occasionally a saw-tooth wave.

A harmonic oscillator is based on a circuit unit that responds in a particular way at a definite frequency. The response of the circuit unit is used to keep the oscillator running. One kind of harmonic oscillator is based on the phase shift network (Fig.9). In Fig.10 we see this network incorporated in the feed-back loop of an inverting amplifier. At the selected frequency, the output of the network is 180° out of phase with its input. When this is fed to an inverting amplifier, the phase is shifted a further 180°. Thus the output of the amplifier is shifted 360° with respect to the input, a complete circle, which brings it back in phase with the input. part of the output voltage from the amplifier is fed back to the input of the phase shift network. When the circuit is first switched on there are small surges of current in different parts of it. The positive feedback boosts any oscillations in the circuit that happen to be at the selected frequency. The oscillations are fed back to the input of the phase-shift network and the circuit begins to oscillate continuously at that frequency. The output of the oscillator is a sine wave.

***Investigation 5 – a phase-shift oscillator.***

Fig.11 is a breadboarded version of a phase-shift oscillator. Which component is responsible for feeding the output back to the phase-shift network?

Listen to the signal coming from the earphone, after adjusting VR1 if necessary. What is the signal frequency? Replace the 1k resistors with 330 Ohm resistors. What is the frequency now?

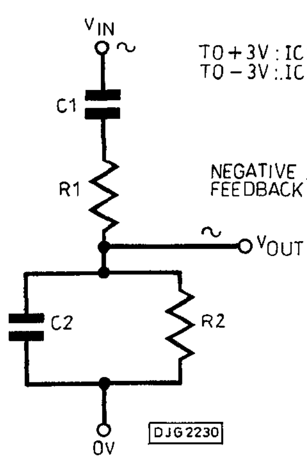
## OSCILLATORS

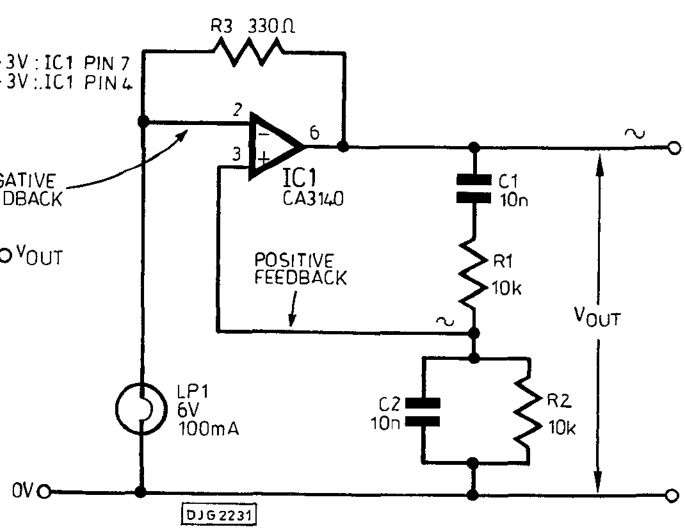
This is another example of a phase-shift oscillator. The RC network has the circuit shown in Fig.12. The characteristics of this network are that, at the given frequency, the phase shift is 0°, and Vout is one third of Vin. To use this network in an oscillator, we do not need any inversion in the amplifier as the output is already in phase with the input. Thus we feed back the network output to the positive input of the amplifier. The precise gain of the amplifier is critical:

| Gain is | Effect |
|---|---|
| 3 or less | Oscillations die out |
| just over 3 | Oscillations maintained, with sine-wave output |
| Much more than 3 | Saturates and gives square-wave output |

One version of the Wein bridge oscillator uses a filament lamp to stabilise the gain of the amplifier (Fig.13). The current passing through R3 also passes through the filament of the lamp. If the average output current is too high, the increased current warms the filament slightly. This increases its resistance, and the voltage at the (-) input rises slightly. This negative Feedback reduces the output of the amplifier. Conversely, if the output begins to fall, the resistance of the lamp decreases, lowering the voltage at the (-) input. The

**Fig. 12 and 13 (below). Wien bridge network and oscillator.**



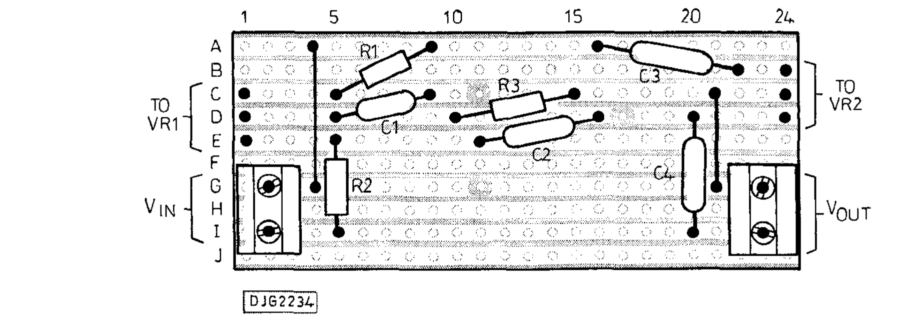



**Fig. 16. Module 16.**

effect of this is to increase the amplifier output. When we refer to amplifier output in this explanation we are referring to the RMS output current, that is, the output averaged over many cycles, not the instantaneous output as the current alternates through one cycle. The lamp takes a second or so to respond to changes in current and thus has the relatively long response time essential for this type of stabilisation.

## LC OSCILLATORS

These are normally used only for high frequencies, for example in radio circuits, because an inductor with an inductance sufficiently high to produce audio frequencies is too massive for most applications. The Colpitts oscillator (Fig.14) is an example of this type. The circuit shown is based on a transistor, but an operational amplifier could be used instead of this.

The heart of the circuit (literally, because this is the part that 'beats') is the loop containing the capacitors (C2, VC1) and an inductor L1. As will be explained in more detail next month, the loop is a resonant circuit. Current flows back and forth in the loop at a definate frequency, depending on the capacitance and inductance. VC1 is a variable capacitor, by which the loop is tuned to resonate at a required frequency. The voltage across the loop is controlled by the transistor, which has its base held at a very steady voltage by R1, R2 and C1.

Oscillations in the loop cause an alternating voltage to appear across it. This is tapped off between C2 and VC1 and fed through C3 to the emitter of the transistor. The effect of this is to impose a small alternating voltage on the steady voltage produced by the current flowing through R3. The base voltage is fixed, and, as the emitter voltage falls slightly, the resulting increase in base-emitter voltage causes an increase in collector current. This leads to a fall in collector voltage. Conversely, the collector voltage rises when the emitter voltage rises slightly. In this way the oscillations of the loop, fed back to the transistor, cause an alternating voltage across the loop. This supplied the loop with energy and, because the alternating voltage has the same frequency, is in phase with the oscillations. This is an example of positive feedback.

The output of the circuit is taken from a coil L2, wound on the same former as L1. The alternating magnetic field through L1 caused by oscillations in the loop, induces an alternating current of the same frequency in L2.

## MODULE OF THE MONTH

***Module 16-tone control***

This is based on a type of RC network known as a Baxandall tone-control circuit (Fig.15). There are two variable resistors, VR1 and VR2, which control the base and treble response respectively. The stripboard version (Fig.16) is shown without VR1 and VR2, which are mounted off-board on a panel. If only a fixed response is required, you could use miniature preset resistors mounted on the lower area of the stripboard. The tone control is suitable for use in any audio systems assembled from modules previously described in this series. Since there is a loss of power in this circuit, it is essential to include an amplifier such as Module 15 either as the stage before or after the tone-control.

Parts required.

R1 22k: R2 1k: R3 5.6k: VR1, VR2 100k carbon potentiometers (log track preferred, 2 off): C1, C3, C4 10n polyester (3 off): C2 100n polyester: SKT1, SKT2 2-way pcb sockets: stripboard 10 strips x 24 holes: 1mm terminal pins (6 off).

## DISCUSSION

*Investigation 1:* When the flying lead is connected to the capacitor, the sound becomes crisper, with high-pitched notes predominating. Instruments such as cymbals and side-drums sound clearly, but low-pitched instruments are difficult to hear.

*Investigation 2:* The effect is the opposite to that in Investigation 1. The bass notes are enhanced and high-pitched notes are diminished.

*Investigation 3:* Bass notes predominate. This is a low-pass filter. For low frequencies, the impedance of the inductor is low and Vout rises. The opposite occurs at high frequencies.

*Investigation 4:* With 100nF capacitors the cut-off frequency is:

$f=1/2\pi(330x100x10^{-9})=4.8$ kHz.

This is a high-pass filter with the cut-off frequency fairly high in the audio range, and does not give an acceptable sound for listening to music. The base notes are lost completely and only the highest treble notes come through. In the quiet passages, the tape hiss is clearly heard, because this is white noise, consisting mainly of high frequencies. Investigation 5: The frequency is given by the equation for the phase-shift network. $f=1/2\pi\sqrt{6}(RC)=1/2\pi\sqrt{6}(1000x100x10^{-9})=650$Hz, a note near the middle of the musical scale. With 330Ω resistors, $f=1/2\pi\sqrt{6}(330x10\ x10^{-9})$ =2166Hz, a higher-pitched note, about 3 octaves above middle C.

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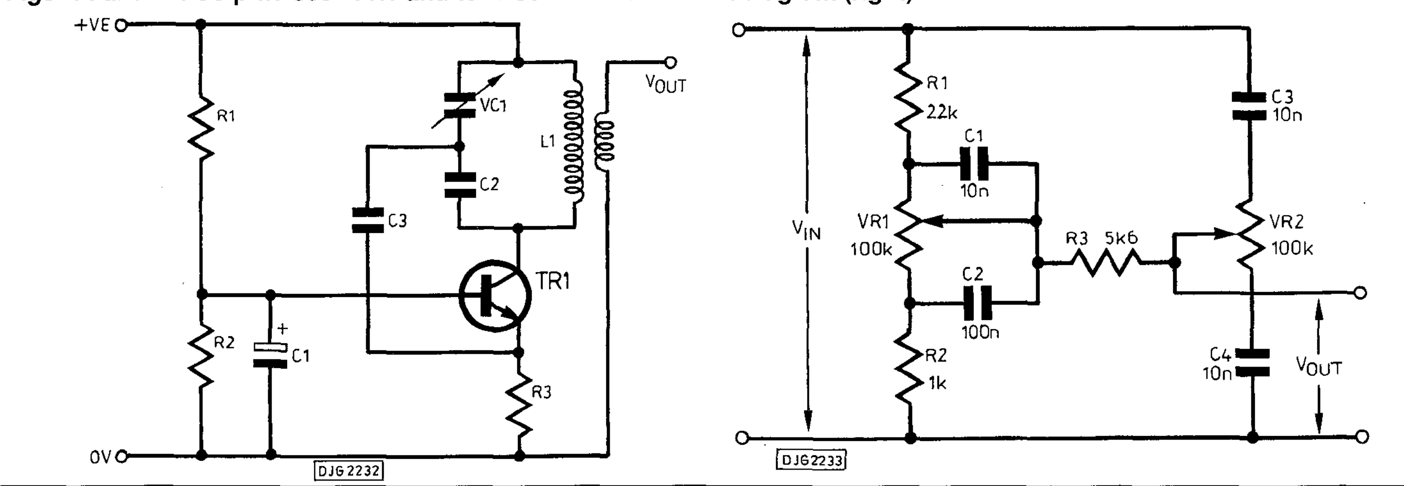
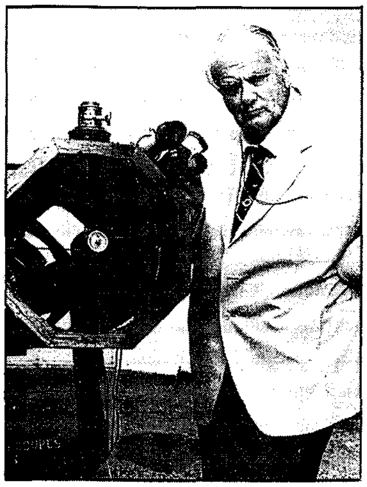
**Figs. 14 and 15. Colpitts oscillator and tone control filter circuit diagram (right).**



# SPACE WATCH



BY DR PATRICK MOORE CBE

**News from the asteroids, expansion at the UK's radio research facility, and the Search for Extra Terrestrial Intelligence goes on.**

Galileo, the Jupiter probe, has now made its encounter with the Earth, picking up extra speed by means of what is known as 'gravity-assist technique', and is on its way back through the asteroid belt. If all goes well, close-range pictures of two asteroids will be secured.

## MARTIAN TROJAN

Meanwhile, there is other interesting news about these curious little worlds. The so-far unnamed asteroid 1990 MB has been confirmed as a Mars 'Trojan' – that is to say it is moving round the Sun in virtually the same orbit as Mars, keeping a respectful distance well away from the Red Planet. There are many Trojans sharing the orbit of Jupiter, but 1990 MB is the first to be detected in the same orbit as Mars; no doubt there are others, though none can be more than a mile or two in diameter.

Two asteroids in the main belt (between the paths of Mars and Jupiter), 279 Thule and 1269 Rollandia, have been examined spectroscopically by British, Swedish and Irish astronomers, and appear to be covered with a layer of organic (in other words carbon-based) compounds. Of course, it has long been known that asteroids are of different types; some are highly reflective, while others are as dark as coal-dust. Both Thule and Rollandia are of the dark type and there may be a link here with the nucleus of Halley's Comet, which was found by the Giotto space-probe to show the same characteristics.

## MERLIN AWAKES

On 23 November Kenneth Clarke, then Secretary of State for Education and Science, officially opened the 32-metre radio telescope as part of the MERLIN facility, a section of which is based at Cambridge. MERLIN consists of seven telescopes at sites scattered over England and at a wavelength of 6cm it has a resolving power of 0.05 arc seconds, and can perform many functions, including resolving close radio sources, measuring the proper motions and parallaxes of pulsars, and studying active galaxies and quasars. The new Cambridge instrument will form a vital part of the European and World Very Long Base Line Interferometry networks.

## SETI REPRIEVED

The SETI project - Search for Extra-Terrestrial Intelligence - has been in danger because of lack of funds.

# THE DECEMBER SKY

If we have a cold winter (and at the time when I write this column, there is no way of telling!) it may be of interest to know that on January 3 the Earth is at its closest to the Sun: 91,400,000 miles, which is some three million miles closer than it will be in midsummer. The Earth's path is so nearly circular, however, that the changing distance does not have a marked effect, and our seasons are due to the fact that the Earth's axis is tilted to the perpendicular at an angle of 23.5 degrees.

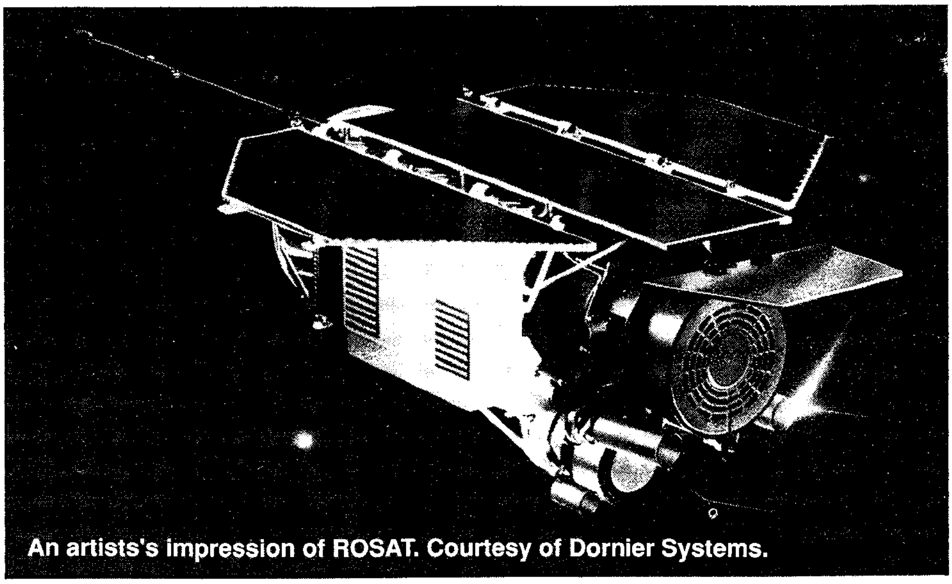
Of the planets, Mercury is to all intents and purposes out of view, and Saturn completely so. Venus can be glimpsed very low in the south-west after sunset, but is not yet well placed; Mars is fading rapidly as it moves away from us, but it is still very prominent in the evening sky, between the two famous star-clusters of the Pleiades and Hyades in Taurus. Even at the end of January, Mars is still brighter than any star apart from Sirius. Strange things have been happening there; the planet's north pole has been covered with a large cloudy 'hood'. Jupiter reaches opposition on January 29, and is therefore visible all through the hours of darkness; it too has been of special interest to planetary observers, because one of the two main belts, the South Equatorial, has reappeared after its period of invisibility. If you have a telescope, you can find a great deal of enjoyment in following the movements of the four large Jovian satellites. Voyager results have shown that they make up a fascinating family: Ganymede and Callisto icy and cratered, Europa icy and smooth, and Io red and violently volcanic!

The Moon is at last quarter on January 7, new on the 15th, at first quarter on the 23rd and full on the 30th. An annular eclipse of the Sun occurs on January 15-16, but as it is then night in Britain I am afraid you will have to go to Australia or Indian Ocean area to see it. It will, however, be worth seeing, as the maximum duration of the annular phase is almost 8 minutes. (In case anyone is unsure of the cause of the phenomenon: an annular eclipse occurs when the Moon passes in front of the Sun at a time when the Earth-Moon distance is almost at its greatest; the Moon then appears smaller than the Sun, so that a ring of sunlight is left showing).

Orion dominates the evening sky, with its two brilliant leaders, the orange-red Betelgeux and the white Rigel. Lower down is Sirius in Canis Major, much the brightest star in the sky. It looks far superior to Rigel - though in fact it is 'only' 26 times as luminous as our Sun, while Rigel could match 60,000 Suns! The yellow Capella, in Auriga, is almost overhead, with Ursa Major (the Great Bear or Plough) at its lowest in the north. The Square of Pegasus is setting in the west; in the east Leo, the Lion, rises in the early hours.

However, at almost the last moment the US Congress restored the full funding of just over 12,000,000 dollars, so that the search can continue. We have to admit that the chances of success are not very high, but at least they are not nil!

## ROSAT ON COURSE


An artists's impression of ROSAT. Courtesy of Dornier Systems.

The ROSAT satellite, launched last June, has now completed its initial tests, and is working well. It is named in honour of the German scientist Wilhelm Rontgen, who discovered X-rays as long ago as 1895. It carries two main instruments, the German XRT (X-ray telescope) and the British-built WFC (Wide Field Camera). Its most important role will be to study radiations at EUV wave-lengths. EUV stands for Extreme Ultra-Violet, that part of the electromagnetic spectrum which lies between normal ultra-violet and the X-ray region.

Up to now this part of the electromagnetic spectrum has been neglected because UEV is strongly absorbed by the interstellar medium and it had been thought that no penetration far beyond the Solar System would be possible. This has proved to be a wrong assumption. The blocking by the interstellar medium is much less than expected, and is also patchy, so that in some directions – for instance, toward that part of the sky marked by the constellation of Canis Major – EUV signals can be received from very great distances.

Before ROSAT, only a few discrete EUV sources were known. The total now is well over 100, and ROSAT may increase this to something like 2000. Some fascinating sources have been found - for instance WFC 1, made up of a very hot white dwarf together with a dim red star. Another white dwarf, HZ 43, may have a surface temperature of about 200,000 degrees. In November the Vela supernova remnant was also detected at EUV wavelengths.

ROSAT has an active life expectancy of between 5 and 7 years, but may last for much longer. Certainly it is already marked down as a success, and it is adding greatly to our knowledge of the universe at hitherto almost unexplored wavelengths.

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INDUSTRY NOTEBOOK

# BIOSENSORS

**By Tom Ivall**

## New-Tech devices flourish in the meeting ground between biology and electronics.

Ever since Luigi Galvani demonstrated the effect of electricity on frogs' two centuries ago, the relationship between biology and electrical science has been deepening.

In medicine, for example, we have developed treatments using electric currents and electromagnetic fields, as well as a great range of instruments for measurement, analysis and diagnosis, assisted by digital signal processing and microcomputers.

## BIOTECHNOLOGY

While we have been increasing our knowledge of electronic phenomena in a vacuum, gases and solid material, biology has also been exploring deeper – into the physics and chemistry of living organisms. Out of this have come specialised fields like molecular biology and biotechnology. the relationship which began centuries ago at the macroscopic level has now penetrated down to the microscopic and common atomic level.

A meeting point between electronics and biology which has become particularly busy is the chemistry of proteins. These complex molecules are essential constituents of all living matter. Animals get fresh supplies through their food.

Protein molecules are formed of chains of amino acids. What distinguishes one protein from another is the sequence of the amino acids in the chain, the way it folds up into a three-dimensional structure and the exact spatial position of each atom of the molecule within this structure.

Knowledge of the composition and structure of proteins enables new drugs and vaccines, consisting of newly designed molecules, to be developed for treating diseases. Here the exact structure of the protein molecule must be established to ensure that the new drug will bind to it chemically at the molecular level. This is where electronics technology comes in.

## SUPERCOMPUTERS

Computerised databases have been used for some time for storing the composition of tens of thousands of proteins. But to investigate molecular structure more advanced techniques are needed – in particular, computer simulation of proteins. Here the amount of computing power required is so enormous that even today's supercomputers are being pushed to their limits by the task.

So the molecular biologists are turning to parallel processors to cope with the job. One particular kind of parallel processor is the artificial neural network (see April 1990 p. 57). Researchers in this field have reported that neural networks can now predict protein structures from amino acid sequences much more accurately than was previously possible.

But apart from the research aspect, proteins are now beginning to appear in new kinds of electronic sensors called biosensors. Unlike conventional sensors, which detect and measure simple physical qualities like heat or light intensity, biosensors respond to the presence of particular organic chemicals in living substances. The first simple 'enzyme electrode' was invented twenty years ago.

Essentially biosensors are analytical devices. Small, neat and robust, they are convenient for direct and rapid testing in fields such as agriculture, health care, biotechnology and the food and drinks industry. So they avoid the need to send biological samples away to 'wet chemistry' laboratories for analysis.

Electronics firms around the world are now beginning to develop these biosensors as commercial products. In the UK they include the Cranfield Biotechnology Centre, Amersham International, Thorn EMI Microsensors, the MRC's National Institute for Medical Research and Cambridge University's Institute of Biotechnology.

Two classes of proteins which are very good at recognising other molecules – and so are selective for sensing purposes – are enzymes and antibodies. Both are being used in biosensors. Enzymes catalyse chemical reactions in living matter. Their molecules combine with the molecules of the sample material to produce different molecules which then separate from the enzyme and leave it free to carry on. Antibodies are formed in response to antigens (disease agents) and are part of the immune system. They recognise and combine with antigens.

## DESIGN PROBLEM

The design problem is to convert the result of the chemical reaction into a useful electrical signal. One approach, adopted by Thorn EMI Microsensors, is to utilise the current control principle in a field-effect transistor (FET). This method derives from the company's ion-selective FET – a modification of the conventional metal-insulator-silicon FET (MISFET) – which has been under development for some time as a more general chemical sensor.

Sensing takes place at the gate electrode of the FET. Coated on the gate region is a silicon nitride insulating layer. On top of this is a layer of material sensitive to pH – hydrogen ion concentration. At the top of the structure is the highly specific enzyme material – for example, *urease* for detecting urea. A bias voltage applies a steady electric field to the gate region through all these layers.

When the biosensor is applied to the test substance, the enzyme catalyses a reaction which results in a change of pH – a change in the hydrogen ion concentration. Since hydrogen ions are positively charged this change of ion concentration – and hence of electric charge – causes a variation, superimposed on the steady bias, in the electric field in the gate region. As a result the drain-source current in the FET varies and an electrical signal is generated in response to the enzyme reaction.

## ANTIBODY BIOSENSORS

Antibody biosensors, for detecting disease agents, are less common. One sensing principle relies on the fact that when an antigen binds to an antibody layer it becomes thicker. This increase can be detected optically, for example by reflecting laser light from an antibody layer on a diffraction grating.

PE

# PRACTICAL ELECTRONICS

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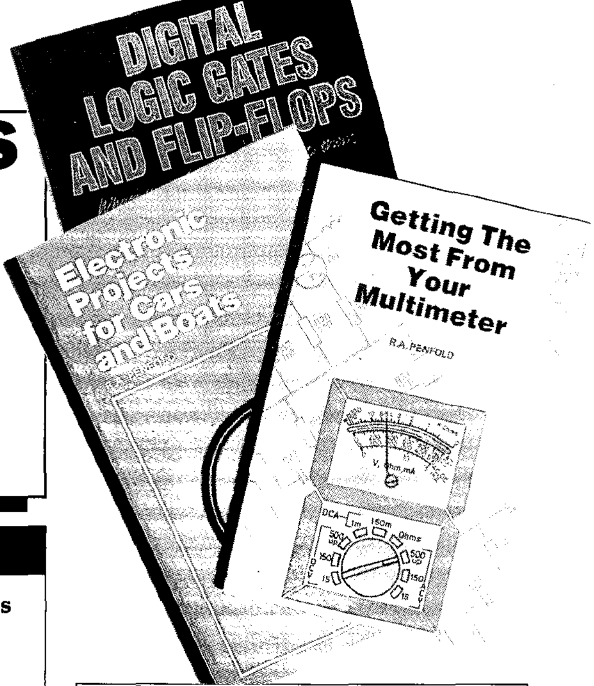
***Here is your Editor's choice of books he thinks will be of interest to electronics and computer enthusiasts***

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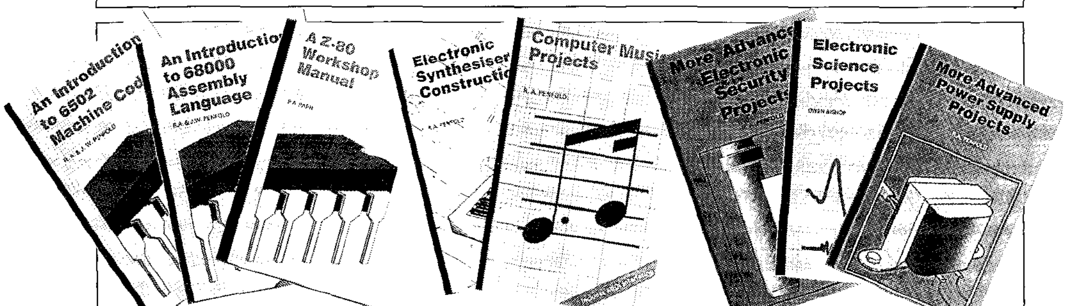


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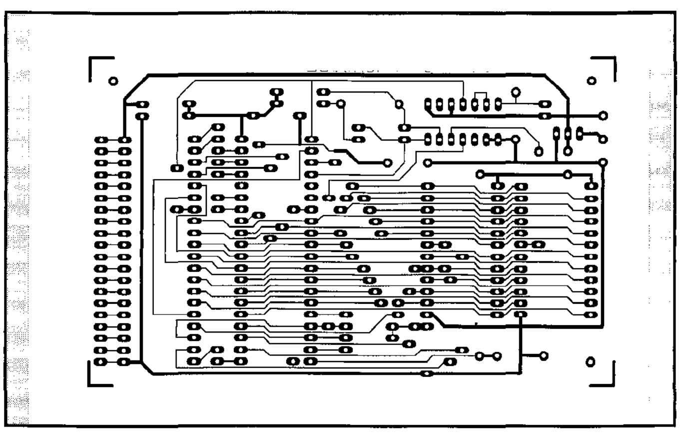

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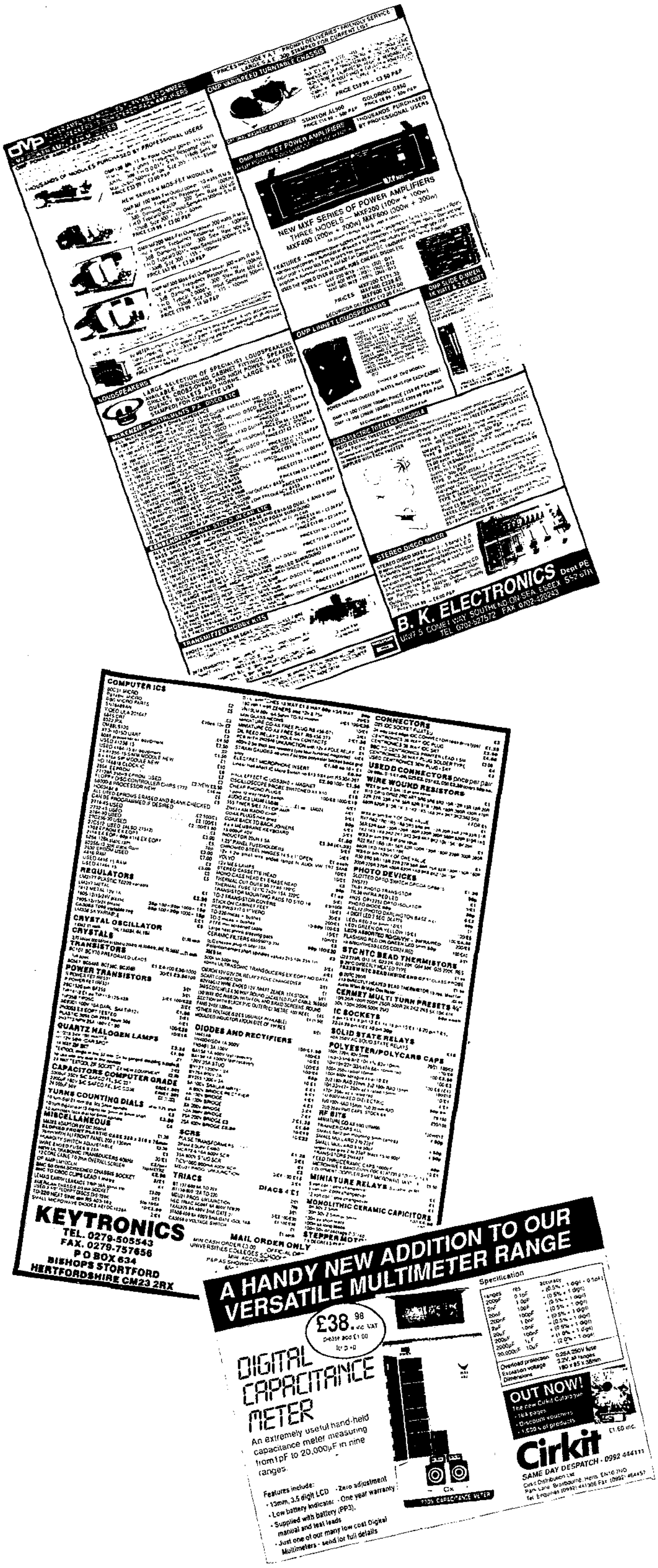


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