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**MAY 2000**

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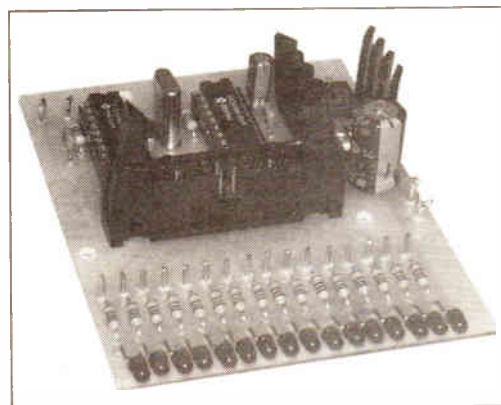
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Our June 2000 issue will be published on Friday, 5 May 2000. See page 323 for details



# NEXT MONTH

## CANUTE TIDE PREDICTOR

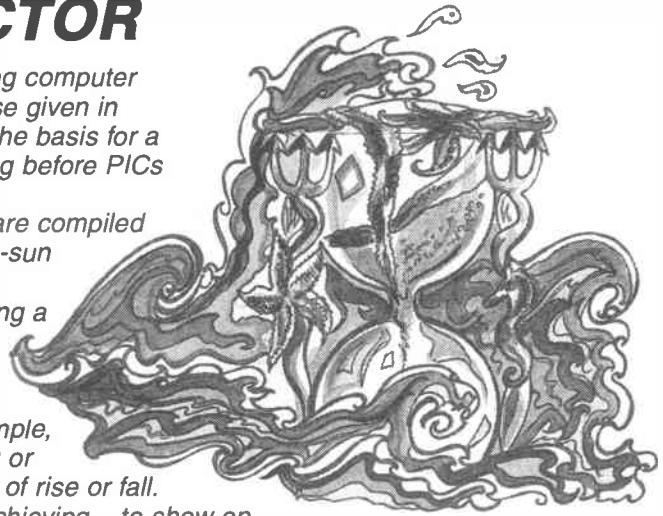
For several years the author experimented with writing computer software intended to produce results that matched those given in published tide tables, and which could ultimately form the basis for a low-power microprocessor controlled tide predictor (long before PICs came along).

Eventually he became aware that official tide tables are compiled not just according to the geometries of the Earth-moon-sun system, but also in relation to local data compiled over generations. There was no hope, therefore, of developing a simple system that could match standard tide table accuracy.

However, most people do not need the accuracy of official tide tables. All they might be interested in, for example, is whether it is better to go to the beach in the morning or afternoon in order to find the tide at the preferred state of rise or fall.

That is what the Canute Tide Predictor is aimed at achieving – to show on an l.c.d., a tide-state bargraph and high-low tide times accurate to within about an hour. The use of a PIC16F876 microcontroller has allowed a very simple unit to be designed.

Anyone who loves the sea, sandy beaches or rocky shore lines will find this design a useful guide when considering a quick trip to the coast.



## TECHNOLOGY TIMELINES – THE FUTURE

It's been interesting and fun looking back over the last 100 years or so to see how we got where we are – quite a staggered path, with all sorts of odd developments coming together to produce major forward steps in technology. Finally we get to peer into the future, it's not quite as exact an art as looking back, but Max and Alvin are taking a stab at it from their starting point at the forefront of technology in the USA. We may not need to wait long to see if what they predict actually happens with the rate of development of new technology.

## ATMOSPHERIC ELECTRICITY

The ionised layers of the atmosphere extend from about 40km to 200km (25 to 125 miles) above the Earth. This ionisation is caused by the "Solar Wind" passing the Earth and leaves the upper atmosphere positively charged.

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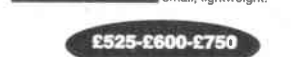
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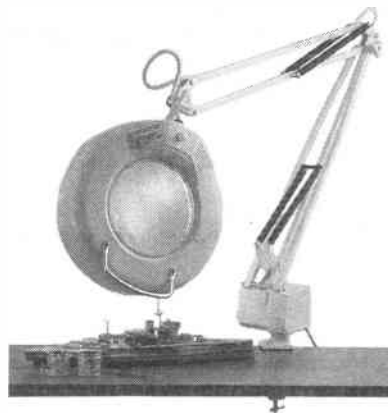
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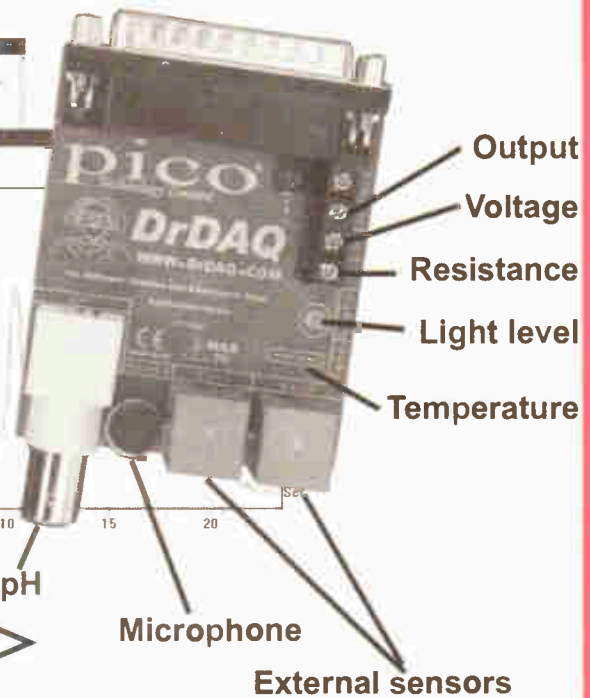
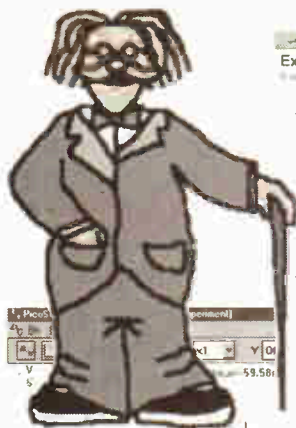
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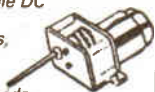


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### CHIPPER

Every so often a new chip comes along that looks like it will be very popular for a wide range of applications, just such a chip forms the basis of our main cover subject this month – the Versatile Microphone/Audio Preamplifier. The problem with specialised chips of this nature is that sometimes they don't stay in production for a long period and, for hobbyists, who seem to like to build projects years after they have been published, this can obviously cause headaches. It's why we advise readers to check that all components are still available before commencing any project in a back dated issue. Whilst it is sometimes possible to find old chips (particularly via the internet) they are often highly priced and obviously supplies do eventually get exhausted.

We do, however, have high hopes that this chip will be around for some time as it appears to have been designed to cover a very wide range of applications, including use for microphone inputs to PCs. This fact alone will ensure high demand and therefore longevity, should it be taken up by the computer manufacturers. Let's hope it is. However, that in itself does not entirely get us out of the woods – the PC makers will no doubt use a surface mount device which does not necessarily guarantee continuing availability of the d.i.l. version. Once development has taken place, the industrial requirement for d.i.l. versions often falls dramatically so they can sometimes be discontinued.

### NO WAY

I suppose the answer is to build it now and hope for the best. There seems to be no way of knowing which chips will hang around and also no way of knowing of all the chips that have been discontinued. We usually only find this out when readers ring us with buying problems. Thankfully we can often help them out, but we have an ever increasing list of past projects that are no longer viable because of obsolete components. Unfortunately it is not a problem we expect to improve as time goes by.



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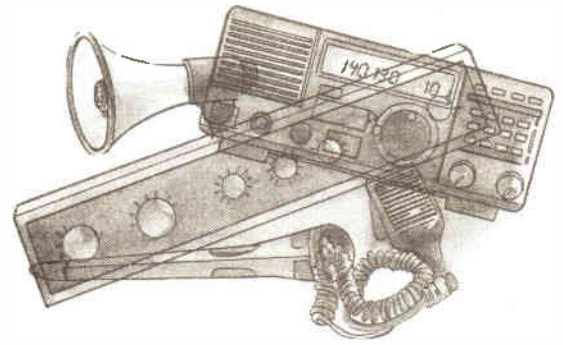
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# Constructional Project

# VERSATILE MIC/AUDIO PREAMPLIFIER

RAYMOND HAIGH



Use one of the latest chips on the block to produce an audio pre-amp, with a.g.c., compression, limiting and noise reduction.

INTENDED primarily as a means of processing microphone inputs to computers, the SSM2166P integrated circuit (manufactured by Analog Devices) has a wider range of possible applications. Public address and surveillance systems immediately spring to mind, and the device will be of particular interest to radio enthusiasts, especially now that the popular Plessey 6270 i.c. mic/pre-amp, with voice gain, is no longer available.

This article describes how the new i.c. can be used for a variety of signal inputs, and additional circuitry is given for readers who require a signal-strength meter.

## THE CHIP

The various amplifying and control stages built into the SSM2166 chip are shown in Fig.1.

Signal inputs are buffered by op.amp A, internally connected to a rectifier stage, B, which produces a d.c. voltage which varies in proportion to signal strength.

After processing by the control circuit, C, the d.c. voltage is used to fix the large and small signal gain of a second op.amp, D.

## AMPLIFIERS

The input impedance of buffer amplifier, A, is 180 kilohms (180k) and its gain can be set, by external feedback resistors, between 0dB and 20dB. There is a standing d.c. voltage on the input, and a blocking capacitor must be used.

The input and output impedances of the controlled amplifier, D, are 1k, and 75 ohms, respectively. A standing d.c. voltage necessitates the use of a blocking capacitor at the output.

Provision is made for setting the nominal gain of the controlled stage between 0dB and 20dB, but a.g.c. action will increase amplification, at the lowest signal levels, to as much as 60dB. The output can be muted.

Interestingly, the noise generated by the controlled stage is designed to be at a minimum when its gain is at a maximum, and this significantly improves the overall signal-to-noise ratio of the system.

## RECTIFIER

The circuit of the rectifier, or level detector stage (B), has been specially developed for this application. It produces a d.c. control voltage which is proportional to the log of the true r.m.s. value of the input signal.

The speed at which the control voltage responds to changes in signal level, or the "attack time", can be controlled by the user. Response to high-level changes is automatically speeded up by the i.c. in order to minimise the duration of any overload.

## CONTROL CIRCUIT

The control circuit (C) enables the user to programme the performance of the i.c. in a very comprehensive way, and the amount of signal compression can be set between zero and 60dB.

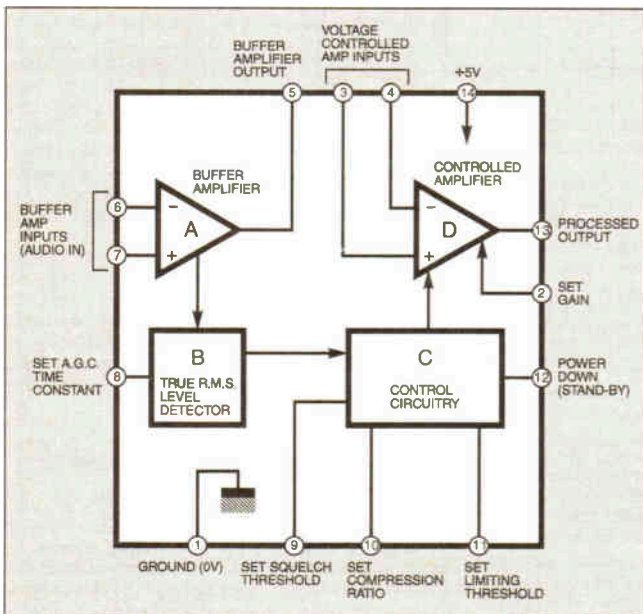


Fig.1. Internal block schematic for the SSM2166P microphone preamplifier, with variable compression and noise gating.

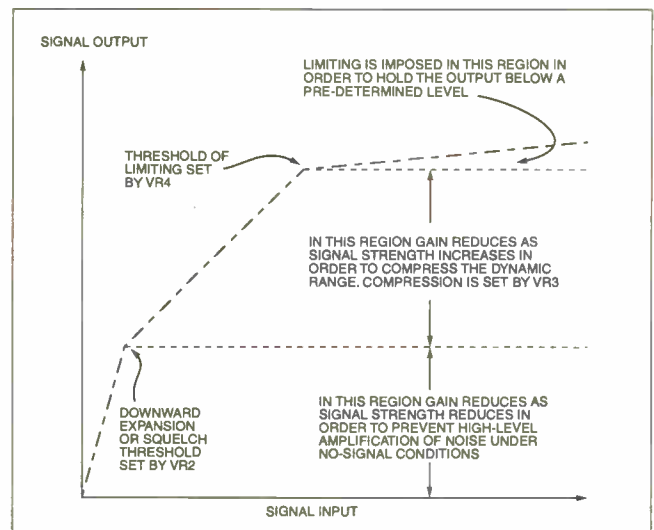


Fig.2. Relationship between limiting, compression and downward expansion or "squelch".

Signal limiting can also be applied to prevent the occasional transient exceeding the desired maximum output. It can be set at outputs ranging from 30mV to 1V. Above this threshold, the maximum compression ratio of 15:1 is applied.

The response of the system to very low level inputs can be reduced in order to prevent the amplification of noise under no-signal conditions. The threshold of this downward expansion (the lower the signal the less it is amplified), can be set at inputs of between 250µV and 20mV.

Provision is made for the device to be placed in a "power-down" or stand-by mode, and this feature will be of particular interest when it is used in sophisticated surveillance systems. In this state, current consumption is reduced to around 10µA and the input and output ports assume a high impedance.

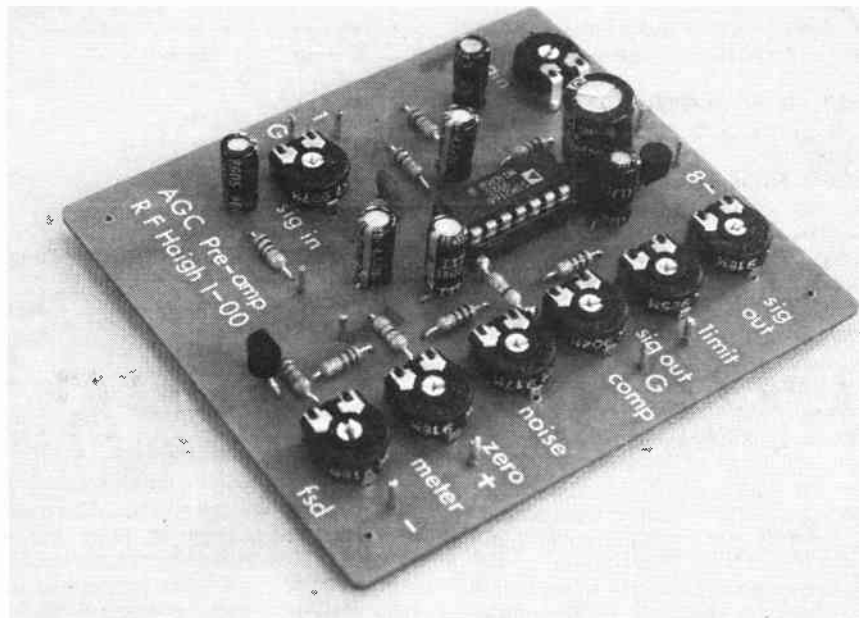
User programmable control circuitry, coupled with the complex rectifier or level detector, contribute significantly to the chip's performance. The relationship between the noise reduction, compression and limiting functions is displayed in Fig.2.

### RATINGS

No doubt with computer circuit compatibility in mind, the SSM2166 is designed for a 5V supply. The absolute maximum supply voltage is 10V. Current consumption is approximately 10mA.

The maximum input to the buffer is 1V, and the maximum output from the controlled amplifier is 1.4V r.m.s. for 1 per cent total harmonic distortion. Frequency response extends well into the r.f. spectrum.

Static discharges can damage the i.c., and the usual precautions (discharging the body) should be taken when handling and connecting it into circuit.



The SSM2166P is embedded in a 14-pin, dual-in-line package, and the suffix "P" refers to the standard-size version. This is the type most likely to be stocked by suppliers. However, surface-mount types are also manufactured: these carry the suffix "S".

### CIRCUIT DETAILS

The full circuit diagram for the Versatile Mic/Audio Preamplifier, incorporating a signal strength meter, is given in Fig.3. Provision for controlling so many functions results in a plethora of preset potentiometer controls. However, they do enable the signal processing to be tailored to individual requirements, and their adjustment is not critical or difficult. A summary of their various functions is set out in Table 1.

Preset VR1 permits adjustment of the input signal level to prevent overload and to optimise the performance of the circuit. Its value is appropriate for moving coil and electret microphones, and for audio signals derived from most transistor circuits. Keeping the value below 5 kilohms increases the stability margin of IC1.

Power can be supplied to an electret microphone's integral f.e.t. (field-effect-transistor) buffer via resistor R1, and C1 acts as a d.c. blocking capacitor. The input arrangements for alternative microphones and other signal sources are discussed at greater length later.

The input signal to IC1 is applied to the non-inverting (+) input of the buffer amplifier stage (Pin 7 - see Fig.1) via blocking capacitor C2. This i.c. has an extended

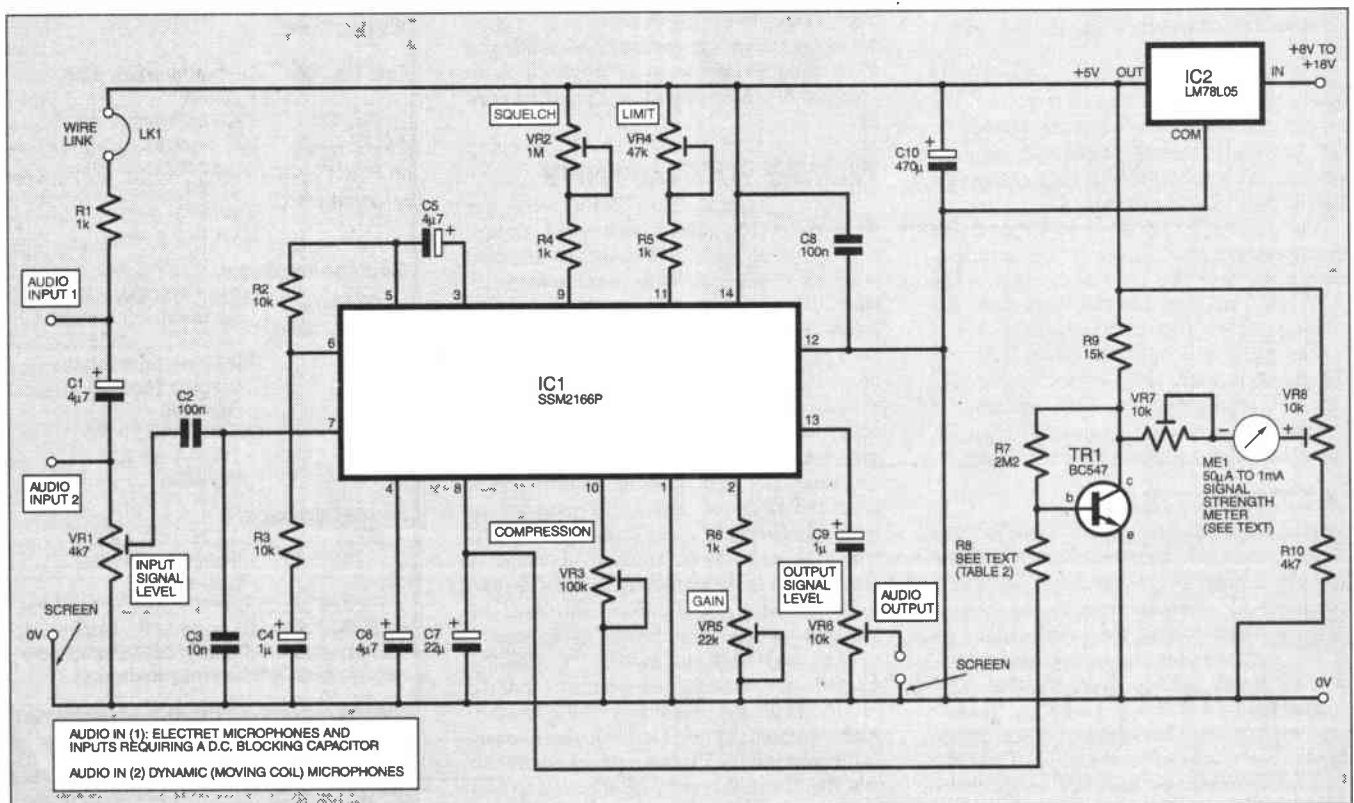


Fig.3. Complete circuit diagram for the Versatile Mic/Audio Preamplifier.

frequency response and C3 introduces a measure of roll-off above 20kHz or so, again in the interests of stability.

## BUFFER GAIN

The gain of the buffer amplifier is set at 6dB by resistors R2 and R3, and this is likely to be sufficient for most purposes. Gain can be increased to a maximum of 20dB by decreasing R3 to about 1.2 kilohms. Adding this to the gain of the controlled amplifier results in an overall system gain, when signals are too small to initiate compression, of 80dB.

This is a great deal of amplification in a small package, and particular care must be taken with the screening and routing of input and output leads, and the connections to a shared power supply, if instability is to be avoided. Separate ground, or 0V leads, from signal source circuitry, the preamplifier, and the power amplifier, should be run to a common point at the power supply. The screening braid of signal cables should be connected to ground at the preamplifier end *only*.

If desired, the gain of the buffer can be set at unity by deleting R3 and inserting a wire link in place of resistor R2 (to connect pin 5 and pin 6). Blocking capacitor C4 maintains the correct d.c. conditions.

## CONTROLLED AMPLIFIER

The output from the buffer stage (pin 5) is connected, via d.c. blocking capacitor C5 to the non-inverting (+) input (pin 3) of the controlled amplifier stage. A capacitor of identical value, C6, at pin 4 connects the inverting (-) input to ground (0V). (This connection makes any electrical noise on the ground rail appear as a common mode signal to the controlled amplifier and the differential input circuitry rejects it).

The nominal gain of the controlled amplifier can be set, by preset VR5, between unity and 20dB. Resistor R6 ensures that the gain does not fall below unity.

Switched muting can be achieved by grounding pin 2 via a 330 ohm resistor (the switch should be located at the ground or 0V rail end). Switch clicks can be suppressed by connecting a 10nF capacitor between pin 2 and ground.

The i.c. can be put in stand-by mode by disconnecting pin 12 from ground and connecting it, via a 100 kilohms resistor, to the +5V rail. Provision has not been made for muting or powering-down on the p.c.b.

The processed output is taken from pin 13 and connected, via d.c. blocking capacitor C9, to preset VR6. This enables the output signal level to be adjusted to suit the input sensitivity of the power amplifier.

## ATTACK TIME

The response or "attack" time of the a.g.c. system can be controlled by adjusting the value of the rectifier reservoir capacitor C7. The i.c. manufacturer suggests a value within the range 2.2μF to 47μF, with smaller capacitors being suitable for music and the larger for speech.

Too low a value will result in "pumping" effects, with background noise "rushing up" between bursts of speech. This will become increasingly apparent as the compression ratio is raised.

Table 1: Preset Control Functions

Pre-set	Value	Function
VR1	4k7	Set input signal level: clockwise to increase.
VR2	1M	Set threshold of downward expansion (squelch): clockwise to lower.
VR3	100k	Set compression: clockwise to increase.
VR4	47k	Set threshold of signal limiting: clockwise to lower.
VR5	22k	Set gain of controlled amplifier: clockwise to increase.
VR6	10k	Set output signal level: clockwise to increase.
VR7	10k	Set signal strength meter pointer at full scale (when strongest signal being processed): clockwise gives clockwise pointer movement.
VR8	10k	Set signal strength meter pointer at zero (under no-signal conditions): clockwise gives clockwise pointer movement.

Conversely, too high a value will excessively slow the response of the system to changes in signal level. The 22μF component specified for C7 has been found to work well with both speech and music inputs.

The attack time is controlled mainly by the value of C7, but the much longer "decay" time is dependant upon this capacitor and the internal control circuit. Fast attack and slow decay help to reduce the pumping effect, which seems far less pronounced with this i.c. than with simpler audio a.g.c. systems.

## COMPRESSION

The amount of compression is determined by preset VR3, which connects pin 10 to ground. There is no compression with the potentiometer set to zero. When its resistance is at maximum, a 60dB change in input level (above the downward expansion or squelch threshold) changes the output by less than 6dB.

The onset of limiting is controlled by preset VR4. Setting this potentiometer to maximum resistance fixes it at 30mV. With VR4 at minimum resistance, it is around 1V r.m.s. Above the threshold of limiting, a 15:1 compression ratio is imposed, irrespective of the setting of compression control VR3.

## NOISE REDUCTION

Preset potentiometer VR2 sets the threshold below which downward expansion (gain reduces as the signals become weaker) is applied. With maximum resistance, downward expansion starts at signal levels in the region of 250μV. Turned to zero resistance, the threshold is raised to around 20mV.

Gain rises to a maximum under no-signal conditions with all conventional a.g.c. systems, and the amplification of external and internally generated noise produces a loud and tiresome hiss in the speaker or 'phones. The i.c.'s noise reduction facility, which operates as a "squelch" control, is very effective in overcoming this. It can reduce output noise below the level of audibility when signal levels fall to zero.

With any squelch system, a need to resolve very weak signals overlaid by noise compromises the usefulness of the feature. Radio enthusiasts with a particular interest in it could mount VR2 as a panel control so that the threshold could be adjusted to suit reception conditions.

## COMPONENTS

### Resistors

R1,R4, R5,R6. 1k (4 off)  
R2,R3. 10k (2 off)  
R7 2M2  
R8 (See Table 2)  
R9 15k  
R10 4k7  
All 0.25W 5% carbon film

See  
**SHOP**  
**TALK**  
page

### Potentiometers

VR1 4k7 enclosed carbon preset, horizontal  
VR2 1M enclosed carbon preset, horizontal  
VR3 100k enclosed carbon preset, horizontal  
VR4 47k enclosed carbon preset, horizontal  
VR5 22k enclosed carbon preset, horizontal  
VR6, VR7, VR8 10k enclosed carbon preset, horizontal (3 off)

### Capacitors

C1, C5, C6. 4μ7 radial elect. 10V (3 off)  
C2, C8. 100n ceramic (2 off)  
C3 10n ceramic.  
C4, C9. 1μ radial elect. 10V (2 off)  
C7 22μ radial elect.  
C10 470μ radial elect.

### Semiconductors

TR1 BC547 npn low power transistor (or similar i.e. BC239, BC548)  
IC1 SSM2166 microphone preamp (Analog Devices)  
IC2 LM78L05ACZ +5V 100mA voltage regulator

### Miscellaneous

ME1 50μA to 1mA f.s.d. moving coil meter (see text)

Printed circuit board available from the EPE PCB Service, code 260; 14-pin d.i.l. socket; screened cable; multistrand connecting wire; solder pins; solder etc.

Approx. Cost  
Guidance Only

**£17**  
excluding meter



## POWER SUPPLY

The maximum safe supply voltage is 10V, and it should be noted that, under a light load, a fresh 9V alkaline battery will usually deliver a higher voltage than this.

However, in order to ensure the correct operation of the device, and provide a high degree of isolation from other equipment sharing the same power supply, a 5V 100mA voltage regulator, IC2, is included in the circuit. This enables supplies with outputs ranging from 8V to 18V (or more, depending on IC2 rating) to be used.

Bypass capacitors C8 and C10 shunt the noise in the regulator output to ground. Note that C8 is essential to the stability of IC1 and it must be located as close as possible to pin 14, even when the unit is battery powered.

## SIGNAL STRENGTH METER

Some readers, especially those wishing to incorporate the unit into a radio receiver, may welcome the provision of a signal strength meter. This is included in the circuit diagram of Fig.1 and consists of transistor TR1, meter ME1 and associated components.

The a.g.c. control voltage appears on pin 8 of IC1. It ranges from 290mV under no-signal conditions to approximately 720mV with high level inputs.

Transistor TR1, configured as a d.c. amplifier, ensures that IC1's a.g.c. line is only lightly loaded, even when a 1mA meter is used. It forms one arm of a bridge circuit, the other three being its collector load, R9, and the potential divider chain comprising preset VR8 and resistor R10. The bridge is balanced, and the meter set at zero under no-signal conditions, by preset potentiometer VR8.

When a signal is being processed, the rising a.g.c. voltage on the base (b) of TR1 increases its collector current and, hence, the voltage drop across resistor R9. This unbalances the bridge and drives the meter pointer over. Preset VR7 adjusts the sensitivity of the meter so that the pointer can be set just short of full-scale deflection (f.s.d.) when registering a strong signal.

The circuit can be made to accommodate meters with full-scale deflections ranging from 50µA to 1mA by adjusting the value of resistor R8. This resistor controls the flow of current through the base-emitter junction of transistor TR1, and values to suit a range of meter f.s.d.s are given in Table 2. Bias resistor R7 provides a measure of negative feedback which helps to stabilise the operation of the circuit.

Almost any small-signal npn transistor should prove suitable for TR1, and a 2N5827 or 2N5828 could be used in addition to the types listed in the Components list. These devices have different case styles and the base connections must be checked.

**Table 2: Signal Strength Meter**  
(Values of R8 for different meter sensitivities)

Meter f.s.d.	R8
50µA	1M
100µA	470k
500µA	100k
1mA	47k

## CONSTRUCTION

All the components, with the exception of the meter ME1, are assembled on a small, single-sided, printed circuit board (p.c.b.). The topside component layout, together with a full-size underside copper foil master pattern, is shown in Fig.4. This board is available from the *EPE PCB Service*, code 260.

Commence construction in the usual way by mounting the smallest components first working up to the largest, but fit IC1, IC2 and TR1 last (see earlier comments

about the static sensitive nature of IC1). A holder for IC1 will facilitate substitution checking. Solder pins, inserted at the lead-out points, will ease the task of off-board wiring.

## SPOT-CHECKS

When all the components have been soldered in position on the p.c.b., double-check the orientation of electrolytic capacitors, the i.c.s and the transistor. Also, check the p.c.b. for bridged tracks and poor solder joints.

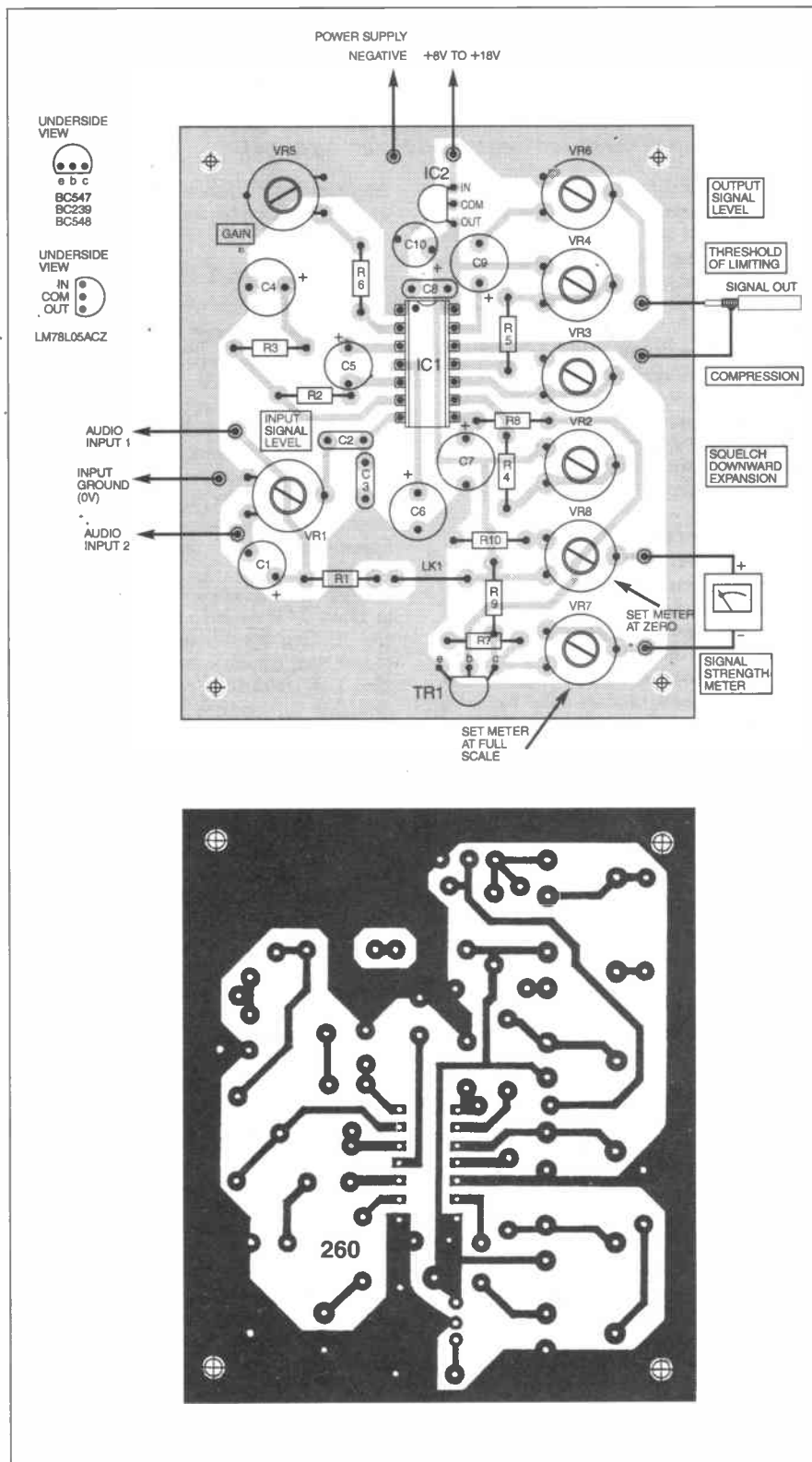


Fig.4. Printed circuit board component layout, interwiring details and full size underside copper foil master.

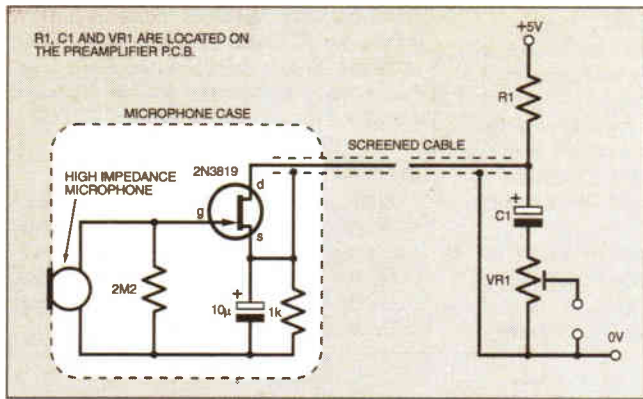


Fig.5. The line-powered buffer stage built into electret microphones can also be used for ceramic and crystal types. (Most f.e.t.s will function in this circuit with the source grounded, eliminating the need for the source resistor and bypass capacitor.)

Next, with IC1 "out of circuit", connect a supply voltage of between 7V and 9V and check that the output from regulator IC2 is producing 5V. A fault in this device, or its wrong connection, could result in the destruction of IC1 when higher voltages are applied.

Once all is well, place IC1 in its socket (checking orientation), connect, via screened cable, a signal source and a power amplifier. Adjust the various preset potentiometers until the processing meets your requirements. All preset functions are summarised in Table 1 for ease of reference.

## MICROPHONES

The unit works well with dynamic (moving coil), electret, crystal and ceramic microphones. Screened cable must, of course, be used to connect any type of microphone to the preamplifier.

Very high quality studio microphones can be insensitive and require balanced feeders to minimise hum pick-up. The pre-amplifier described here is configured for unbalanced inputs, and is not likely to be suitable, as it stands, for microphones of this kind.

A few words about the various types of signal input may prove helpful.

### Dynamic Microphones

Dynamic microphones are manufactured with impedances ranging from 50 ohms to 600 ohms. Output tends to be greatest with the higher impedance units.

This type of microphone should be connected to Input 2 (i.e., directly across preset VR1), and the wire link *must* be removed to isolate resistor R1 from the 5V rail.

### Electret Microphones

Electret microphones are a modern development of the capacitor microphone (a permanently charged diaphragm, the electret, eliminates the need for an external charging voltage). The output from the actual unit is low and at a high impedance, so these microphones have an integral f.e.t. buffer. The drain load for the internal f.e.t. is provided at the amplifier end of the cable (resistor R1 in Fig.3), to facilitate line powering.

Electret microphones *must* be connected to Input 1, and the wire link must be in place to connect resistor R1 to the supply rail. The 1 kilohm drain load (R1), fed from the 5V supply, should ensure the

optimum performance of most microphones of this kind.

### Crystal and Ceramic Microphones

Crystal and ceramic microphones rely upon the piezo-electric effect to produce a signal voltage. The vibrating diaphragm induces stresses in a wafer of crystal, often Rochelle salt, or in a barium titanate element in the case of ceramic units.

These microphones should be connected to Input 2. They have a high impedance, and feeding them into preset VR1 will reduce their response to low audio frequencies. Low frequency roll-off is, however, desirable for communications work, and more is said about this later.

The use of long connecting cables will attenuate the signal but have little effect on frequency response (cable capacitance is modest compared to the self-capacitance of these microphones, which can be as high as 30nF).

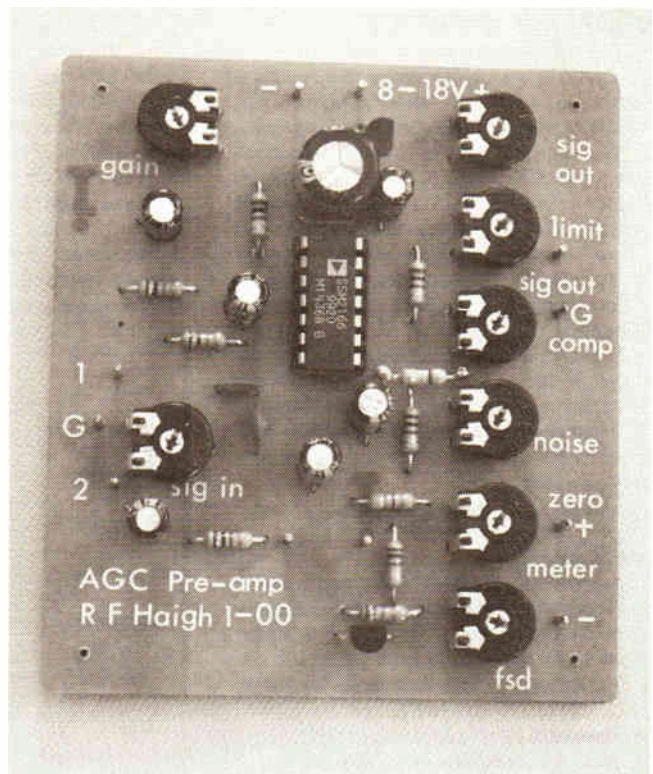
If an extended frequency response is required from microphones of this type, the use of an external, line-powered, f.e.t. buffer, as built into electret microphones, is recommended. This will also prevent signal losses when long cables are used.

A suitable circuit diagram is given in Fig.5 and the circuit can be built inside the microphone case. When this arrangement is adopted, resistor R1 must, of course, be connected to the supply rail, and the signal must be fed to Input 1.

## RADIO RECEIVERS

Audio derived a.g.c. is often incorporated into direct conversion radio receivers. Even simple superhets can benefit from this form of control (sometimes a conventional r.f. derived system is not very effective when amateur single-side-band signals are being processed).

Direct conversion and regenerative receivers will require a single transistor audio amplifier, after the product detector or regenerative detector, in order to ensure sufficient signal voltage for the SSM2166P. The output from the detector stage in most superhets will be more than adequate.



Layout of components on the completed circuit board. The "Signal Strength Meter" components, except the meter, have been included on the board (bottom right).

Radio receivers should be connected to Input 1, and the wire link removed. The orientation of electrolytic capacitor C1 will usually be correct when the receiver has a negative ground or 0V rail.

However, some diode detectors in superhets are configured to provide an output which is negative going with respect to ground (to suit the receiver's a.g.c. circuit). The polarity of C1 will need to be reversed when equipment of this kind is connected.

## SIGNAL PROCESSING

The preamplifier's frequency response is reasonably flat from below 100Hz to more than 20kHz. Speech clarity, especially under noisy conditions, can be improved by "rolling off" frequencies below 300Hz and above 3000Hz, and active or passive band-pass filters are often used for this purpose.

A big improvement can, however, be made by modifying some of the coupling and bypass components in the preamplifier. Constructors wishing to limit the frequency response in this way should reduce the value of capacitor C9, to 47nF (a Mylar or ceramic capacitor is then suitable). This will attenuate the lower frequencies.

Wiring a 220nF ceramic capacitor across preset VR1 will attenuate the higher frequencies. Although extremely simple, these measures are quite effective. □



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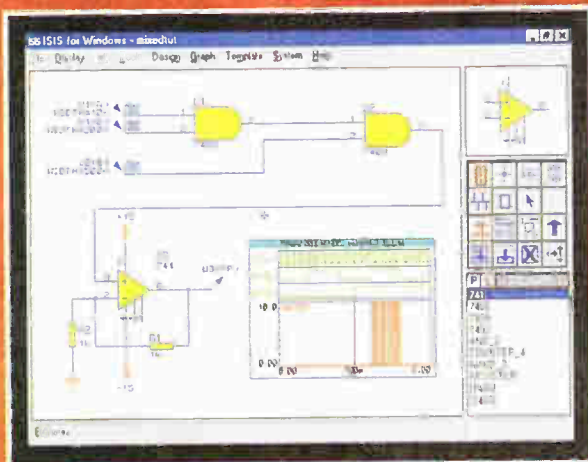
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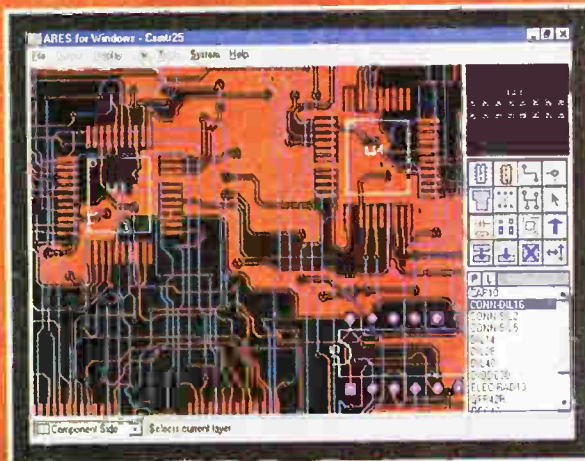


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## BACK TO THE FUTURE WITH MILLIPEDES

Millipedes may help bring back punched card technology for PC data storage. Barry Fox reports.

A TEAM of researchers from IBM's laboratory in Zurich recently revealed their road map for the future of data storage. One surprise is that punched cards are due for a comeback, but around a million times smaller than they were the first time round.

The real density of hard disk recorders is now increasing at 120 per cent per year, thanks to IBM's 1988 discovery of GMR, the giant magneto-resistive material which was ready for commercial exploitation two years ago and is now used in 70 per cent of all hard drive read heads – either made by IBM or under licence.

GMR is a multi-layer sandwich of magnetic and non-magnetic materials which show dramatic changes of resistance in a changing magnetic field. This makes the read head ten times more sensitive, and so lets it detect smaller magnetic domains.

### Hard Drive Density

Currently hard drives can record around 20 Gigabits of data for every square inch (6.45cm<sup>2</sup>) of surface area and 35 Gbit/sq.inch, drives are already working in the lab. The likely practical limit looks like being 100Gbit. At this density the individual magnetic domains are so small and close that they affect each other, making storage unreliable. Before this limit is reached, the current method of recording a signal, with a miniature inductive head, will have become unworkable.

IBM's Magneto-electronics team leader, Dr Stuart Parkin, believes that in two years time hard drives will have to use vertical, instead of horizontal, recording. For VR the domains are switched by a field which aligns the magnetic particles through the disk coating.

IBM's Microdrive, the hard drive no bigger than a large postage stamp, currently stores 340 Megabytes, or nearly 900 still pictures from a video camera. The next Microdrives will hold 1GB. By comparison an 8MB Compact Flash card holds around 20 pictures.

So what happens when disk drives run out of space? Dr Bernard Meyerson, IBM's Director of Telecommunications Technology, dismisses the idea that optical disk can take over from magnetic hard disks.

"IBM has worked for years on optical storage, including disks with several layers to increase density. But there is a basic limiting factor – the wavelength of light".

### Millipede Tips

Big Blue's Blue Sky research efforts are now concentrated on an extraordinary new

technology called Millipede. A silicon chip, the size of a finger nail, is made with a matrix of 1024 tiny cantilever arms, each with a sharp tip, around 1nm in size. When the tips are moved, by feeding current to activate drive coils, they press down on a spinning plastic film disk to create tiny indentations. These can then be read by sensor tips.

The fundamental science on Atomic Force Microscopy was done in 1980, and won a Nobel Prize for IBM's Dr Gerd Binnig in 1986. The first laboratory demonstrations are now nearly ready. "It's back for the future", says Gerd Binnig, alluding to the original punch card, developed in the last century for census data processing and then used by early computers.

But whereas original punch cards had permanent perforations, the new Millipede recording material can be erased, by heating the plastic to re-flow depressed areas. The chip moves across the surface, in a scanning raster, writing 1GB of data in a 3mm x 3mm area.

The write/read system must be kept

surgically clean, but the techniques used to keep hard drives clean are applicable. Air is continually blown over the surface, through very fine filters.

### Tunnelling Ram

There are also new developments coming in Random Access Memory. Current RAM needs power to retain data. TMJ (tunnelling magnetic junction)-RAM retains data even when the power is switched off. So it works like flash memory, but with much higher capacity, and much lower power needed for writing. With Magnetic RAM a PC could boot up within seconds.

The system relies on the ability to detect and control the spin parameters of electrons in ferromagnetic materials. Switching at low power is possible because of the quantum physics phenomenon known as tunnelling, whereby if enough electrons confront a barrier, some will pass through, even though their energy state is theoretically too low to allow it.

## MICROCHIP HANDBOOK



MANY of you will already have found how useful Microchip's *Embedded Control Handbook* can be when writing PIC microcontroller software. The latest update to this book has been released and provides a comprehensive reference tool for anyone using PICs and related products.

The 848-page updated handbook provides current application notes, technical briefs and reference designs which have been written and published since the previous edition. The book can be obtained through any authorised Microchip representative. The material is also available individually on Microchip's website at [www.microchip.com](http://www.microchip.com).

It is interesting to note from another Microchip press release that the organisation is offering a comprehensive University Programme within the UK, designed to help university professors give their engineering students a hands-on understanding of PICs and related products. Details can be found via [www.microchip.com/university](http://www.microchip.com/university).

Microchip's UK HQ is at Microchip House, 505 Eskdale Road, Winnersh Triangle, Wokingham, Berks RG41 5TU. Tel: 0118 921 5858. Fax: 0118 921 5835.

## Greenweld Catalogue

YOU will be glad to hear that Greenweld have reopened. Chris Knight tells us that after many months of work they have finally got the business going again. You will probably recall that the original Greenweld Electronics ceased trading last year, but the remaining stock was astutely bought by Chris and Tim Knight and Geoffrey Carter.

The trio have a scientific background and wide business experience, along with interests ranging from computers to cars and robots to recycling.

We are pleased to have received the new Greenweld catalogue, the first under the new ownership and management team. The catalogue lists many ranges of the types of component that anyone involved in electronics is likely to need, not only resistors, capacitors, potentiometers, logic i.c.s, l.c.d.s and so on, but also items such as meters and tools, hardware and surplus stocks, and there is a selection of books as well.

Good wishes to Greenweld from us all at *EPE*.

For more information, contact Greenweld Ltd., Dept EPE, PO Box 144, Hoddesdon, Herts, EN11 0ZG. Tel: 01277 811042. Fax: 01277 812419. Web: [www.greenweld.co.uk](http://www.greenweld.co.uk). E-mail: [admin@greenweld.co.uk](mailto:admin@greenweld.co.uk).

## MILLENNIUM TIME CAPSULE

THE Millennium Time Capsule is a major national project in celebration of the new millennium. Businesses, schools, clubs and the general public are invited to take part in this prestigious event and to send a personal message to future generations. The Millennium time capsule will be buried for 200 years. Inside, contributors will have their own box containing whatever they wish to include. Photographs, videos, books, tapes, letters – the list is as long as your imagination.

The time capsule will be the largest ever constructed, providing a snapshot of the UK at the end of the millennium. But it will also be a very personal record. Every contributor will be sent certification, identifying their box within the capsule. In this way individual boxes can be passed down from generation to generation and inherited by our descendants in the year 2200.

The massive site will house thousands of time capsules from people from all over Britain and abroad. Time capsules can be sent to the project throughout the year 2000. The site will be sealed in 2001 and shall remain buried for 200 years. A trust is being established to ensure the site is excavated in 2200. Anyone can take part by filling a time capsule pack and sending it back to the project. Each pack contains a time capsule measuring 340mm x 250mm x 80mm, along with specialised folders and envelopes which help to preserve the items within it.

Records of the project, including the participants and location of the site shall be kept with The International Time Capsule Society in Atlanta, key regional record repositories in Britain and within the records of the project itself.

The location of the site will be announced later this year.

Everyone who takes part receives a certificate giving them legal title to their time capsule and its contents, allowing them to leave their legacy to future generations.

Packs can be ordered by sending a cheque for £41 made payable to: The Millennium Time Capsule Project and sent with the participants name and address to: The Millennium Time Capsule Project, PO Box 736, Newcastle upon Tyne NE99 1LQ. Tel: 0191 261 6784. Fax: 0191 232 1274. E-mail: [editorial@millennium-timecapsule.com](mailto:editorial@millennium-timecapsule.com).

Alternatively, packs can be ordered through the website at: [www.millennium-timecapsule.com](http://www.millennium-timecapsule.com).

Why not tell us, for possible inclusion in *Readout*, what you are sending or would like to have sent if the capsules had been large enough? Replies may be serious or humorous (but at least *loosely* connected with electronics)!

## WIND POWER

A BOOK called *Windpower Workshop: Building your own wind turbine*, has been written by Hugh Piggott, the technical consultant to the BBC 1 docusoap *Castaway 2000*, in which the castaways rely on renewable energy for their power needs.

Hugh has lived for 25 years on a similar island and runs his own wind turbine company. His book is based on his knowledge of wind power harnessing and is aimed at helping budding survivalists, hobby engineers, self-sufficiency hopefuls and students of renewable energy to learn more about wind power.

The book is priced £10 + £1.75 p&p, and available by mail order from the Centre for Alternative Technology, Machynlleth, Powys SY20 9AZ. Tel: 01654 702400. Fax: 01654 702782. E-mail: [media@catinfo.demon.co.uk](mailto:media@catinfo.demon.co.uk). Web: [www.cat.org.uk](http://www.cat.org.uk).

## Three Counties Radio & Computer Rally

SUNDAY 21 May 2000. By popular demand following the 1999 rally, the Three Counties annual radio and computer rally is to be staged a week *before* the Spring Bank holiday. It will be held at the Perdiswell Leisure Centre, Bilford Road, Worcester.

For those not familiar with the venue, the following facilities are available: full restaurant services from 7 a.m., licensed bar from 11 a.m., all traders in two adjacent halls, easy access to the halls which are at ground level, free parking for 900 cars and coaches.

The organisers point out that, being close to the City Centre, wives and children can spend a pleasant day in Historic Worcester, sight seeing, shopping or a boat trip on the river Severn (we'd like to ask why wives and children should be shuttled off – we are sure they are just as interested in what the rally has to offer as the rest of us are!).

For more details contact William E. Cotton G4PQZ, tel/fax: 01905 773181 (for fax please ring first).

## Farnell's Catalogue

NO longer need you complain that "the Farnell catalogue is great but it's just too big"! This renowned supplier is separating its catalogue into six books, split by product. It will be available from April.

Farnell say that this allows emphasis to be placed on their core product strengths, market the full range, provide the "ultimate one stop shop" and to focus on new products three times a year instead of twice, as at present.

From the summer edition onwards, colour pages will also be made available for suppliers to advertise their products in these books.

Farnell's catalogue always has been a "must" to have in your electronics workshop. This change of binding will surely be welcomed. Don't forget, also, that Farnell have product data on CD-ROM as well.

For more information contact Farnell, Canal Road, Leeds LS12 2TU. Tel: 0113 263 6311. Fax: 0113 263 3411. Web: [www.farnell.com](http://www.farnell.com).

## RADIO BYGONES WEB SITE

HAVE you browsed the web site of our sister publication *Radio Bygones*? This bi-monthly magazine is aimed at anyone with an interest in vintage radios and is only available via subscription. The *RB* web site can be accessed via [www.radiobygones.co.uk](http://www.radiobygones.co.uk). Through it you can take out a subscription to *RB*, use the "small ads" section and use the Message Board. You can also contact *RB* via E-mail at [radiobygones@wimborne.co.uk](mailto:radiobygones@wimborne.co.uk). More information is given in the *RB* advert elsewhere in this issue.

The *RB* Bulletin Board is for the benefit of not only *RB* readers, but visitors to the web-site as well. Via the Board, you can post questions, chat about magazine-related topics and to discuss views, nostalgia, information and tips. Editorially, *RB* does not offer a personal follow-up to readers' queries posted on the Board. However, you are always welcome to contact *RB* via *EPE* HQ if you would like Editorial replies, or if you would like your offerings to be considered for publication in *RB* itself.

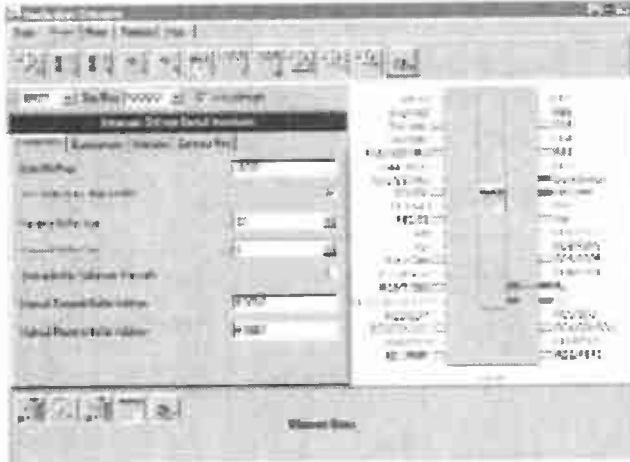
We must deny, though, the humorous(?) suggestion of Webmaster Alan Winstanley, that you need a *Long Wave* computer to use the site!

Alan, of course, will be familiar to you as *Circuit Surgeon*, *Net Work Surfer*, *Ingenuity Unlimiter*, and indeed Webmaster of the *EPE* site. Should you be looking for a superbly designed website of your own, Alan's company Amaryllys Design is a Web Design Bureau well-capable of producing an excellent result for you. Contact can be made via [arw@amaryllys.co.uk](mailto:arw@amaryllys.co.uk), whilst the site itself is at [www.amaryllys.co.uk](http://www.amaryllys.co.uk).

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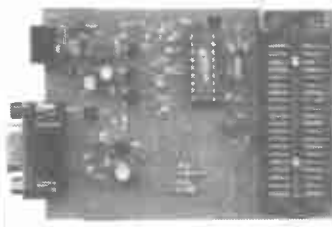
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## Forest Electronic Developments

60 Walkford Road, Christchurch, Dorset, BH23 5QG.

E-mail – info@fored.co.uk, or sales@fored.co.uk

Web Site – <http://www.fored.co.uk>

01425-274068 (Voice/Fax)

Prices are fully inclusive. Add £3.00 for P&P and handling to each order. Cheques/POs payable to Forest Electronic Developments, or phone with credit card details.

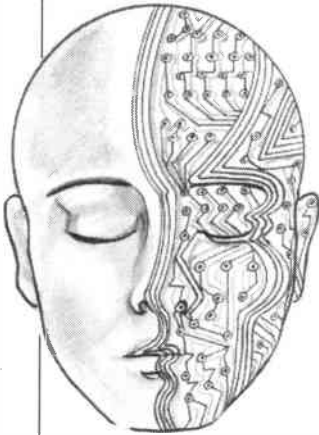


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- 50MSPS Dual Channel Storage Oscilloscope
- 25MHz Spectrum Analyser
- Multimeter • Frequency Meter
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## Sensitive Hall Effect Switch – Feel the Field

USING the UGN3503U linear Hall Effect sensor with a dual op.amp allows the construction of a simple but extremely sensitive Hall Effect switch that could prove useful in many applications. A circuit diagram for just such a switch is shown in Fig. 1. The Hall Effect device is IC1, which has just three terminals, for positive and negative supplies and the output. A regulated 5V supply is suggested for most applications.

With a 5V supply and in the absence of a magnetic field, the output from IC1 is about 2.5V. On the approach of a magnet, the output will rise or fall, depending on the magnetic field's polarity. With a 5V supply, the AD8532 is an excellent choice for the dual op.amp IC2 as it is designed for this supply voltage, has rail-to-rail inputs and outputs and, being a CMOS component, has very high input impedances. In addition it can supply up to 250mA of output current.

The first op.amp, IC2a, is used as a non-inverting amplifier with a voltage gain of about 20 to amplify the output of IC1 to more useful levels. Because a.c. coupling via capacitor C1 is used for the input, resistor R3 sets the working point to half the supply. This is necessary to

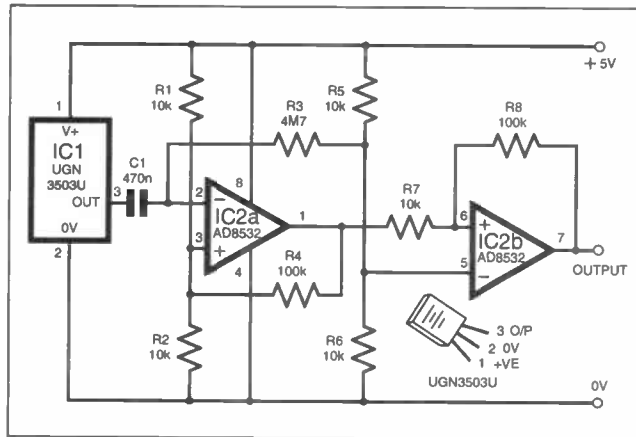


Fig. 1. Sensitive Hall Effect Switch circuit diagram.

avoid drift in the Hall Effect sensor IC1. The high value of R3 allows the circuit to operate at very low frequencies, down to less than 1Hz. The second op.amp IC2b is connected as a comparator with hysteresis set by resistors R7 and R8 to about 500mV to ensure a rapid, bounce-free switching action.

With the values shown this circuit can detect the approach of a small bar magnet of the type commonly used for operating reed

switches, at a range of about 25mm. Sensitivity could be adjusted by altering the gain of the amplifier stage or the hysteresis. Note that the strength of a magnetic field falls in proportion to the square of the distance from its source.

The polarity of the output change from IC1 depends on the polarity of the magnetic field. When the face bearing the device markings is approached by a North pole the output voltage falls, whilst the approach of a South pole will make it rise. The sensor is said to be capable of operating up to 23kHz, so for most practical applications the upper speed limit will not be an issue!

It is also possible to place a magnet behind the sensor so that the flux passing through it will change on the approach of a ferrous, but not necessarily magnetic, object. Applications of this type might include sensing passing steel gear-wheel teeth, or the movement of a steel lever.

Since the current consumption of IC1 is about 9mA this circuit is unsuitable for micropower applications but it should find plenty of uses where power consumption is not critical.

Andy Flind, Taunton, Somerset.

## Infra-Red Remote

### Tester - Sounds Good

AN Infra-Red Remote Control Tester, which gives both an audio and visual indication that a remote control is functioning, is shown in Fig.2. Its operation is as follows: D1 is a reverse biased photodiode, which forms an infra-red detector. Its output is buffered by IC1a and then enters a pulse stretcher comprising capacitor C2, resistor R2 and IC1b.

The pulse stretcher enables even the shortest of pulse trains to trigger the following oscillator. Diode D3 is a low current red l.e.d. which sinks into the output of IC1b and provides the visual indication.

An oscillator is formed of IC1c and IC1d, which drives a piezo disc element X1. This is connected across IC1e (rather than more conventionally to 0V) to provide a louder output. Oscillation is stopped by the normally high output from IC1b via diode D2. When an IR

pulse train is detected, IC1b goes low and the input to IC1d sees only a high impedance from the diode and oscillation starts. The input of gate IC1f is grounded for stability.

The circuit runs from a 9V PP3, and the standby current of a little under 2µA means there is no real need for an on/off switch.

Matthew Waite, Leeds.

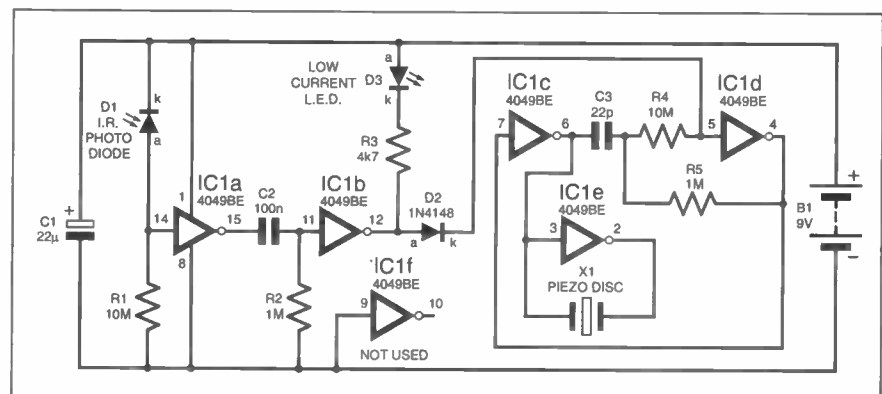


Fig.2. Circuit diagram for an Infra-Red Remote Tester.



## Auditory Illusion – Revved-up 'phones

THE circuit pictured in Fig. 3 is a classic auditory illusion which has puzzled psychologists and neuroscientists for decades. A two-tone "siren" plays into stereo headphones. The tones are separated by one octave, and alternate at roughly 4Hz.

However, the siren is played out of phase into each headphone. If all were well, each ear would perceive a two-tone siren: in actual

fact, the mind perceives a two-tone "ping-pong" effect, which jumps from ear to ear.

What has the mind done with the missing tones? Further, if one reverses the headphones, the tones jump back to where they were before!

Two oscillators, formed from IC1a and IC1c, are fed to quad bilateral switch IC2, which, with IC1d, is wired as an electronic

d.p.d.t. relay. Oscillator IC1b switches the "relay" at roughly 4Hz, so causing the two oscillators to play the two-tone siren out of phase.

Pre-set VR1 is adjusted so that oscillator IC1a is one octave higher than oscillator IC1c. The output can be fed to high-impedance headphones, or an amplifier as the effect is the same when loudspeakers are used.

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

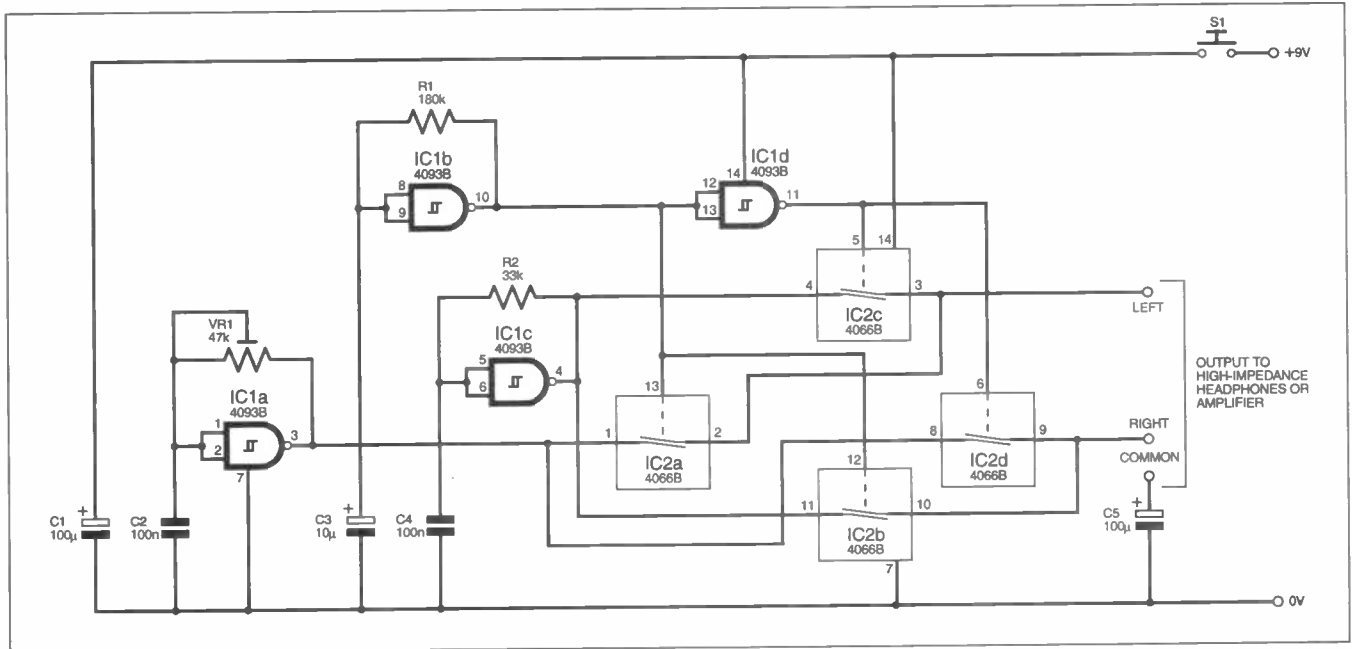


Fig.3. Experimental Auditory Illusion circuit diagram.

## Experimenter's Power Supply – Variable States

A CIRCUIT for a handy Variable Power Supply which will meet the needs of many electronics hobbyists is shown in Fig.4. It provides 0V to 25V at up to 250mA. The error amplifier within a 723-type voltage regulator chip (IC3) cannot function with rail-to-rail input and therefore a precision, shunt reference, TL431C (IC2) biases pin 5 of the 723 regulator to +2.50V.

The regulator's inverting input (pin 4) sees a set point potential from potentiometer VR1 which can swing either above or below this

level. Hence the output voltage, attenuated by the 10k and 100k resistors R5 and R6 is forced to extend from 0V (CCW) to +25V (CW) to track the +2.50V reference.

An external TIP29C power transistor TR1 extends the current limit to 250mA and is offset by a second programmable Zener diode IC4 at pin 10 of the 723 regulator. This voltage difference plus two  $V_{BE}$  drops gives sufficient headroom at pin 13 for the amplifier stage when  $V_{out} = 0$ .

The 723's internal Zener diode at pin 9 was not used, as the 6.2V requires a larger source from the transformer at maximum output, 25V. Even with this precaution it is possible to exceed the 723's absolute maximum voltage at pins 11 and 12: therefore, a three terminal regulator, 78L05ACZ (IC1) was added to maintain 30V.

As constructed, a single mains transformer with two, isolated 12VA windings allowed dual, floating d.c. sources of 0V to 25V magnitude, a convenience if both positive and negative voltages or their sum is desired.

*John A. Haas, Fort Collins, CO. USA.*

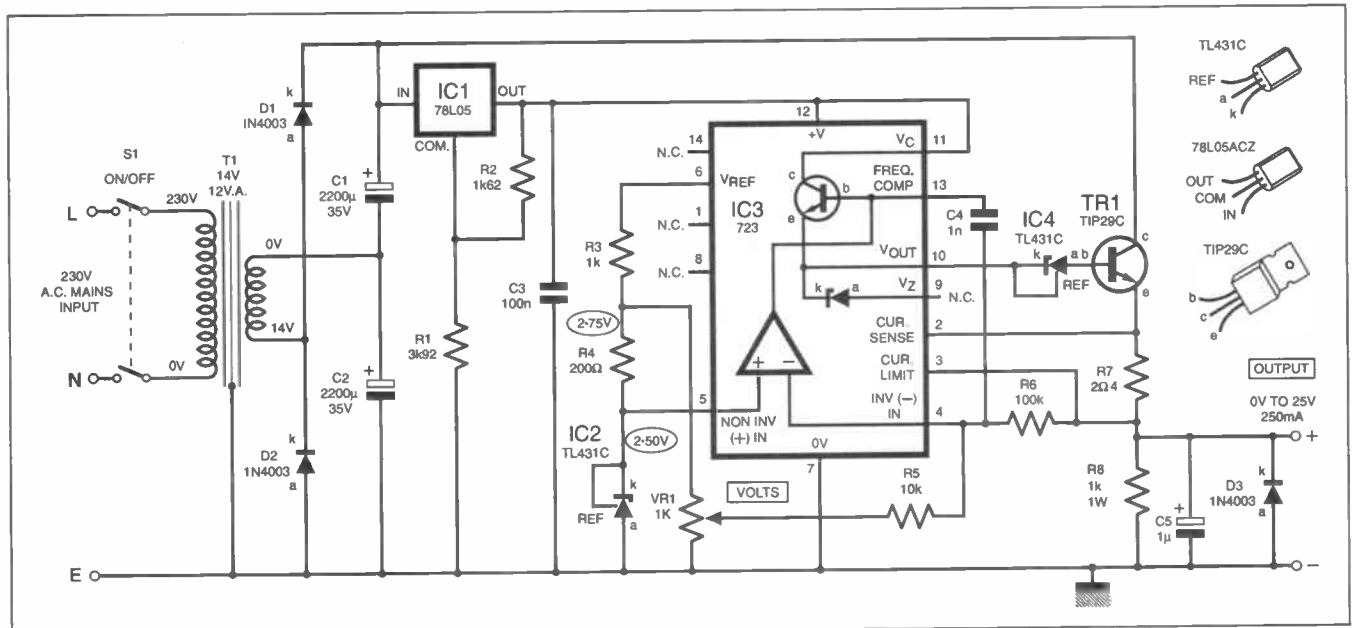
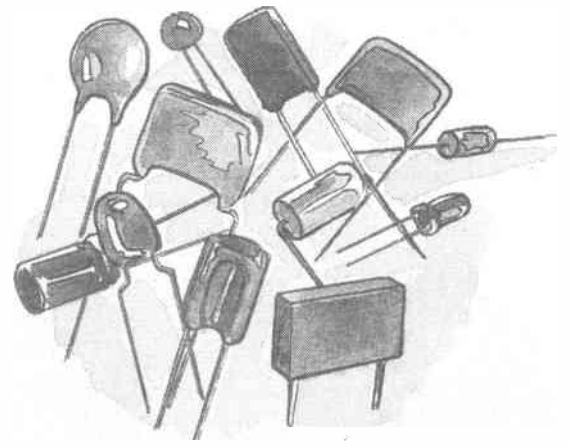


Fig.4. Experimenter's Power Supply circuit using the 723 variable voltage regulator.

# LOW-COST CAPACITANCE METER

ROBERT PENFOLD



*A simple starter project that will let you get the measure of most capacitors. Five switched ranges: 1nF to 10μF*

A TYPICAL multimeter can measure voltage, current and resistance over a wide range of values, and usually has a few "tricks up its sleeve" such as continuity tester and transistor checker facilities. Some multimeters have capacitance measuring ranges, but this feature remains something of a rarity. This is a pity, because anyone undertaking electronic faultfinding will soon need to check suspect capacitors and a ready-made capacitance meter is an expensive item of equipment.

The unit featured here offers a low-cost solution to the problem of testing capacitors. It is an analogue capacitance meter that has five switched ranges with full-scale values of 1nF; 10nF; 100nF; 1μF; and 10μF. It cannot measure very high or low value components, but it is suitable for testing the vast majority of capacitors used in everyday electronics.

## SYSTEM OPERATION

The block diagram for the Low-Cost Capacitance Meter is shown in Fig.1. Like most simple capacitance meter designs, this unit is based on a

monostable circuit. When triggered by an input pulse a monostable produces an output pulse having a duration that is controlled by a CR network. In this case the monostable is triggered manually using a pushbutton switch each time a reading is required.

The resistor in the timing network is one of five resistors selected via a switch, and these resistors provide the unit with its five ranges. The capacitor in the CR network is the capacitor under test.

The duration of the output pulse is proportional to the values of both components in the CR network. If a 1nF capacitor produces an output pulse of one millisecond in duration, components having values of 2.2nF and 4.7nF would respectively produce pulse lengths of 2.2ms and 4.7ms.

Each output pulse must be converted into a voltage that is proportional to the pulse duration. A moving coil panel meter can then read this voltage, and with everything set up correctly it will provide accurate capacitance readings.

If we extend the example given previously, with a potential of one volt per millisecond being produced, a meter having a full-scale value of 10V would actually read 0 to 10nF. This time-to-voltage conversion is actually quite simple to achieve, and is provided by a constant current generator and a charge storage capacitor.

When charged via a resistor the potential across the capacitor does not rise in a linear fashion. As the charge potential increases,

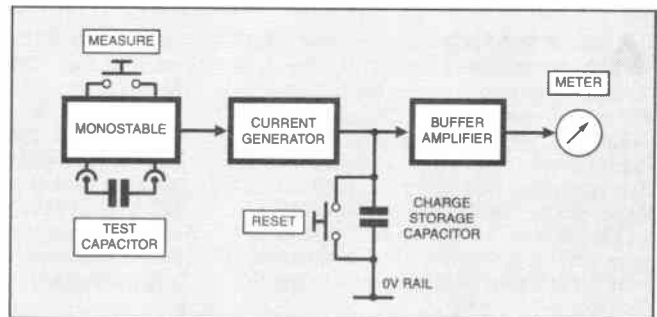


Fig.1. Schematic block diagram for the Low-Cost Capacitance Meter.

the voltage across the resistor falls, giving a steadily reducing charge current. The voltage therefore increases at an ever-decreasing rate (inverse exponentially).

A current regulator avoids this problem by ensuring that the charge current does not vary with time, giving a linear rise in the charge voltage. The circuit therefore provides the required conversion from capacitance to voltage, but it is important that loading on the storage capacitor is kept to a minimum.

Tapping off a significant current could adversely affect the linearity of the circuit and would also result in readings rapidly decaying to zero. The meter is, therefore, driven via a buffer amplifier that has a very high input impedance. Once a reading has been taken and noted, operating the Reset switch discharges the storage capacitor and returns the reading to zero so that a new reading can be taken.



## CIRCUIT OPERATION

The complete circuit diagram for the Low-Cost Capacitance Meter project appears in Fig.2. The monostable is based on a low-power 555 timer (IC1) used in the standard monostable configuration.

Apart from the fact it gives much longer battery life, a low-power 555 is a better choice for this type of circuit due its lower self-capacitance. This produces much better accuracy on the 1nF range, and a standard 555 is therefore not recommended for use in this circuit.

Switch S1 sets the Range and R1 to R5 are the five timing resistors. Resistors R1 to R5 respectively provide the 1nF, 10nF, 100nF, 1 $\mu$ F, and 10 $\mu$ F ranges.

One slight flaw in the 555 for this application is that it will only act as a pulse stretcher and not as a pulse shortener. In other words, the output pulse will not end at the appropriate time if the input pulse is still present.

output current. This is around 115 $\mu$ A with the specified value. Transistors TR1 and TR2 switch off again at the end of the pulse from IC1, and the charge voltage on C3 is then read by the voltmeter circuit based on panel meter ME1.

## METER CIRCUIT

Operational amplifier (op.amp) IC2 is used as the buffer amplifier, and the PMOS input stage of this device ensures that there is no significant loading on the "charge" capacitor C3. The input resistance of IC2 is actually over one million megohms.

However, the voltage on C3 will gradually leak away through various paths, including C3's own leakage resistance. The reading should remain accurate for at least a minute or two, and in most cases it will not change noticeably for several minutes. There will certainly be plenty of time for a reading to be taken before any significant drift occurs.

Briefly operating Reset switch S3 discharges C3 and zeros the meter so that another reading can be taken. Resistor R12 limits the discharge current to a level that ensures the contacts of S3 have a long operating life. The rate of discharge is still so high that it appears to be instant.

Preset VR1 enables the sensitivity of the voltmeter ME1 to be adjusted, and in practice this is adjusted so that the required full-scale values are obtained. In order to ensure good accuracy on all five ranges it is essential for range resistors R1 to R5 to be close tolerance (one or two percent) components.

There is no overload protection circuit for the meter, but this protection is effectively built into the design. The circuit driving the meter is only capable of producing minor overloads, and is incapable of inflicting any damage. The current consumption of the circuit is only about 3mA, and a PP3 size battery is adequate to power the unit.

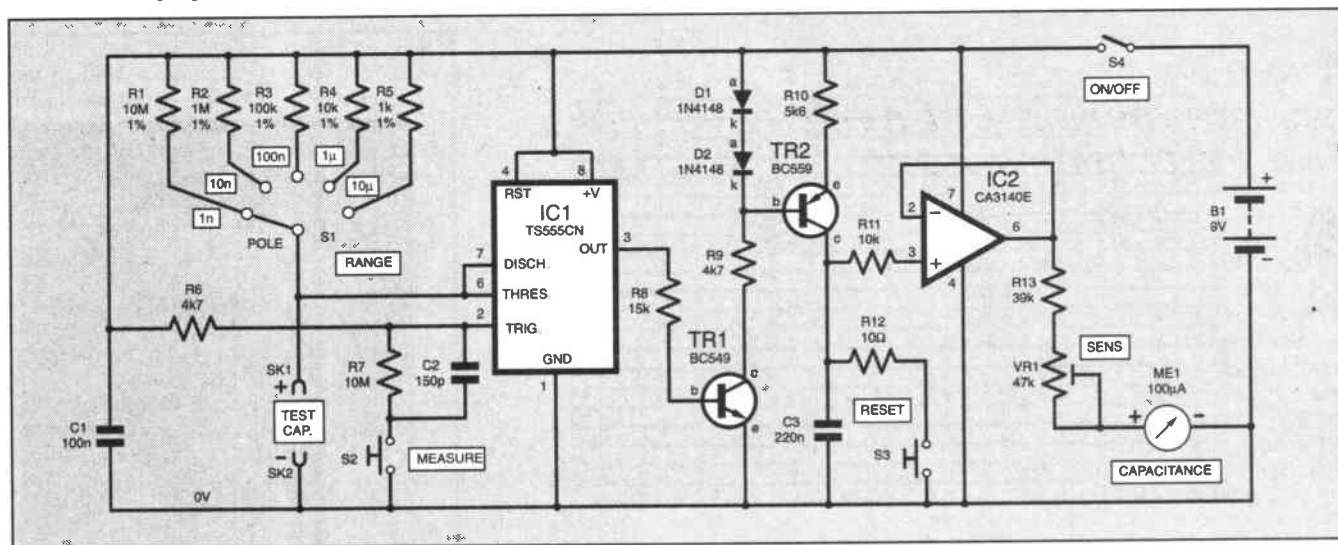


Fig.2. Complete circuit diagram for the Low-Cost Capacitance Meter.

If it were used to directly trigger IC1, the input pulse from pushbutton switch S2 would invariably be far too long. A simple CR circuit is therefore used to ensure that IC1 will always receive a very short trigger pulse, regardless of how long Measure switch S2 is pressed.

Resistor R6 holds the trigger input of IC1 (pin 2) high under standby conditions, but it is briefly pulsed low when S2 is operated and capacitor C2 charges via R6. When S2 is released, resistor R7 discharges C2 so that the unit is ready to trigger again the next time S2 is operated. Resistor R7 has been given a very high value so that the discharge time of C2 is long enough to prevent spurious triggering if S2 does not operate "cleanly". Most mechanical switches suffer from contact bounce, and without this debouncing it is likely that retriggering would occur practically every time S2 was released.

Under standby conditions the output at pin 3 of IC1 is low, and both transistor TR1 and TR2 are switched off. Consequently, only insignificant leakage currents flow into the charge storage capacitor C3. An output pulse from IC1 switches on TR1, which in turn activates TR2.

Transistor TR2 is connected as a conventional constant current generator, and the value of resistor R10 controls the

## COMPONENTS

Approx. Cost  
Guidance Only  
excluding batt., case, meter

£12

### Resistors

R1	10M 1% metal film
R2	1M 1% metal film
R3	100k 1% metal film
R4	10k 1% metal film
R5	1k 1% metal film
R6, R9	4k7 (2 off)
R7	10M
R8	15k
R10	5k6
R11	10k
R12	10 $\Omega$
R13	39k

All 0.25W 5% carbon film, except where specified

### Potentiometer

VR1	47k min enclosed or skeleton preset, horizontal
-----	---

### Capacitors

C1	100n ceramic
C2	150p ceramic plate
C3	220n polyester

### Semiconductors

D1, D2	1N4148 signal diode (2 off)
TR1	BC549 npn transistor
TR2	BC559 pnp transistor
IC1	TS555CN low power timer
IC2	CA3140E PMOS op.amp

### Miscellaneous

ME1	100 $\mu$ A moving coil panel meter
SK1	2mm socket, red
SK2	2mm socket, black
S1	12-way single-pole rotary switch (set for 5-way operation) (see text)
S2, S3	pushbutton switch, push-to-make (2 off)
S4	s.p.s.t. min toggle switch
B1	battery (PP3 size), with connector leads

Metal instrument case (or type to choice), size 150mm x 100mm x 75mm; stripboard 0.1-inch matrix, size 34 holes by 21 copper strips; 8-pin d.i.l. socket (2 off); control knob; calibration capacitor (see text); test leads (see text); connecting wire; solder pins; solder, etc.

See  
SHOP  
TALK  
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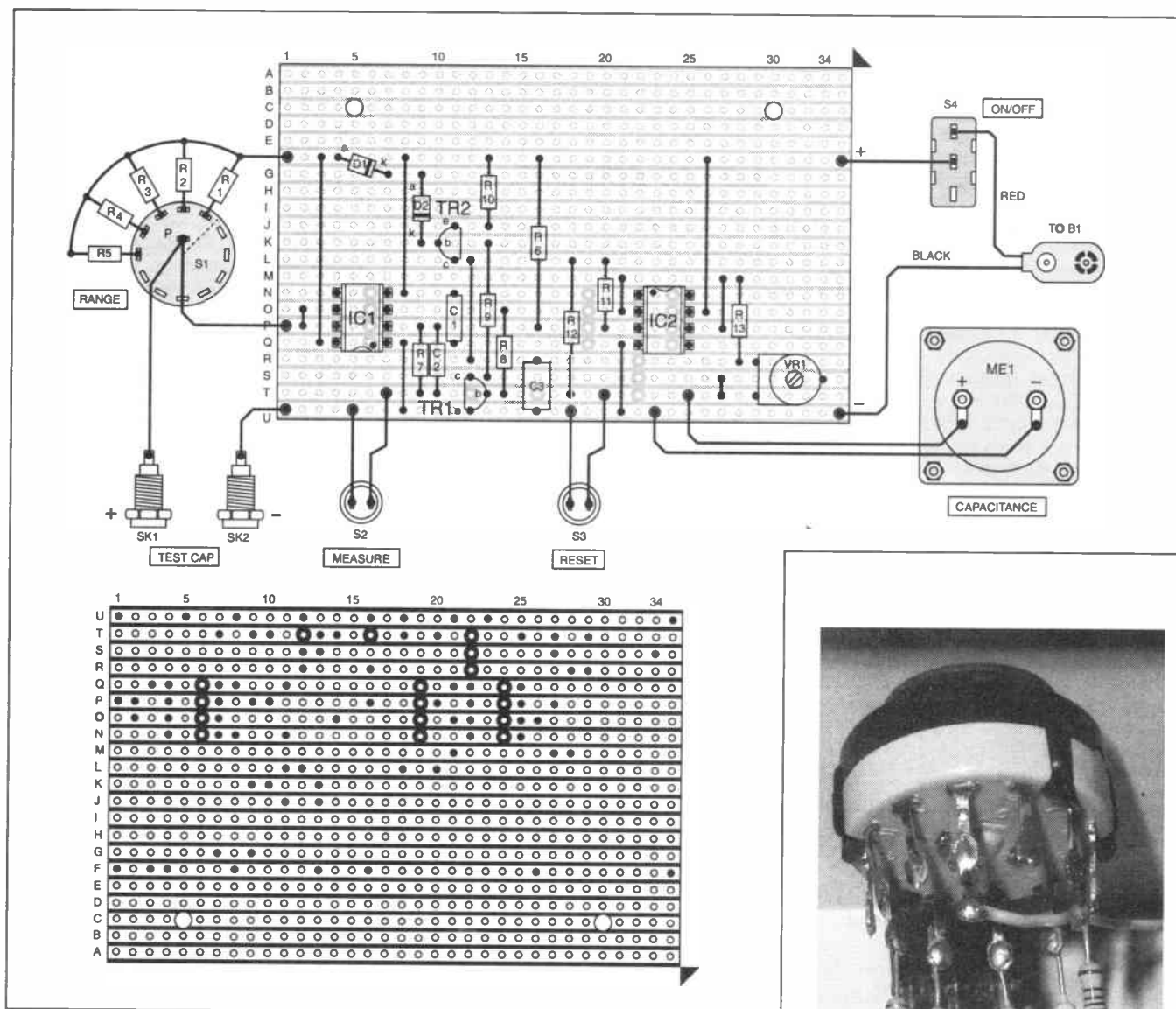


Fig.3. Stripboard component layout, interwiring and details of breaks required in underside copper tracks.

### CONSTRUCTION

The Low-Cost Capacitance Meter is built up on a small piece of stripboard having 34 holes by 21 copper strips. The top-side component layout, underside details and interwiring to off-board components is shown in Fig.3.

As this board is not of a standard size, a piece will have to be cut from a large board using a small hacksaw. Cut along rows of holes rather than between them, and smooth any rough edges produced using a file. Then drill the two 3mm diameter mounting holes in the board and make the 17 breaks in the copper strips. There is a special tool for making the breaks in the copper strips, but a handheld twist drill bit of around 5mm dia. does the job very well.

The circuit board is now ready for the components, linkwires and solder pins to be added. The CA3140E used for IC2 has a PMOS input stage that is vulnerable to damage from static charges, and the appropriate handling precautions must therefore be taken when dealing with this i.c.

It should be fitted to the board via a holder, but it should not be plugged into place until the unit is otherwise finished, and the board and wiring double-checked for any errors. It should be left in its anti-static

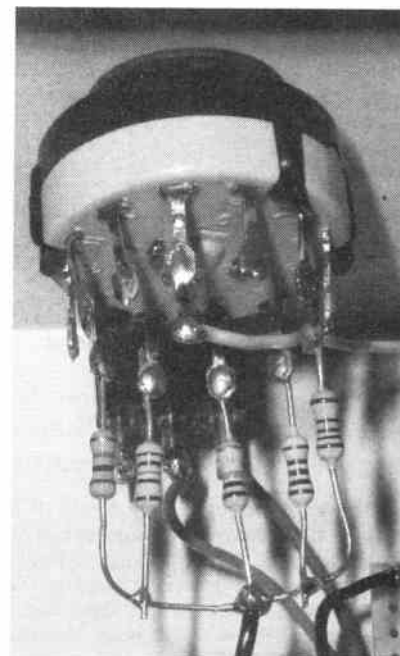
packing until then. Try to handle the device as little as possible when fitting it in its i.c. socket, and keep well away from any likely sources of static electricity such as television sets and computer monitors.

Although the TS555CN timer used for IC1 is not static-sensitive it is still a good idea to fit it in an i.c. socket. Be careful to fit IC1 the right way around because it has the opposite orientation to normal, with pin one at the bottom. This chip could easily be destroyed if it is fitted the wrong way around.

In all other respects construction of the board is fairly straightforward. The linkwires can be made from the trimmings from resistor leadouts or 22 s.w.g. tinned copper wire. In order to fit into this layout properly capacitor C3 should be a printed circuit mounting component having 7.5mm (0.3-inch) lead spacing. Be careful to fit the diodes and transistors with the correct orientation. Note that transistors TR1 and TR2 have opposite orientations.

### RANGE RESISTORS

The five range resistors (R1 to R5) are mounted directly on the Range rotary switch S1, which helps to minimise stray capacitance and pick up of electrical noise.



Mount the Range resistors directly on the switch tags before switch is fitted in the case.

This aids good accuracy, especially on the InF range. It is best to mount the resistors on S1 before this switch is fitted in the case.

Fitting the resistors is made much easier if the switch is stuck to the workbench using Plasticine or Bostik Blu-Tack. Provided the tags and the ends of the leadouts are tinned with solder it should then be quite easy to build this sub-assembly.

Try to complete the soldered joints reasonably swiftly so that the resistors do not overheat. It takes quite a lot of heat to destroy resistors, but relatively small amounts can impair their accuracy.

### CASING UP

A medium size metal instrument case is probably the best choice for a project of this type, but a plastic box is also suitable. The exact layout is not critical, but mount SK1 and SK2 close together.

Many capacitors will then connect directly into the sockets without too much difficulty, but a set of test leads will also be needed to accommodate some capacitors. All that is required are two insulated leads about 100mm long. Each lead is fitted with a 2mm plug at one end and a small crocodile clip at the other.

Fitting the meter on the front panel is potentially awkward because a large round cutout is required. For most meters a cutout of 38mm dia. is required, but it is advisable to check this point by actually measuring the diameter of the meter's rear section. DIY superstores sell adjustable hole cutters that will do the job quickly and easily, or the cutout can be made using a coping saw, Abrafile, etc.

Four 3mm dia. holes are required for the meter's threaded mounting rods. Marking the positions of these is quite easy as they are usually at the corners of a square having 32mm sides, and the same centre as the main cutout. Once again though, it would be prudent to check this by making measurements on the meter prior to drilling the holes.

The circuit board is mounted on the base panel of the case towards the left-hand side of the unit, leaving sufficient space for the battery to the right of the board. The component panel is mounted using either 6BA or metric M2.5 bolts, and spacers or nuts are used to ensure that the underside of the

board is held well clear of the case bottom. To complete the unit the hard wiring is added. This offers nothing out of the ordinary, but be careful to connect the battery clip and meter ME1 with the correct polarity.

### **CALIBRATION**

Preset potentiometer (wired as a "variable resistor") VR1 must be given the correct setting in order to obtain good accuracy from the unit, and a close tolerance capacitor is needed for calibration. For optimum accuracy this capacitor should have a value equal to the full-scale value of the range used during calibration.

In theory it does not matter which range is used when calibrating the unit, but in practice either the 1nF or 10nF range has to be used. Suitable capacitors for the other ranges are either unavailable or extremely expensive.

The 10nF range is the better choice as the small self-capacitance of IC1 is less significant on this range, although this factor seems to have very little affect on accuracy. Probably the best option is to calibrate the unit on the 10nF range using a 10nF polystyrene capacitor having a tolerance of one percent.

It is possible that a large reading will be produced on the meter when the unit is first switched on, but pressing Reset switch S3 should reset the meter to zero. If it is not

possible to zero the meter properly, switch off at once and recheck the entire wiring, etc.

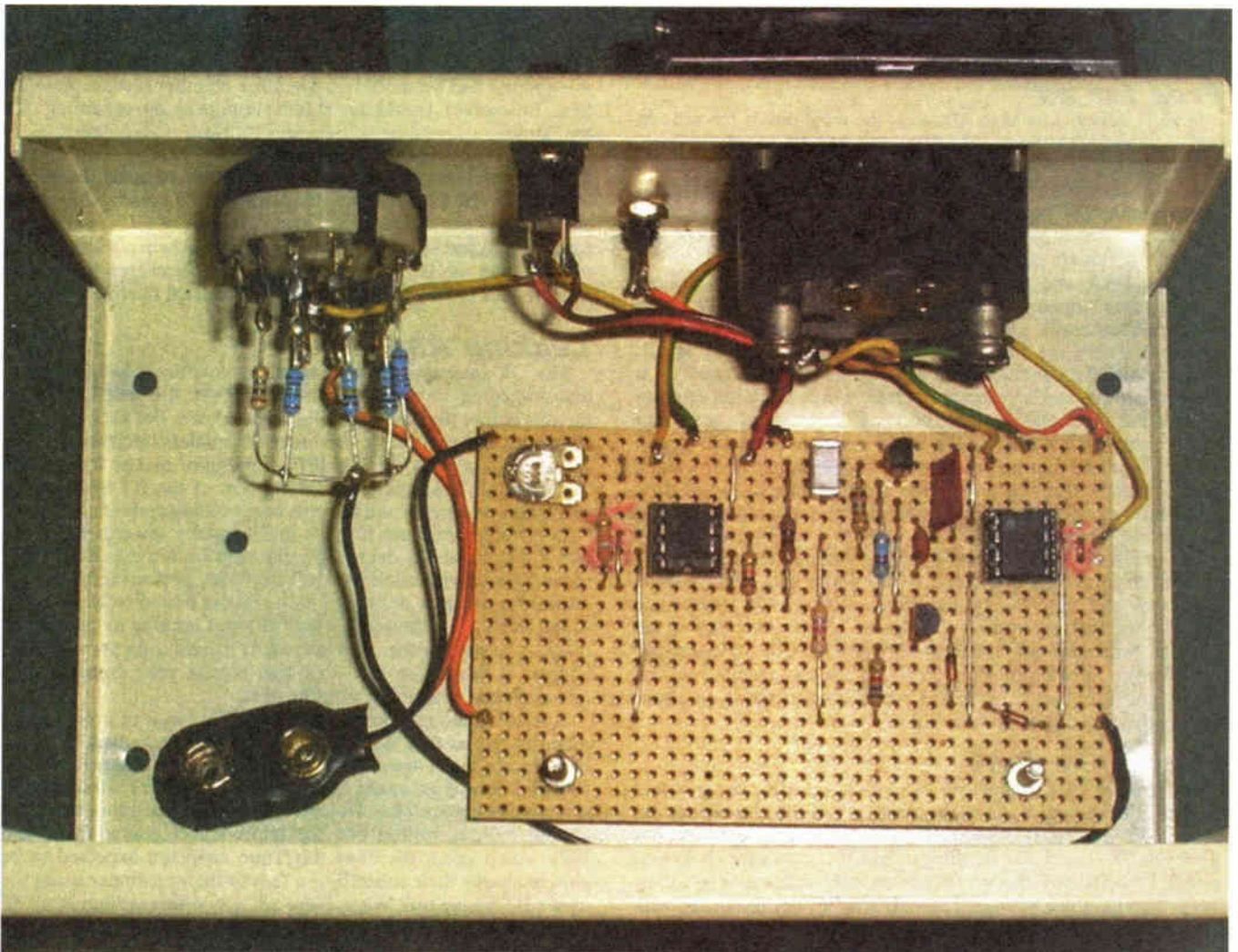
If all is well, set preset VR1 at maximum resistance (adjusted full clockwise). Then with the unit set to the correct range and the calibration capacitor connected to SK1 and SK2, operate pushswitch S2. This should produce a strong deflection of the meter, and VR1 is then adjusted for precisely full-scale reading on meter ME1. The unit should then provide accurate readings on all five ranges.

### **IN USE**

The Meter is suitable for use with polarised capacitors such as electrolytic and tantalum types. However, it is essential that they are connected to SK1 and SK2 with the correct polarity. The positive (+) lead connects to SK1 and the negative lead connects to SK2.

Especially when using the 1nF and 10nF ranges, avoid touching the lead that connects to SK1 when a reading is being taken. Otherwise electrical noise might be introduced into the system producing inaccurate results.

Avoid connecting a charged capacitor to this or any other capacitance meter, since doing so could result in damage to the semiconductors in the meter circuit. If in doubt always discharge a capacitor before testing it. □

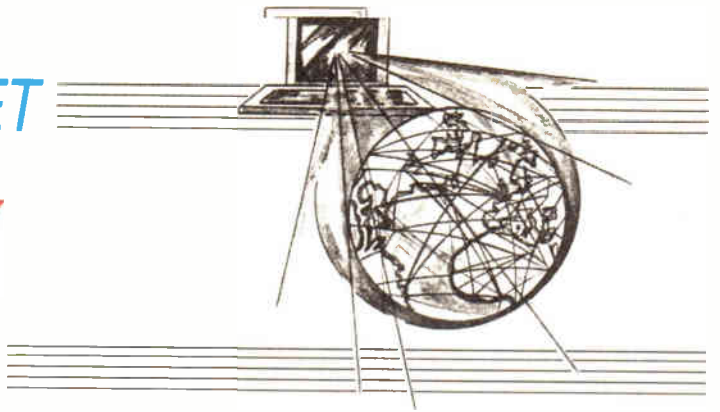


Layout of components inside the metal case of the completed Low-Cost Capacitance Meter. The circuit board is mounted to one side to leave space for the battery.

# SURFING THE INTERNET

## NET WORK

ALAN WINSTANLEY



### Google Box

**E**AGLE-EYED readers will have noticed that I recently placed a Google search engine in the 100 per cent revalidated *Net Work A-Z* page on our web site, containing many of the existing links I have highlighted in the past. Google is hugely fast and easy to use. Instead of trying to index every known web site, Google actually indexes on the basis of *all the other links* made to those same web sites. The search engine makes the reasonable assumption that the better a web site is, the greater the number of links pointing to that site. More importantly, Google keeps a cache of stored web pages, so that even if a web site is taken down there is still a possibility that you can retrieve the content from Google's cache. Give it a try.

In March 2000 *Net Work* I outlined the evolution of Alta Vista, Digital Equipment's leading search engine and portal site which was acquired by computer manufacturer Compaq in early 1998. There is no doubt that Alta Vista is a first-rate search engine, offering further options to non-English users courtesy of its Babel Fish language translator. Alta Vista continues to roll out across Europe, starting out in Germany almost a year ago, followed by Sweden and more recently the UK in December 1999. The Californian-based company then launched into France and the Netherlands last month.

### Free for all

In early March Alta Vista UK took the wind out of the sails of cable operator NTL ([www.askntl.com](http://www.askntl.com)) as well as British Telecom, by announcing its new free Internet access service for UK users. In fact it isn't entirely free – there will be a one-off set-up charge of anything up to £50 being reported, and an annual cost of say £20. The new service, to be called *AltaVista0800*, will be rolled out at a rate of 90,000 users per month starting in June 2000.

In the USA and Canada, a service called AltaVista Free Access has been available since August 1999 (see [www.microav.com](http://www.microav.com)), offering completely free Internet access to its users. There are no set-up or subscription charges at all. Instead, AltaVista Free Access employs a "Micro Portal" – a window on the user's computer screen which contains rotating adverts and other customisable content. The technology behind this is provided by [1stUp.com](http://1stUp.com), a US developer specialising in advert-supported dial-up accounts. The advertising window must always remain open to enjoy free Internet access, which is a powerful incentive for many consumers already conditioned to banner ads., to remain loyal.

In the UK, by using an 0800 access number, subscribers are relieved of the worry of the cost of the phone call, though obviously they still have to pay line rental charges. Alta Vista UK's new service will not allow a permanent 24x7 connection to the Internet, because it will time out after five minutes of inactivity. Furthermore, any attempt to "ping" an open connection with a keep-alive utility such as WakeUp will be treated as an abuse presumably leading to withdrawal of the service.

### Under the Surf

The new service announced by Alta Vista UK wrong-footed British Telecom into declaring its own revised plan for unmetered access. BT previously suggested its SurfTime package (see *Net Work* Feb '00) could cost anything up to £35 a month for always-on access. I showed how this was five times more than a user in Dallas, Texas who pays just \$12 (£7 a month) after loyalty discounts, with local Internet and voice calls thrown in for free.

In light of Alta Vista UK's new 0800 package, BT was forced into firming up its own position. They make much of the fact that their SurfTime option will be available to businesses as well as home

users, and they are attempting to cater for users' differing habits, given that many users are obviously at work during the day and only access the Internet during evenings and weekends. The cheapest option that BT now proposes is for occasional users, paying 1 pence per minute daytimes, 0.6 pence evenings and 0.5 pence weekends, on top of line rental at £9.26 per month.

As usual, BT's press release is not entirely straightforward, partly because they hint at an all-inclusive cost for Internet access by bundling in rental figures plus an estimate of monthly ISP charges. For a service fee of £5.99 a month excluding rental, BT customers can choose the evening and weekend package which allows for unmetered access plus up to 80 minutes' voice calls. BT's always-on package is likely to cost £19.99 per month plus rental for home users and £29.74 exc. VAT (inc. rental) for business users.

Realising that the rates will be scrutinised by an increasingly impatient audience, BT has gone to extraordinary lengths to emphasise how competitive they say their dial-up Internet packages are in comparison with similar ones in the USA.

The rates won't be available to end users until June 2000, and there is a further complication: BT SurfTime will require users to access their preferred ISP by using an 0844 04 number. If your preferred ISP doesn't offer one, then you can't use the SurfTime package. More problems in store include the fact that no wholesale pricing had been offered, therefore no other service provider (e.g. Freeserve) would be able to compete by re-selling BT SurfTime.

As if BT's convoluted phone tariffs aren't enough, don't forget the offerings over at BT Internet ([www.btinternet.com](http://www.btinternet.com)), the telco's Internet Service Provider arm. Unmetered 0800 evening and weekend access is now available at a new lower rate of £9.99 a month or £109.98 p.a., and as a sign of their eagerness to help novices getting to grips with the Internet, BT have actually *increased* the cost of support calls to 50 pence a minute up from local rate.

### Looking Ahead

The UK Internet market remains as volatile as ever, and further sweeping changes are probable over the next 12 to 18 months before the market finally settles down. For Freeserve, the 18-month old pioneer of the free ISP model, interesting times are ahead. As with all free ISPs, Freeserve makes its revenue from that all-important slice of the cost of the BT 0845 phone call, plus advertising and the cost of providing technical support.

Consumers tend not to have much loyalty towards their ISP and if they suddenly decide to jump ship from the free ISPs and move to a service such as AltaVista0800, preferring to pay an annual fee for free unlimited calls, this is bound to have a profound impact on Freeserve which charges nothing as an ISP but makes you pay for the calls instead. It is hard to know what will happen to those free ISPs that also bundle your domain name and technical support in with the deal.

It is not as though any of these free ISPs can levy even a small monthly fee, as they don't have any billing mechanism in place. Freeserve's latest move involves offering free Internet access, provided customers make £10 of calls per month routed through Energis, its parent telco. However, BT is now spending the intervening months rolling out the interconnect components, and ISPs which adopt the 0844 SurfTime tariff are expected to be able to charge their subscription fees to their customer using the user's BT phone bill. When there are new offers springing up all the time, it makes sense not to commit to a long-term agreement until all the players have made their moves.

You can E-mail me at [alan@epemag.demon.co.uk](mailto:alan@epemag.demon.co.uk). My web site is at <http://homepages.tcp.co.uk/~alanwin>.

# CONTROL & ROBOTICS

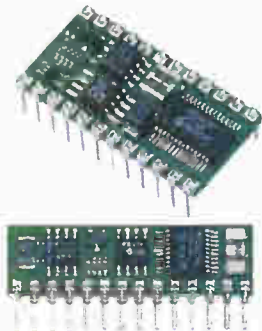
Milford Instruments

## BASIC Stamp Microcontrollers

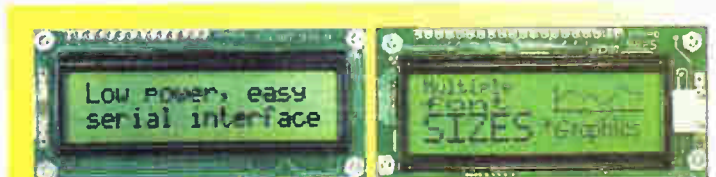
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New to PICs or just wanting to learn more tricks? We stock the excellent PIC primer books from David Benson - suitable for the complete beginner to the advanced user.

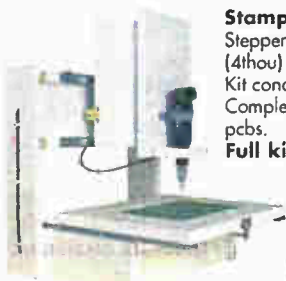


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### Stamp2 based 3-axis machine

Stepper drive to X, Y and Z axes with 0.1mm (4thou) resolution. Kit contains pre-machined frame components. Complete with Windows software for drilling pcbs. **Full kit at £249, Part kit at £189**



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New range of robotic arms for educational and hobbyist use with super powerful servos. Controlled from PC (Windows freeware provided) or from optional keypad. Stands about 450mm high when fully extended. Kit includes all pre-cut body parts, servo controller board, servos and software. Requires 9v Dc. Kits start at **£189**



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Stamp1 based walking humanoid. Walks forwards/backwards with left and right turn when detects obstacles. Electronics pcb pre-built and tested. Programme pre-loaded but may be changed with supplied software. **Full kit £68**



### On Screen Display

Superimpose text onto standard CCTV from simple RS232 serial line. Ready built/tested at **£59**



### Alex- Animated Head

Stamp2 based controller with voice record-playback capability, PIR input and/or random playback. 4-servo actions are recorded/edited one track at a time. May also be controlled from PC. **Head kits start at £29. Controllers from £29**



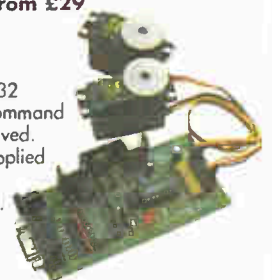
### IR Decoder Board

Control your project using a standard domestic IR remote. 7 Output lines (5v @ 20mA) may be set to momentary or toggle action. Simple teaching routine. Requires 9-12vDC. Supplied built and tested. **£29 single quantity**



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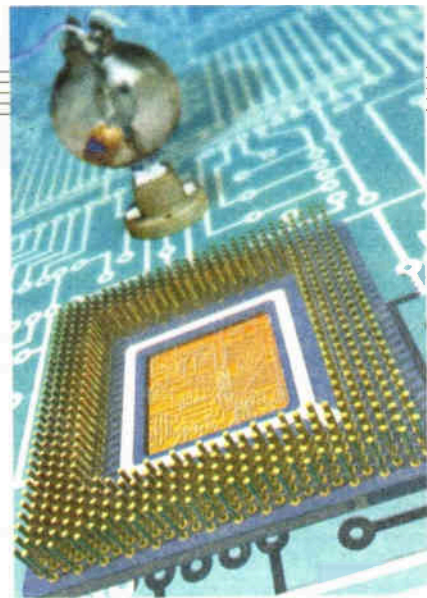
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# TECHNOLOGY TIMELINES

## PART 4 – COMPUTING 1900-1999



CLIVE “MAX” MAXFIELD AND ALVIN BROWN

*Boldly going behind the beyond, behind which no-one has boldly gone behind, beyond, before!*

**T**HE purpose of this series is to review how we came to be where we are today (technology-wise), and where we look like ending up tomorrow. In Part 1 we cast our gaze into the depths of time to consider the state-of-the-art in electronics, communications, and computing leading up to 11:59pm on 31 December 1899, as the world was poised to enter the 20th Century.

Parts 2 and 3 covered fundamental electronics and communications in the 20th Century, respectively. Now, in Part 4 we consider some of the key discoveries in computing that occurred during the 20th Century. These developments have set the scene for what is to come as we plunge forth into the third millennium. But before we start, let's first consider logic diagrams and logic machines, which usually receive little mention . . .

### LOGIC AND LOGIC DIAGRAMS

With the exception of Charles Babbage's proposal for a mechanical computer called the *Analytical Engine* in 1832, very little thought was given to computing prior to 1900. Instead, effort was focused on simple mechanical calculators, and also on variations of another mechanism put forward in 1882 by Babbage called a *Difference Engine*, which could be used to generate certain mathematical tables.

However, this is not to say that nothing of interest (computing-wise) was taking place, because there were a number of developments that would prove to be extremely interesting to computer scientists in the 20th Century.

First of all, the self-taught British mathematician George Boole published two key papers in 1847 and 1854. These papers described how logical expressions could be represented in a mathematical form that is now known as Boolean Algebra. What Boole was trying to do was to create a mathematical technique that could be used to represent and rigorously test logical and philosophical arguments.

We can only imagine what he would have thought had he realised that his new

mathematics would find application in designing digital computers 100 years in his future. But we digress . . .

### LOGIC WONDERLAND

In 1881, a lecturer in logic and ethics at John Hopkins University called Allan Marquand invented a graphical technique of representing logical problems using squares and rectangles. Marquand's efforts set a number of people to pondering, including the Reverend Charles Lutwidge Dodgson, who published his own diagrammatic technique in a book called *The Game of Logic* in 1886. (The Reverend is better known to most of us as Lewis Carroll, the author of *Alice's Adventures in Wonderland*.)

In the early 1890s, yet another approach was put forward by the English logician John Venn, who was extremely impressed by Boole's work. Unlike earlier graphical techniques, Venn's diagrams were based on the use of circles and ellipses, which could be employed to represent Boolean equations.

The rectangles and squares of Marquand and Carroll eventually led to Maurice Karnaugh inventing a graphical technique for both representing and minimising Boolean expressions in the 1950s. These techniques were to become tremendously useful to designers of digital logic, and Karnaugh maps and Venn Diagrams are both still taught and used to this day.

### LOGIC MACHINES

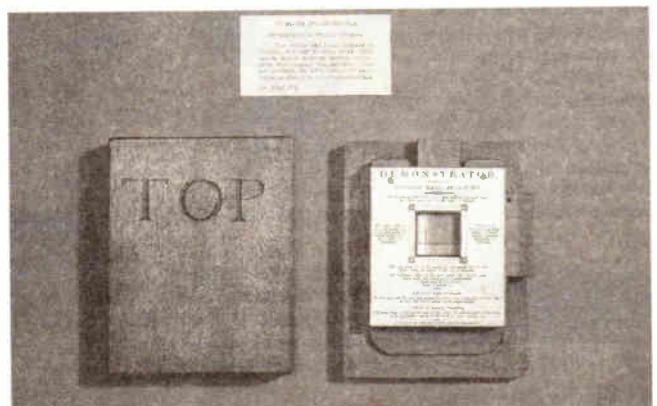
In addition to speculating about logic, it should come as no surprise to learn that people have been experimenting with so-called "logic machines" for quite some

time. Perhaps the earliest example is a set of concentric, nested discs revolving around a central axis as proposed by the Spanish theologian Ramon Lull in 1274. Each disc contained a number of different words or symbols, which could be combined in different ways by rotating the disks.

Lull's disks were followed by a variety of other techniques over the centuries, most of which we would now consider to be "half-baked" on a good day.

The world's first real logic machine (that is, one that could actually be used to solve simple logic problems, as opposed to Lull's which tended to create more problems than it solved) was invented in the late 1700s by the British scientist and statesman Charles Stanhope (third Earl of Stanhope).

This device, the *Stanhope Demonstrator*, was a small box with a window in the top, along with two different coloured slides that the user pushed into slots in the sides. Although this doesn't sound like much it was a start, but Stanhope wouldn't publish



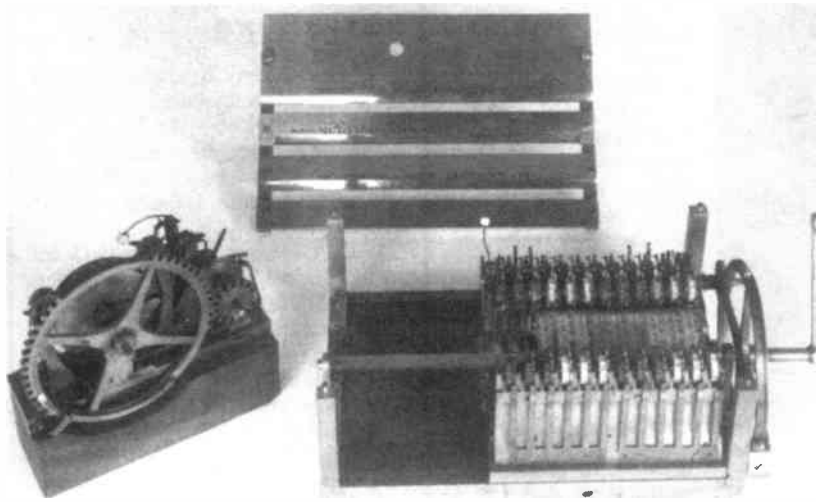
*Stanhope Square Demonstrator, late 18th century.* Courtesy Science Museum/Science and Society Picture Library.

any details and instructed his friends not to say anything about what he was doing.

In fact, it wasn't until around sixty years after his death that the Earl's notes and one of his devices fell into the hands of the Reverend Robert Harley, who subsequently

*Everyday Practical Electronics, May 2000*





Stanhope's calculating machine, 1777. Courtesy Science Museum/Science and Society Picture Library.

published an article on the Stanhope Demonstrator in 1879.

Stanhope also invented a circular demonstrator and a mechanical calculating machine.

## LOGIC PIANOS

Working on a somewhat different approach was the British logician and economist William Stanley Jevons, who, in 1869, produced the earliest model of his famous *Jevons' Logic Machine*. This device is notable because it was the first machine that could solve a logical problem faster than that problem could be solved without using the machine!

Jevons was an aficionado of Boolean logic, and his solution was something of a cross between a logical abacus and a piano (in fact it was sometimes referred to as a "Logic Piano"). This device, which was about a metre (three feet) tall, consisted of keys, levers and pulleys, along with letters that could be either visible or hidden. When the operator pressed keys representing logical operations, the appropriate letters appeared to reveal the result.

The next real advance in logic machines was made by Allan Marquand, whom we previously met in connection with his work on logic diagrams. In 1881, by means of the ingenious use of rods, levers, and springs, Marquand extended Jevons' work to produce the *Marquand Logic Machine*. Like

Jevons' device, Marquand's machine could only handle four variables, but it was smaller and significantly more intuitive to use.

## ROCKET-POWERED FRISBEEES

Things continued to develop apace. In 1936, the American psychologist Benjamin Burack from Chicago constructed what was probably the world's first electrical logic machine. Burack's device used light bulbs to display the logical relationships between a collection of switches, but for some reason he didn't publish anything about his work until 1949.

In fact, the connection between Boolean algebra and circuits based on switches had been recognized as early as 1886 by an educator called Charles Pierce. However, nothing substantial happened in this area until 1938, at which time the American engineer Claude E. Shannon published an article based on his master's thesis at MIT.

Shannon's thesis has been described as: "Possibly the most important Master's thesis of the twentieth century." In his paper, which was widely circulated, Shannon showed how Boole's concepts of TRUE and FALSE could be used to represent the functions of switches in electronic circuits. (Shannon is also credited with the invention of the rocket-powered Frisbee, and is famous for riding down the corridors at Bell Laboratories on a unicycle while simultaneously juggling four balls.)

Following Shannon's paper, a substantial amount of attention was focused on developing electronic logic machines. Unfortunately, interest in special-purpose logic machines waned in the 1940s with the advent of general-purpose computers, which proved to be much more powerful and for which programs could be written to handle formal logic.



Monroe's "Full Automatic" calculating machine, 1922, the first machine to offer fully automatic multiplication and division. Courtesy Science Museum/Science and Society Picture Library.

## TIMELINES

**1274:** Spain. Theologian Ramon Lull proposes a "logic machine" consisting of a set of concentric, nested disks.

**1777:** Charles Stanhope invents a mechanical calculating machine.

**Late 1700s:** Charles Stanhope invents the Stanhope Demonstrator.

**1822:** England. Charles Babbage starts to build a mechanical calculating machine – the Difference Engine.

**1832:** England. Charles Babbage conceives the first mechanical computer – the Analytical Engine.

**1847:** England. George Boole publishes his first ideas on symbolic logic.

**1869:** William Stanley Jevons invents the Logic Piano.

**1881:** Alan Marquand invents a graphical technique of representing logic problems.

**1886:** Reverend Charles Lutwidge Dodgson (Lewis Carroll) publishes a diagrammatic technique for logic representation in *The Game of Logic*.

**1890s:** John Venn proposes logic representation using circles and ellipses.

**1925:** America. Scientist, engineer and politician Vannevar Bush designs an analogue computer called the Product Intergraph.

**1930:** America. Vannevar Bush designs an analogue computer called a Differential Analyzer.

**1936:** America. Efficiency expert August Dvorak patents his layout for keys on a typewriter called the Dvorak Keyboard.

**1936:** America. Psychologist Benjamin Burack constructs the first electrical logic machine (but he didn't publish anything about it until 1949).

**1937:** America. George Robert Stibitz, a scientist at Bell Labs, builds a simple digital calculator machine based on relays called the Model K.

**1937:** England. Graduate student Alan Turing (of Colossus fame) writes his ground-breaking paper *On Computable Numbers with an Application to the Entscheidungsproblem*.

**1937:** England. Alan Turing invents a theoretical (thought experiment) computer called the Turing Machine.

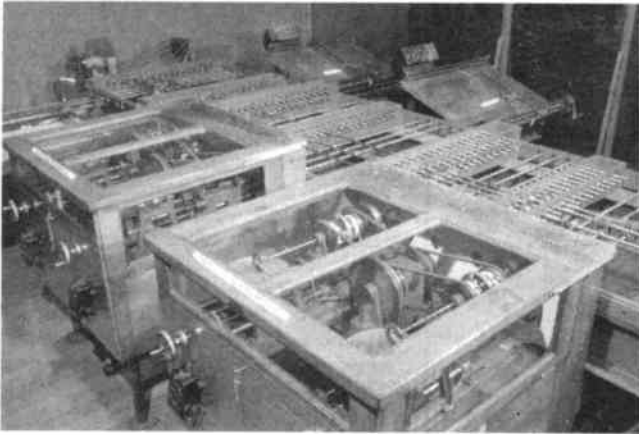
**1938:** America. Claude E. Shannon publishes an article (based on his master's thesis at MIT) that showed how Boolean algebra could be used to design digital circuits.

**1938:** Germany. Konrad Zuse finishes the construction of the first working mechanical digital computer (the Z1).

**1939:** America. George Robert Stibitz builds a digital calculator called the Complex Number Calculator.

**1939:** America. John Vincent Atanasoff (and Clifford Berry) may or may not have constructed the first truly electronic special-purpose digital computer called the ABC (but it did not work until 1942).

**1940:** America. George Robert Stibitz performs first example of remote computing between New York and New Hampshire.



*Hartree Differential Analyser, 1935, based on that invented by Vannevar Bush. Courtesy Science Museum/Science and Society Picture Library.*

## ELECTROMECHANICAL COMPUTERS

In 1927, with the assistance of two colleagues at MIT, the American scientist, engineer and politician Vannevar Bush designed an analogue computer that could solve simple equations. This device, which Bush dubbed a *Product Intergraph*, was subsequently built by one of his students.

Bush continued to develop his ideas and, in 1930, built a bigger version, which he called a *Differential Analyzer*. The *Differential Analyzer* was based on the use of mechanical integrators that could be interconnected in any desired manner. To provide amplification, Bush employed torque amplifiers, which were based on the same principle as a ship's capstan. The final device used its integrators, torque amplifiers, drive belts, shafts, and gears to measure movements and distances (not dissimilar in concept to an automatic slide rule).

Although Bush's first *Differential Analyzer* was driven by electric motors, its internal operations were purely mechanical. In 1935 Bush developed a second version, in which the gears were shifted electro-mechanically and which employed paper tapes to carry instructions and to set up the gears.

In our age, when computers can be constructed the size of postage stamps, it is difficult to visualize the scale of the problems that these early pioneers faced. To

provide some sense of perspective, Bush's second *Differential Analyzer* weighed in at a whopping 100 tons! In addition to all of the mechanical elements, it contained 2000 vacuum tubes, thousands of relays, 150 motors, and approximately 200 miles of wire.

As well as being a major achievement in its own right, the *Differential Analyzer* was also significant because it focused attention on analogue computing techniques, and therefore detracted

from the investigation and development of digital solutions for quite some time.

## FLASHLIGHT BULBS AND TIN CANS

However, not everyone was enamoured by analogue computing. In 1937, George Robert Stibitz, a scientist at Bell Laboratories built a digital machine based on relays, flashlight bulbs and metal strips cut from tin-cans, which he called the *Model K* (because most of it was constructed on his kitchen table).

Stibitz's machine, worked on the principle that if two relays were activated they caused a third relay to become active, where this third relay represented the sum of the operation. For example, if the two relays representing the numbers 3 and 6 were activated, this would activate another relay representing the number 9. (A replica of the *Model K* is on display at the Smithsonian.)

Stibitz went on to create a machine called the *Complex Number Calculator*, which, although not tremendously sophisticated by today's standards, was an important step along the way. In 1940, Stibitz performed a spectacular demonstration at a meeting in New Hampshire.

Leaving his computer in New York City, he took a teleprinter to the meeting and proceeded to connect it to his computer via telephone. In the first example of remote

## TIMELINES

**1941:** Germany. Konrad Zuse finishes the first true relay-based general-purpose digital computer (the Z3).

**1942:** Germany. Between 1942 and 1943 Konrad Zuse builds the Z1 and Z2 computers for the Henschel aircraft company.

**1942:** Germany. Between 1942 and 1945/6 Konrad Zuse develops the ideas for a high-level computer programming language called Plankalkül.

**1943:** England. Alan Turing and team build a special-purpose electronic (vacuum tube) computer called Colossus.

**1944:** America. Howard Aiken and team finish building an electromechanical computer called the Harvard Mark I (also known as the IBM ASCC).

**1945:** America. Hungarian/American mathematician Johann (John) Von Neumann publishes a paper entitled *First Draft of a report on the EDVAC*.

**1946:** America. John William Mauchly, J. Presper Eckert and team finish building a general-purpose electronic computer called ENIAC.

**1948:** America. Work starts on the first commercial computer, UNIVAC 1.

**1948:** America. First commercial computer, UNIVAC 1, is completed.

**1949:** England, Cambridge University. Small experimental computer called EDSAC performs its first calculation.

**1949:** England. EDSAC computer uses first assembler called Initial Orders.

computing, Stibitz astounded the attendees by allowing them to pose problems which were entered on the teleprinter; within a short time the teleprinter presented the answers generated by the computer.

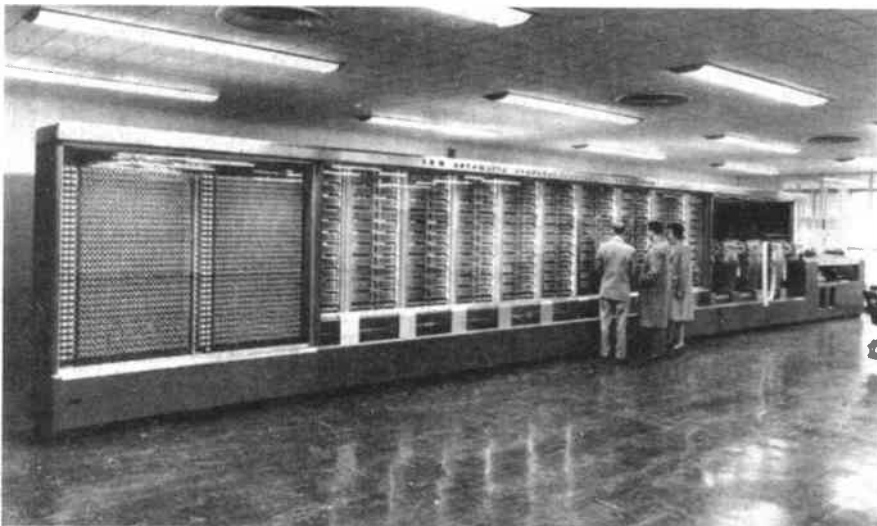
## HARVARD MARK I

Many consider that the modern computer era commenced with the first large-scale automatic digital computer, which was developed between 1939 and 1944. This device, the brainchild of a Harvard graduate, Howard H. Aiken, was officially known as the IBM automatic sequence controlled calculator (ASCC), but is more commonly referred to as the *Harvard Mark I*.

The Mark I was constructed out of switches, relays, rotating shafts, and clutches, and was described as sounding like a "roomful of ladies knitting." The machine contained more than 750,000 components, was 50 feet long, 8 feet tall (15.2m x 2.4m), and weighed approximately five tons (5080kg)!

Although the Mark I is considered to be the first digital computer, its architecture was significantly different from modern machines. The device consisted of many calculators which worked on parts of the same problem under the guidance of a single control unit.

Instructions were read in on paper tape, data was provided separately on punched cards, and the device could only perform operations in the sequence in which they were received. This machine was based on numbers that were 23 digits wide – it could

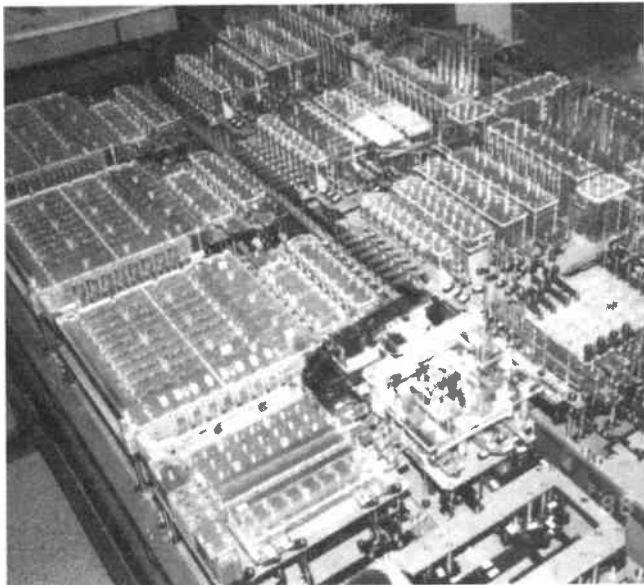


*Harvard Mark I, the first large-scale automatic digital computer. Courtesy of IBM.*

add or subtract two of these numbers in three-tenths of a second, multiply them in four seconds, and divide them in ten seconds.

## KONRAD ZUSE

In the aftermath of World War II, it was discovered that a program controlled calculator called the Z3 had been completed in Germany in 1941, which means that the Z3 pre-dated the Harvard Mark I. The Z3's architect was a German engineer called Konrad Zuse, who developed his first machine, the Z1, in his parents' living room in Berlin in 1938.



Rebuilt version of Konrad Zuse's Z1 computer. The original was built in his parent's living room in Berlin in 1938. Courtesy of Horst Zuse.

Although based on relays, the Z3 was very sophisticated for its time; for example, it utilized the binary number system and could handle floating-point arithmetic. (Zuse had considered employing vacuum tubes, but he decided to use relays because they were more readily available and also because he feared that tubes were unreliable).

In 1943, Zuse started work on a general-purpose relay computer called the Z4. Sadly, the original Z3 was destroyed by bombing in 1944 and therefore didn't survive the war (although a new Z3 was reconstructed in the 1960s). However, the Z4 did survive – in a cave in the Bavarian Alps – and by 1950 it was up and running in a Zurich bank.

It is interesting to note that paper was in short supply in Germany during the war, so instead of using paper tape, Zuse was obliged to punch holes in old movie film to store his programs and data. We may only speculate as to the films Zuse used for his hole-punching activities; for example, were any first-edition Marlene Dietrich classics on the list? (Marlene Dietrich fell out of favour with the Hitler regime when she emigrated to America in the early 1930s, but copies of her films would still have been around during the war.)

Zuse was an amazing man who was well ahead of his time. In fact there isn't enough space to do him justice in this article, but you can find a "world-exclusive" feature article on Zuse at the *EPE Online* web site at [www.epemag.com](http://www.epemag.com). This article, which

was written by Konrad's eldest son, Horst Zuse, contains over 100 photographs from Horst's private collection, many of which have never been published before!

## FIRST ELECTRONIC COMPUTERS

We now turn our attention to an American mathematician and physicist, John Vincent Atanasoff, who has the dubious honour of being known as the man who either did or did not construct the first truly electronic special-purpose digital computer.

A lecturer at Iowa State College (now Iowa State University), Atanasoff was disgruntled with the cumbersome and time-consuming process of solving complex equations by hand. Working alongside one of his graduate students (the brilliant Clifford Berry), Atanasoff commenced work on an electronic computer in early 1939, and had a prototype machine by the autumn of that year.

In the process of creating the device, Atanasoff and Berry evolved a number of ingenious and unique features. For example, one of the biggest problems for computer designers of the time was to be able to store numbers for use

in the machine's calculations.

Atanasoff's design utilized capacitors to store electrical charge that could represent numbers in the form of logic 0s and logic 1s. The capacitors were mounted in rotating bakelite cylinders, which had metal

bands on their outer surface. These cylinders, each approximately 12 inches tall and 8 inches in diameter (30cm x 20cm), could store thirty binary numbers, which could be read off the metal bands as the cylinders rotated.

Input data was presented to the machine in the form of punched cards, while intermediate results could be stored on other cards. Once again, Atanasoff's solution to storing intermediate results was quite interesting – he used sparks to burn small spots onto the cards. The presence or absence of these spots could be automatically determined by the machine later, because the electrical resistance of a carbonized spot varied from that of the blank card.

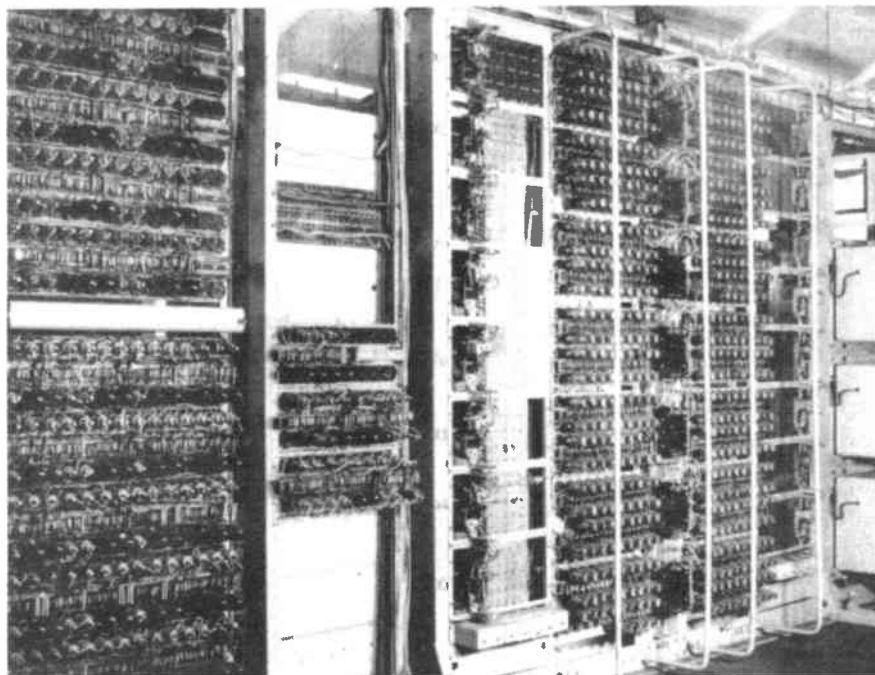
Some references report that Atanasoff and Berry had a fully working model of their machine by 1942. However, while some observers agreed that the machine was completed and did work, others reported that it was almost completed and would have worked, while still others stated that it was just a collection of parts that never worked. So unless more definitive evidence comes to light, it's a case of: "You pays your money and you takes your choice".

## GENIUSES AND ECCENTRICS

Many of the people who designed the early computers were both geniuses and eccentrics of the first order, and the English mathematician Alan Turing was first among equals. In 1937, while a graduate student, Turing wrote his ground-breaking paper *On Computable Numbers with an Application to the Entscheidungsproblem*.

Since Turing did not have access to a real computer (not unreasonably as they didn't exist at the time), he invented his own as an abstract "paper exercise". This theoretical model, which became known as a *Turing Machine*, was both simple and elegant, and subsequently inspired many "thought experiments".

During World War II, Turing worked as a cryptographer, decoding codes and cyphers



The Colossus computer, Bletchley Park, 1943. Used to decypher the German "Enigma" codes during WWII. Courtesy Science Museum/Science and Society Picture Library.

at one of the British government's top-secret establishments located at Bletchley Park. During this time Turing was a key player in the breaking of the German's now-famous code generated by their Enigma machine. However, in addition to Enigma, the Germans had another cypher that was employed for their ultra-top-secret communications. This cypher, which was vastly more complicated than Enigma, was generated by a machine called a *Geheimfenschreiber* (secret telegraph), which the allies referred to as the "Fish".

In January 1943, along with a number of colleagues, Turing began to construct an electronic machine to decode the *Geheimfenschreiber* cypher. This machine, which they dubbed *Colossus*, comprised 1,800 vacuum tubes and was completed and working by December of the same year!

By any standards *Colossus* was one of the world's earliest working programmable electronic digital computers. But it was a special-purpose machine that was really only suited to a narrow range of tasks (for example, it was not capable of performing decimal multiplications). Having said this, although *Colossus* was built as a special-purpose computer, it did prove flexible enough to be programmed to execute a variety of different routines.

## ENIAC AND EDVAC

By the mid-1940s, the majority of computers were being built using vacuum tubes rather than switches and relays. Although vacuum tubes were fragile, expensive and used a lot of power, they were much faster than relays (and much quieter). If we ignore Atanasoff's machine and *Colossus*, then the first true general-purpose electronic computer was the electronic numerical integrator and computer (*ENIAC*), which was constructed at the University of Pennsylvania between 1943 and 1946.

*ENIAC*, which was the brainchild of John William Mauchly and J. Presper Eckert Jr., was a monster – it was 10 feet (3m) tall, occupied 1,000 square feet (300m<sup>2</sup>) of floor-space, weighed in at approximately 30 tons (30480kg), and used more than 70,000 resistors, 10,000 capacitors, 6,000 switches, and 18,000 vacuum tubes. The final machine required 150 kilowatts of power, which was enough to light a small town.

One of the greatest problems with computers built from vacuum tubes was reliability; 90 per cent of *ENIAC*'s down-time was attributed to locating and replacing

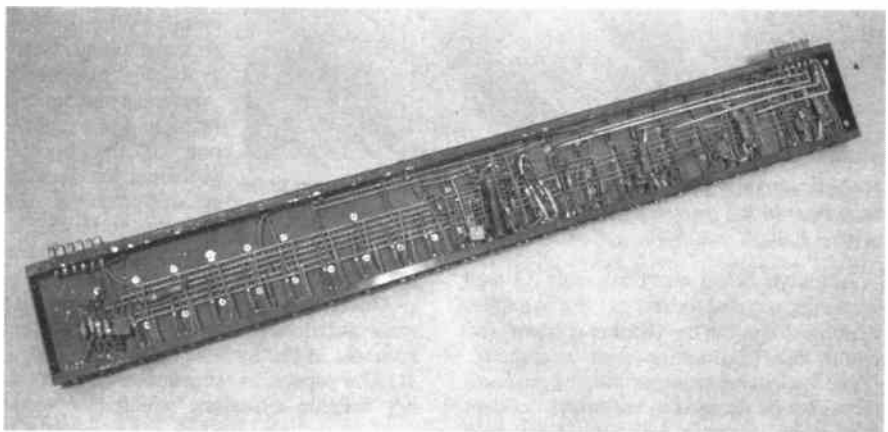
burnt-out tubes. Records from 1952 show that approximately 19,000 vacuum tubes had to be replaced in that year alone, which averages out to about 50 tubes a day!

In August 1944, Mauchly and Eckert proposed the building of another machine called the electronic discrete variable automatic computer (*EDVAC*). This new machine was intended to feature many improvements over *ENIAC*, including a new form of memory based on pulses of sound racing through mercury delay lines.

## FIRST DRAFT

In June 1944, the Hungarian-American mathematician Johann (John) von Neumann first became aware of *ENIAC*. Von Neumann, who was a consultant on the Manhattan Project, immediately recognized the role that could be played by a computer like *ENIAC* in solving the vast arrays of complex equations involved in designing atomic weapons.

Von Neumann was tremendously excited by *ENIAC* and quickly became a consultant to both the *ENIAC* and *EDVAC* projects. In June 1945, he published a paper entitled *First Draft of a report on the EDVAC*, in which he presented all of the basic elements of a stored-program computer:



One small section of the receiver unit for *ENIAC*. Another photo of *ENIAC* was shown in Part 2. Courtesy Science Museum/Science and Society Picture Library.

- A memory containing both data and instructions. Also to allow both data and instruction memory locations to be read from, and written to, in any desired order.

- A calculating unit capable of performing both arithmetic and logical operations on the data.

- A control unit, which could interpret an instruction retrieved from the memory and select alternative courses of action based on the results of previous operations.

The key point made by the paper was that the computer could modify its own programs, in much the same way as was originally suggested by Charles Babbage in the 1830s. The computer structure resulting from the criteria presented in this paper is popularly known as a *von Neumann Machine*, and virtually all digital computers from that time forward have been based on this architecture.

Unfortunately, although the conceptual design for *EDVAC* was completed by 1946, several key members left the project to pursue their own careers, and the machine did not become fully operational until 1952. When it was finally completed, *EDVAC* contained approximately 4,000 vacuum tubes and 10,000 crystal diodes. A 1956 report shows that *EDVAC*'s average error-free up-time was approximately eight hours.

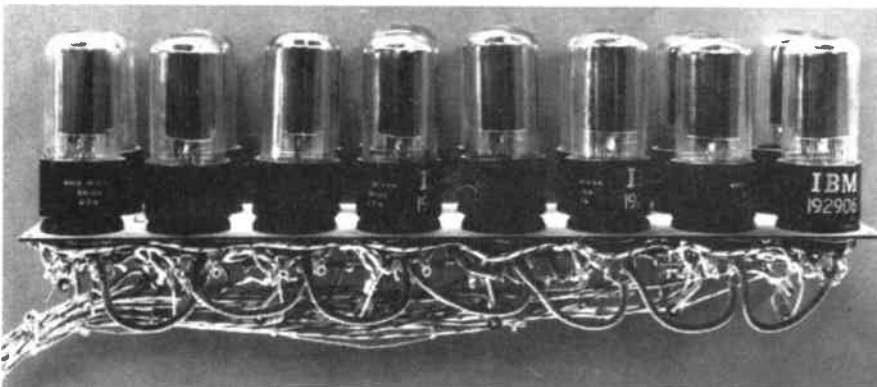
## EDSAC TO UNIVAC

In light of its late completion, some would dispute *EDVAC*'s claim-to-fame as the first stored-program computer. A small

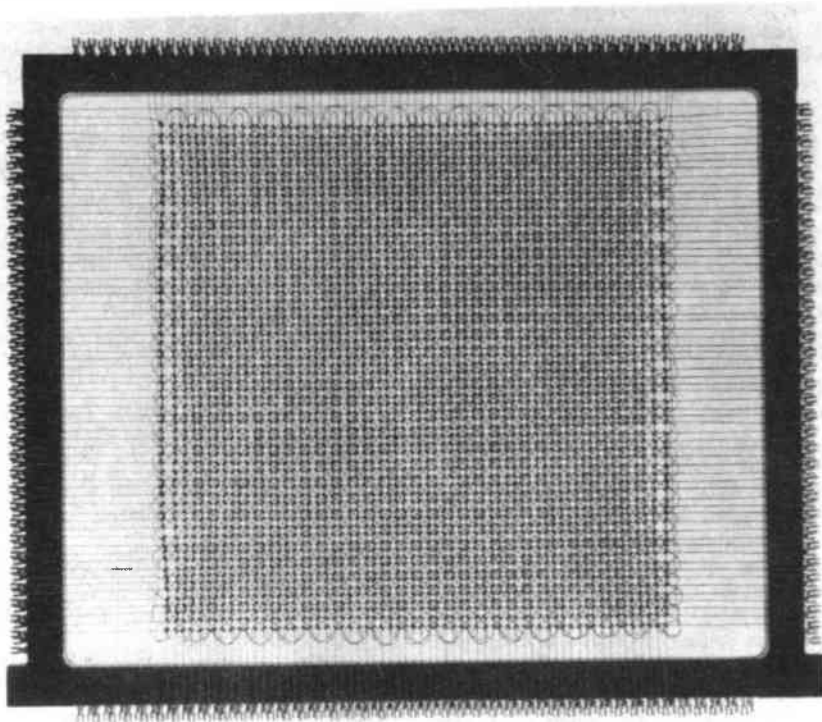
experimental machine based on the *EDVAC* concept consisting of 32 words of memory and a 5-instruction command set was operating at Manchester University, England, by June 1948.

Another machine called *EDSAC* (Electronic Delay Storage Automatic Calculator) performed its first calculation at Cambridge University, England, in May 1949. *EDSAC* contained 3,000 vacuum tubes and used mercury delay lines for memory. Programs were input using paper tape and output results were passed to a teleprinter.

Additionally, *EDSAC* is credited as using one of the first assemblers called Initial Orders, which allowed it to be programmed symbolically instead of using machine code. Last but not least, the first commercially available computer, *UNIVAC I* (Universal Automatic Computer), was also based on the *EDVAC* design. Work started on *UNIVAC I* in 1948, and the first unit was delivered in 1951, which therefore predates *EDVAC*'s becoming fully operational.



Electronic vacuum tubes, 1946, which replaced electric relays and made operational programs that could multiply two 10-digit numbers 40 times per second. Courtesy of IBM.



Magnetic core memory store. Logic 0 and 1 depended on the polarity of the magnetised field for each bead. Courtesy of IBM.

## MAGNETIC CORE STORES

One of the biggest problems faced by early computer designers was the lack of small, efficient memories. In Germany Konrad Zuse experimented with purely mechanical memories (which were surprisingly reliable), whilst other engineers worked with a variety of esoteric techniques, including the phosphorescent effect in storage oscilloscopes, and mercury delay lines as discussed earlier.

Around 1950, Jay Forrester at MIT came up with the idea of using ferromagnetic beads ("cores") threaded onto wires to store logic 0s and 1s (depending on which way they were magnetized). Although unwieldy by today's standards, these core stores were incredibly useful at that time, and they paved the way for bigger and better computers.

Of course, the advent of the transistor was revolutionary in computing circles, because each transistor could replace a vacuum tube that was 100s of times larger, consumed 100s of times more power, and was 100s of times less reliable.

However, transistors by themselves did not oust core stores. This was due to the fact that storing one bit of data required a single core only 1mm or less in diameter, but storing the same bit would require between four and six transistors. Thus, it was not until the invention of the integrated circuit that useful semiconductor memory devices started to appear in the early 1970s. (The development of vacuum tubes, transistors, and integrated circuits were discussed in Part 2.)

## FIRST MICROPROCESSORS

In 1970, the Japanese calculator company Busicom approached Intel with a request to design a set of twelve integrated circuits for use in a new calculator. The task

was presented to one Marcian "Ted" Hoff, a man who could foresee a somewhat bleak and never-ending role for himself designing sets of special-purpose integrated circuits for one-of-a-kind tasks.

However, during his early ruminations on the project, Hoff realized that rather than design the special-purpose devices requested by Busicom, he could create a single integrated circuit with the attributes of a simple-minded, stripped-down, general-purpose computer processor.

The result of Hoff's inspiration was the world's first microprocessor, the 4004, where the '4's were used to indicate that the device had a 4-bit data path (there is a photo in Part 2). The 4004 was part of a four-chip system which also consisted of a 256-byte ROM, a 32-bit RAM, and a 10-bit shift register.

The 4004 itself contained approximately 2,300 transistors and could execute 60,000 operations per second. The advantage (as far as Hoff was concerned) was that by simply changing the external program, the same device could be used for a multitude of future projects.

In November 1972, Intel introduced the 8008, which was essentially an 8-bit version of the 4004. The 8008 contained approximately 3,300 transistors and was the first microprocessor to be supported by a high-level language compiler called PL/M. The 8008 was followed by the 4040, which extended the 4004's capabilities by adding logical and compare instructions, and by supporting subroutine nesting using a small internal stack.

However, the 4004, 4040, and 8008 were all designed for specific applications, and it was not until April 1974 that Intel presented the first true general-purpose microprocessor, the 8080. This 8-bit device, which contained around 4,500 transistors and could perform 200,000 operations per second, was destined for fame as the central processor of many of the early home computers.

## TIMELINES

**1949:** America. MIT's first real-time computer, Whirlwind.

**1950:** America. Jay Forrester at MIT invents magnetic core store.

**1951:** America. Computers are sold commercially.

**1952:** America. John William Mauchly, J. Presper Eckert and team finish building a general-purpose (stored program) electronic computer called EDVAC.

**1956:** America. John Backus and team at IBM introduce the first widely used high-level computer language, FORTRAN.

**1956:** America. John McCarthy develops a computer language called LISP for artificial intelligence applications.

**1956:** America. MANIAC 1 is the first computer program to beat a human in a game (a simplified version of chess).

**1957:** America. IBM 610 Auto-Point computer is introduced.

**1958:** America. Computer data is transmitted over regular telephone circuits.

**1959:** America. COBOL computer language is introduced for business applications.

**1961:** Time-sharing computing is developed.

**1963:** In America, the LINC computer was designed at MIT.

**1965:** John Kemeny and Thomas Kurtz develop the BASIC computer programming language.

**1968:** First Static RAM i.c. reaches the market.

**1970:** First floppy disk (8.5 inch?) is used for storing computer data.

**1970:** America. Ethernet developed at Palo Alto Research centre by Bob Metcalfe and David Boggs.

**1971:** America. Datapoint 2200 computer introduced by CTC.

**1971:** CTC's Kenbak-1 Computer is introduced.

**1971:** America. Ted Hoff designs (and Intel releases) the first computer-on-a-chip, the 4004 microprocessor.

**1971:** Niklaus Wirth develops PASCAL computer language (named after Blaise Pascal).

**1972:** November, America. Intel introduce the 8008 microprocessor.

**1973:** America. Xerox Alto Computer is introduced.

**1973:** May, France. 8008-based Micral microcomputer is introduced.

**1973:** June, the term microcomputer first appears in print in reference to the 8008-based Micral microcomputer.

**1973:** America. Scelbi Computer Consulting Company introduce the Scelbi-8H microcomputer-based do-it-yourself computer kit.

**1973:** PDP-8 becomes the first popular microcomputer.

**1974:** America. Intel introduce the 8080 microprocessor.

**1974:** August, America. Motorola introduce the 6800 microprocessor.

Following the 8080, the microprocessor field exploded with devices such as the 6800 from Motorola in August 1974, the 6502 from MOS Technology in 1975, and the Z80 from Zilog in 1976 (to name but a few).

Unfortunately, documenting all of the different microprocessors would require a book in its own right, so we won't even attempt the task here. Instead, we'll create a cunning diversion that will allow us to leap gracefully into the next topic... Good grief! Did you see what just flew past your window?

## FIRST PERSONAL COMPUTERS (PCs)

Given that the 8008 was not introduced until November 1972, the resulting flurry of activity was quite impressive. Only six months later, in May 1973, the first computer based on a microprocessor was designed and built in France.

Unfortunately the 8008-based Micral, as this device was known, did not prove tremendously successful in America. However, in June of that year, the term "microcomputer" first appeared in print in reference to the Micral.

In the same mid-1973 time-frame, the Scelbi Computer Consulting Company presented the 8008-based Scelbi-8H microcomputer, which was the first microprocessor-based computer kit to hit the market (the Micral wasn't a kit - it was only available in fully assembled form). The Scelbi-8H was advertised at \$565 and came equipped with 1Kbyte of RAM.

In June 1974, *Radio Electronics* magazine published an article by Jonathan Titus on building a microcomputer called the Mark-8, which, like the Micral and the Scelbi-8H, was based on the 8008 microprocessor. The Mark-8 received a lot of attention from hobbyists, and a number of user groups sprang up around the US to share hints and tips and disseminate information.

## LAUNDROMATS IN ALBUQUERQUE

Around the same time that Jonathan Titus was penning his article on the Mark-8, a man called Ed Roberts was pondering the future of his failing calculator company known as MITS (which was next door to a laundromat in Albuquerque, New Mexico). Roberts decided to take a gamble with what little funds remained available to him, and he started to design a computer called the Altair 8800 (the name "Altair" originated in one of the early episodes of *Star Trek*).



Altair 8800b microcomputer, 1975. Courtesy Science Museum/Science and Society Picture Library.

Roberts based his system on the newly-released 8080 microprocessor, and the resulting do-it-yourself kit was advertised in *Popular Electronics* magazine in January 1975 for the then unheard-of price of \$439. In fact, when the first unit shipped in April of that year, the price had fallen to an amazingly low \$375.

Even though it only contained a miserly 256 bytes of RAM and the only way to program it was by means of a switch panel, the Altair 8800 proved to be a tremendous success. (These kits were supplied with a steel cabinet sufficient to withstand most natural disasters, which is why a remarkable number of them continue to lurk in their owner's garages to this day.)

## BASIC GATES

Also in April 1975, Bill Gates and Paul Allen founded Microsoft (which was to achieve a certain notoriety over the coming years), and in July of that year, MITS announced the availability of BASIC 2.0 on the Altair 8800. This BASIC interpreter, which was written by Gates and Allen, was the first reasonably high-level computer language program to be made available on a home computer - MITS sold 2,000 systems that year, which certainly made Ed Roberts a happy camper, while Microsoft had taken its first tentative step on the path toward world domination.

In June 1975, MOS Technology introduced their 6502 microprocessor for only \$25 (an Intel 8080 would deplete your bank account by about \$150 at that time). A short time later, MOS Technology announced their 6502-based KIM-1 microcomputer, which boasted 2K bytes of ROM (for the monitor program), 1Kbyte of RAM, an octal keypad, a flashing l.e.d. display, and a cassette recorder for storing programs. This unit, which was only available in fully-assembled form, was initially priced at \$245, but this soon fell to an astoundingly low \$170.

The introduction of new microcomputers proceeded apace. Sometime after the KIM-1 became available, the Sphere Corporation introduced its Sphere 1 kit, which comprised a 6800 microprocessor, 4K bytes of RAM, a QWERTY keyboard, and a video interface (but no monitor) for \$650.

## JOBS AND WOZNIAK

In March 1976, two guys called Steve Wozniak and Steve Jobs (who had been fired with enthusiasm by the Altair 8800) finished work on a home-grown 6502-based computer which they called the Apple I (a few weeks later they formed the Apple Computer Company on April Fools day).

Although it was not tremendously sophisticated, the Apple I attracted sufficient interest for them to create the Apple II, which many believe to be the first personal computer that was both affordable and usable. The Apple II, which became available in April 1977 for \$1,300, comprised 16K bytes of ROM, 4K bytes of RAM, a keyboard and a colour display.

## TIMELINES

**1974:** June, America. *Radio Electronics* magazine publish an article by Jonathan (Jon) Titus on building an 8008-based microcomputer called the Mark-8.

**1975:** America. MOS Technology introduce the 6502 microprocessor.

**1975:** January, America. Ed Roberts and his MITs company introduce the 8080-based Altair 8800 microcomputer.

**1975:** April, America. Bill Gates and Paul Allen found Microsoft.

**1975:** July, America. Microsoft release BASIC 2.0 for the Altair 8800 microcomputer.

**1975:** America. MOS Technology introduce the 6502-based KIM-1 microcomputer.

**1975:** America. Sphere Corporation introduce the 6800-based Sphere 1 microcomputer.

**1975:** America. Microcomputer in kit form reaches US home market.

**1976:** America. Zilog introduce the Z80 microprocessor.

**1976:** March, America. Steve Wozniak and Steve Jobs introduce the 6502-based Apple I: microcomputer.

**1976:** April 1st, America. Steve Wozniak and Steve Jobs form the Apple computer company.

**1977:** April, America. Apple introduce the Apple II microcomputer.

**1977:** April, America. Commodore Business Machines present their 6502-based Commodore PET microcomputer.

**1977:** August, America. Tandy/Radio Shack announce their Z80-based TRS-80 microcomputer.

**1978:** America. Apple introduce the first hard disk drive for use with personal computers.

**1979:** America, the first true commercial microcomputer program, the VisiCalc spreadsheet, is available for the Apple II.

**1979:** ADA programming language is named after Augusta Ada Lovelace (now credited as being the first computer programmer).

**1981:** America. First IBM PC is launched.

**1981:** America. First mouse pointing device is introduced.

**1981:** First laptop computer is introduced.

**1983:** Apple's Lisa is the first personal computer to use a mouse and pull-down menus.

**1983:** Time magazine names the computer as Man Of The Year.

**1984:** 1MB memory chips introduced.

**1985:** CD-ROMs are used to store computer data for the first time.

Apple was one of the great early success stories - in 1977 they had an income of \$700,000 (which was quite a lot of money in those days), and just one year later this had soared tenfold to \$7 million! (which was a *great* deal of money in those days).

Also in April 1977, Commodore Business Machines presented their 6502-based Commodore PET, which contained 14K bytes of ROM, 4K bytes of RAM, a keyboard, a display and a cassette tape drive for only \$600. Similarly, in August of



A Commodore PET 32K computer, 1979. Cassette recorders provided external data storage. Courtesy John Becker.



An early IBM PC. Its architecture became the foundation which all PC-compatibles must emulate. Courtesy of IBM.

that year; Tandy/Radio Shack announced their Z80-based TRS-80, comprising 4K bytes of ROM, 4K bytes of RAM, a keyboard and a cassette tape drive for \$600.

### **WOT! NO SOFTWARE?**

One point that may seem strange today is that there were practically no programs available for these early machines (apart from the programs written by the users themselves). In fact, it wasn't until late in 1978 that commercial software began to appear.

Possibly the most significant tool of that time was the VisiCalc spreadsheet program, which was written for the Apple II by a student at the Harvard Business School and which appeared in 1979. It is difficult to overstate the impact of this program, but it is estimated that over a quarter of the Apple machines sold in 1979 were purchased by businesses solely for the purpose of running VisiCalc. In addition to making Apple very happy, the success of VisiCalc spurred the development of other applications such as word processors.

When home computers first began to appear, existing manufacturers of large computers tended to regard them with disdain ("It's just a fad . . . it will never catch on"). However, it wasn't too long before the sound of money changing hands began

to awaken their interest. In 1981, IBM launched their first PC for \$1,365, which, if nothing else, sent a very powerful signal to the world that personal computers were here to stay.

The advent of the general-purpose microprocessor heralded a new era in computing – microcomputer systems small enough to fit on a desk could be endowed with more processing power than monsters weighing tens of tons only a decade before. The effects of these developments are still unfolding, but it is not excessive to say that digital computing and the personal computer have changed the world more significantly than almost any other human invention, and many observers believe that we've only just begun our journey into the unknown!

### **EVER SO HUMBLE**

We crave your indulgence and ask you to accept our humblest apologies for all of the things we had to leave out. Surely computer languages like FORTRAN, COBOL, BASIC, C, LISP, FORTH and . . . (the list goes on) deserve a mention? How could we neglect microcomputers such as the PDP and VAX from Digital Equipment Corporation (DEC) that had such an impact on the industry? Are operating systems like VMS, UNIX, and Windows to be

ignored? What about behemoths like SAGE (which consumed a million watts of power) and CRAY Supercomputers?

The problem is that one could go on forever, so we chose to restrict ourselves only to those topics that we felt were particularly germane to this series. As usual you may of course disagree (or you may simply crave more once this series is finished), in which case please feel free to vent your feelings by inundating the Editor with your letters and E-mails.

### **ACKNOWLEDGEMENT**

Portions of this article were abstracted from our book, *Bebop BYTES Back (An Unconventional Guide to Computers)*, with the kind permission of its publisher, Doone Publications. (*Bebop BYTES Back* is available from the EPE Direct Book Service – see page 394 – Ed.)

### **NEXT MONTH**

In the fifth and final instalment of this series we shall gird up our loins and pontificate on the future. Where do you think the technology roller-coaster will take us in the next 10, 100 or 1000 years? Start pondering now and see if you agree with us in next month's exciting issue – same time ... same place ... same channel!



Two of the ballistic track monitors of Sage, the massive US military computer that helped defend the Western World during the Cold War. Courtesy of IBM.

### **QUOTABLE QUOTES**

"Computers in the future may weigh no more than 1.5 tons." *Popular Mechanics*, forecasting the relentless march of science, 1949.

"I think there is a world market for about five computers." Thomas Watson, Chairman of IBM, 1943.

"I have travelled the length and breadth of this country and talked with the best people, and I can assure you that data processing is a fad that won't last out the year." The editor in charge of business books for Prentice Hall, 1957.

"There is no reason for any individual to have a computer in their home." Ken Olson, President of Digital Equipment Corporation (DEC), 1977

"So we went to Atari and said, 'Hey, we've got this amazing thing, even built with some of your parts, and what do you think about funding us? Or we'll give it to you. We just want to do it. Pay our salary, we'll come work for you.' And they said, 'No.' So then we went to Hewlett-Packard, and they said, 'Hey, we don't need you. You haven't got through college yet.'" Apple Computer Inc. founder Steve Jobs on attempts to get Atari and HP interested in his and Steve Wozniak's personal computer.

"640K of memory ought to be enough for anybody." Bill Gates, CEO of Microsoft, 1981.

# New Technology Update

*Whilst lower operating voltages enable microprocessors to run faster, the problem of heat dissipation becomes more significant. Ian Poole reports.*

IT is a commonly known fact that microprocessor clock speeds are increasing all the time. Only a few years ago clock speeds of 1GHz were thought to be many years away. Now a number of manufacturers have offerings with speeds around 1GHz that will shortly hit the marketplace. IBM have a 64-bit Power PC chip. Compaq, have their 1GHz Alpha, and Intel a version of a Pentium III. These devices have been able to achieve their speed as a result of a number of developments that have been undertaken in many research institutes and development areas.

All of the devices have geometries that are less than 0.2 microns, and this means that the operating voltages are low. For example the Alpha operates on a voltage of 1.65 volts. Not only is this low voltage required because of the low breakdown voltages associated with the minute geometries, but it also reduces the power consumption.

## Heat Problems

Power consumption is an increasing problem as demonstrated by the fact that even modest Pentium chips require cooling. However when it is realised that IBM's 64-bit PowerPC uses 19 million transistors it is hardly surprising that very significant amounts of heat are dissipated. Some of the new chips now under development dissipate levels of heat well in excess of 50 watts, and the trend of increasing levels of power dissipation is likely to continue. With the increasing levels of power dissipation, thermal control of chips is an integral part of the design and it is every bit as important and challenging as the electrical performance.

It is interesting to note that when the first bipolar integrated circuits were introduced, limits of around 20 transistors were thought to be the limit of integration as a result of thermal considerations. The introduction of CMOS techniques enabled a quantum leap to be made in the levels of integration and the trend towards ever-larger i.c.s has increased since then.

More recently, the reduction of supply voltage has been of assistance as the thermal boundaries have been approached, because power levels are proportional to the square of the voltage. Even so other effects prevent the picture from being quite so rosy. The design of the transistors in the chip has to be altered to enable them to operate at low voltages. One of the results of this is that they become far more leaky and this effect means that they consume power even when they are switched off.

## Temperature rises

To ensure the highest speed of operation, devices should be operated at a low

temperature. The unwanted additional power consumption from the leaky transistors raises the temperature and this reduces the electron mobility because of the increased number of collisions that occur as the electrons move around the crystal lattice.

Accordingly, it makes the methods and techniques used for heat extraction from the i.c. a point of major importance if speeds are to increase at the current rate. A company named Kryotech is already marketing a chip that is cooled, increasing its performance by a half again. To the same end, IBM are optimising the performance of their basic silicon designs for low temperature operation with a view to this being one of the ways forward for the future.

However, even though speed generally increases with cooling, it also increases the threshold voltage for the individual devices, and this in turn increases the level of leakage and partially offsets any gains that are made. This is one of the factors that makes optimising the design for low temperature operation so important. By choosing the optimum level of threshold voltage, the maximum use can be made of any cooling that is used.

## Extracting heat

There are a number of ways in which heat can be extracted from the chips. One method is to use a system that is effectively a small-scale version of a domestic refrigerator. These systems are very successful, being already employed in a number of high end products and they are able to cool chips down to a temperature of around -50°C.

Whilst this can give significant advantages in performance, lower temperatures can provide even greater improvements. To achieve this there are a number of methods that can be adopted. The most popular idea is that of thermo-electric heat pumps. These do not involve the same level of mechanical hardware and are accordingly less expensive. They can also be interfaced to the basic chip more easily, and can actually be made as part of the same assembly.

However, the basic Peltier devices, although attractive at first sight, leak too much heat back into the chip, and as a result they are not as efficient as they are required to be for this function. Fortunately, new work undertaken at the Massachusetts Institute of Technology has resulted in the production of new materials and structures that give far more effective and efficient solutions.

The requirement is to be able to remove a considerable amount of heat from a small area. One of the new solutions using a thin film semiconductor heat

pump can extract as much as 100 watts per square centimetre. With further work it is expected that these devices could be built into the basic chip package, providing a very convenient, efficient and reliable method of extracting heat from the devices.

## Packages

Whilst heat is a major problem that is being overcome, new package technology is also part of the solution. Long gone are the days when dual-in-line packages were able to meet most requirements. Even the quad flat packs are not suitable, and in addition to this, equipment manufacturers dislike them because they are easily damaged. Flip chip packages where the silicon is directly bonded to the package are able to give performance improvements. This gives a speed increase as a result of its lower resistance and RC delays as well as giving a physically shorter connection.

Further improvements have been made by adopting a system that enables the critical leads to be kept as short as possible. Although this technique requires the addition of an extra layer of metalisation and a complete re-layout of the chip, it provides an increase that although small still helps to increase the overall speed of operation.

A further increase in performance is achieved by using a dielectric with a low value. In turn this reduces the levels of capacitance and cross talk, which were large enough to slow down the speed of operation. The material chosen for this is silicon oxyfluoride (SiOF).

## Summary

Although different manufacturers use different techniques to give the new higher clock speeds, the overall pattern is clear, and it is likely that in a few years time they will all be used as standard. Many of them give minor improvements on their own, but when used with the other techniques they enable a significant improvement in performance to be achieved in the chip as a whole. This demonstrates the fact that is commonly true in technology that a variety of improvements are required to give the overall improvement in performance.

### CHIP LINKS

Are you aware that the *EPE* website ([www.epemag.wimborne.co.uk](http://www.epemag.wimborne.co.uk)) has links to several semiconductor manufacturers' sites from which data sheets can be downloaded?



# Write your PIC programs in BASIC! - No STAMP REQUIRED!

## PIC Basic £49.95

- Quicker and easier than "C" or assembler
- Expanded BASIC Stamp I compatible instruction set
- True compiler provides faster program execution and longer programs than BASIC interpreters
- I2CIN and I2COUT instructions to access external serial EEPROMs
- More user variables
- Peek and Poke instructions to access any PICmicro register from BASIC
- Serial speeds to 9600 baud
- In-line assembler and Call support
- Supports PIC12C67x, PIC14Cxxx, PIC16C55x, 6xx, 7xx, 84, 92x and PIC16F8xx microcontrollers
- Use in DOS or Windows
- Compatible with most PICmicro programmers (we recommend the EPIC PICmicro Programmer)

The low-cost PicBasic Compiler (P8C) makes it easy to write programs for the Microchip PICmicros. P8C converts your basic language these programs into hex or binary files that can be programmed directly into a PICmicro microcontroller. The easy-to-use BASIC language makes PICmicro programming available to everyone with its English-like instruction set. No more scary assembly language!

The PicBasic Compiler instruction set is compatible with the Parallax BASIC Stamp I. Stamp I programs can be compiled into PICmicro code and programmed directly into a PICmicro, eliminating the need for a BASIC Stamp module. These programs execute much faster and may be longer than their Stamp equivalents. They may also be protected so no one can copy your code. Other benefits include substantial cost savings over a BASIC Stamp.

The PicBasic Compiler has many features beyond the BS1. Peek and Poke instructions let you use additional PICmicro features not available on the BASIC Stamp I. These include access to PORTA, B, C, D and E (if the particular PICmicro has them), A/D converters, hardware serial ports and other on-chip features in BASIC, foregoing the need to use assembly language.

But if you really want to use assembly language instructions, they may be mixed with BASIC instructions through the use of the PicBasic Compiler's in-line assembler and Call instruction. Our PICmicro macro assembler is included and automatically invoked by the PicBasic Compiler.

The I2C commands let the PICmicro talk to external I2C devices, such as serial EEPROMs, using only a 2-wire interface. Two PORTA pins have been dedicated to the task (the particular pins assigned may be easily changed if desired) so there is no need to tie up any of the special purpose PORTB pins.

P8C has more user variables. The BS1 only provides variables from B0 - B13 and W0 - W6. The PicBasic Compiler allows variables from B0 - B79 and W0 - W39 when used with PICmicros having 96 RAM registers in bank 0 like the PIC16C622 and 16C74.

The PicBasic Compiler is a DOS command line application (it also works in Windows) and runs on PC compatibles. It can create programs for the PIC12C67x, PIC14Cxxx, PIC16C55x, 6xx, 7xx, 84, 92x and PIC16F8xx microcontrollers and works with most PICmicro programmers, including our EPIC PICmicro Programmer. A printed manual and sample programs are included to get you started.



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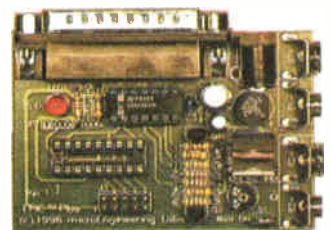
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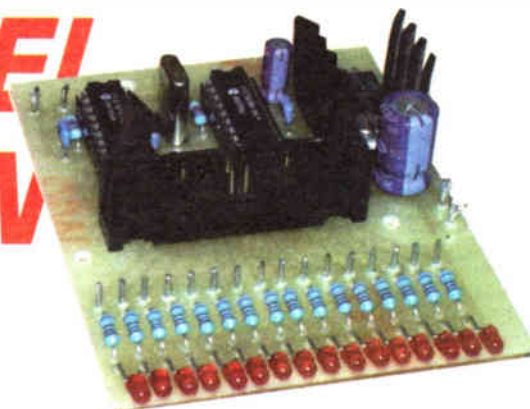
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# MULTI-CHANNEL TRANSMISSION SYSTEM



ANDY FLIND

Part One

*A PIC-based 8 to 16-Channel 2-wire on-off signalling communication link. An add-on Interface (next month) will extend possible options to internal private telephone and intercom systems.*

**T**HIS project provides up to sixteen channels of on-off signalling communication through just a single pair of wires, in one direction or in both directions simultaneously. In a one-way system the Transmitter may be powered through the same pair of wires which allows the monitoring of up to sixteen inputs from locations having no local power supplies. An interfacing option (next month) enables operation through audio circuits, such as private internal telephone and intercom systems.

Although ideal for remote signalling and alarm system monitoring, other possible applications could include such things as environmental monitoring, model railway controls and switching for advanced lighting or display systems. The versatility of using circuit modules, and the ways in which they can be connected together, means that possible applications are limited only by the constructor's own imagination.

## HOSPITAL CALL

Like many designs, this one began with a request from a friend, who on this occasion is the volunteer engineer for the local "Hospital Radio". Although operated by amateurs this service manages to maintain impressively high operating standards.

At present a new studio is being constructed at some distance from their existing one and for a while they will be operating these simultaneously, often with a D.J. working in both. To make this possible a number of signalling channels are required for functions such as indicating when a microphone is in use. Security monitoring channels are also needed since the original studio is housed in a "Portacabin" and has suffered from attempted break-ins.

The request, then, was for the provision of sixteen "on-off" signalling channels to operate through a single circuit from the hospital's internal telephone system. Plus, the icing on the designer's cake, it was required to operate simultaneously in both directions.

## TAKE YOUR PIC

Initial thoughts were that the task could be carried out easily with a suitably programmed PIC. Whilst the programming proved far from easy, it eventually resulted in the extremely versatile system described here.

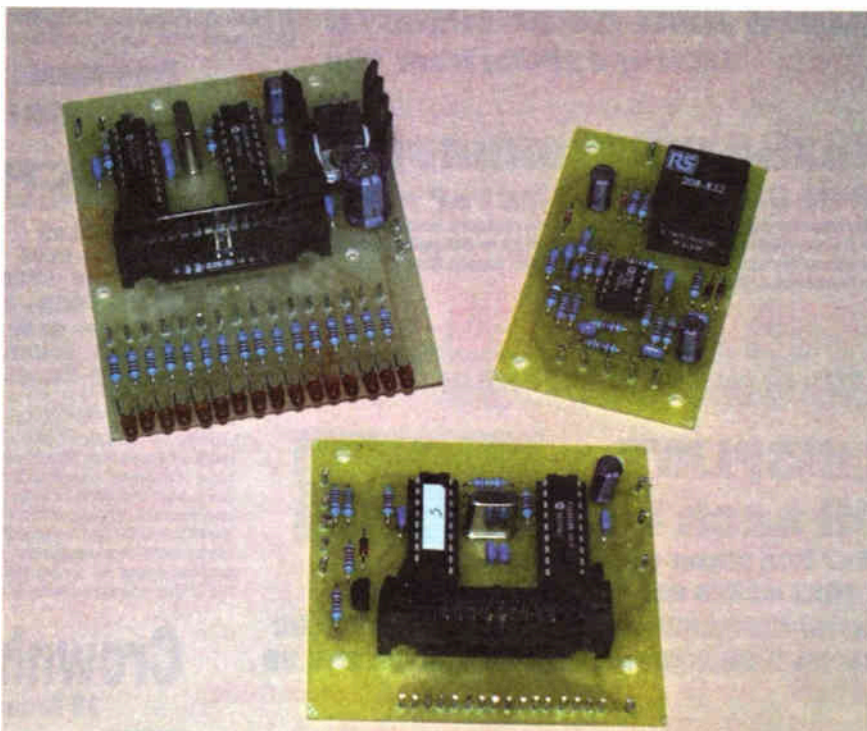
It can operate to the original specification with sixteen channels in each direction through a circuit capable only of handling low-level audio signals, but, as described, it can also be used in several other ways to suit less demanding applications. It can have either eight or sixteen channels, in one or both directions, and in some cases the Transmitter may be

powered through the signalling wires which can sometimes be very useful.

Later upgrading of a system is also simple, as the second eight channels can be added by simply plugging in extra PICs. This is a project offering lots of possible options for tailoring the configuration to suit the individual constructor's needs.

## SENDING A SIGNAL

The method of signal transmission used is relatively simple. A total of sixteen "clock" pulses are sent and for each there is a following "signal" pulse if the associated input is active. Part of the resulting waveform is shown in Fig.1.



The three modules: Receiver board; Interface (next month) and, foreground, Transmitter board.

It can be seen that the pulses are negative-going, with a positive quiescent state which allows the signalling line to serve as the transmitter power supply if required. The basic timing of each pulse is 0.5ms low, 0.5ms high, so that if all the switches are active the sequence becomes a burst of 1kHz tone, a suitable frequency for transmission through an audio circuit.

Squarewaves with a peak-to-peak amplitude of 5V are not suitable for telephone circuits however, as stray coupling into adjacent circuits in the cables is likely to cause interference to other users. The original intention was to "smooth" and attenuate the waveform with passive low-pass filtering and restore it at the far end with a comparator but this idea failed since telephone circuits usually carry only a.c. signals due to coupling transformers and capacitors.

The average d.c. content of the waveform produced by this project varies with the number of active inputs and the resulting variation of the average level at the far end of an a.c. coupled circuit made it impossible to adjust the comparator for reliable operation. A solution was eventually found for this problem, the principle of which is shown in Fig.2.

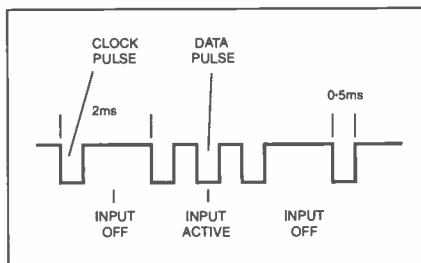


Fig.1. Transmission method used.

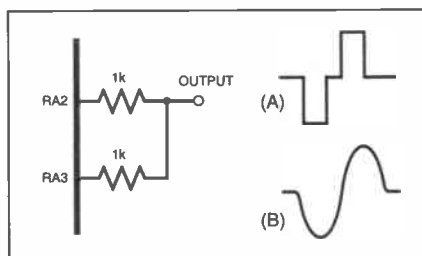


Fig.2. Waveform generation.

Two outputs from the PIC (RA2 and RA3) are connected through a pair of 1 kilohm (1k) resistors and the output is taken from their junction. The quiescent state consists of one output high (positive) and one low (negative) so that the output is half the supply voltage. A "signal pulse" consists of making both outputs low, followed by a return to the quiescent state, then both outputs high, then back to one high, one low.

This results in the waveform shown at Fig.2a, which is much better for transmission through an a.c. circuit. Furthermore, if the "low" and "high" states occupy around 61 per cent of the total period the energy content will be similar to that of a cycle of sine wave. When passed through a suitable low-pass filter this produces a very good approximation of a sine wave as shown in Fig.2b, far more suited to telephone circuits.

In passing, it's worth mentioning that with a 5V supply the current "wasted" by the two resistors in the quiescent state is

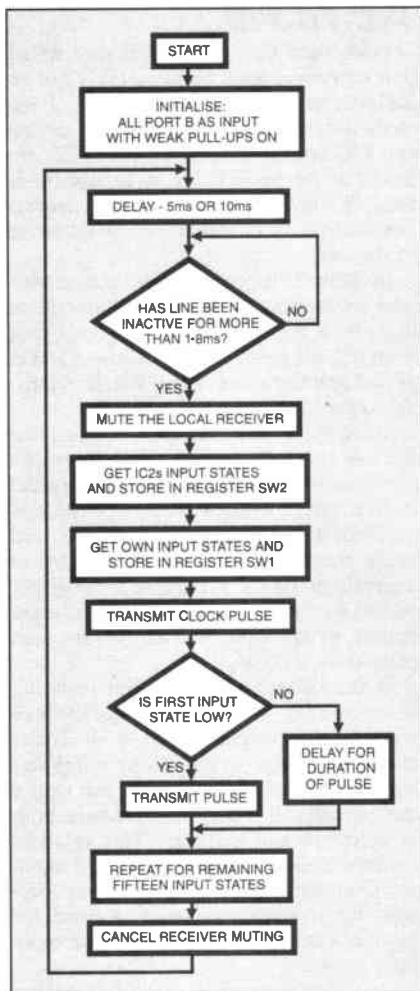


Fig.3. Flow diagram for the first Transmitter PIC, IC1.

only 2.5mA as they present a series resistance of 2 kilohms, whilst the output impedance is only 500 ohms as for this they are effectively in parallel.

### BI-DIRECTIONAL OPERATION

Achieving bi-directional operation was more difficult. In telephony there are "two-to-four-wire" converter circuits which split the conventional two wires into separate transmit and receive pairs. They work by coupling the circuit to the receiver through an impedance of some kind, often just a resistor, and injecting an inverted form of the locally transmitted signal into the receiver to cancel the bit of it that comes through this impedance.

Success with this type of circuit assumes that the transmission path will have a known and constant impedance, both resistive and reactive, and attempts to use it with the proposed telephone circuit failed miserably. Eventually a software solution was found in which each transmitter checks the line for silence before transmitting and mutes the local receiver before doing so. Two such transmitters can be made to synchronise to each other and take turns to transmit.

The PIC16F84 can have internal "weak pull-up" resistors applied to the eight bits of port B when these are configured as inputs, removing the necessity to provide them externally. Each input can then be as simple as just a switch pulling it to ground if required.

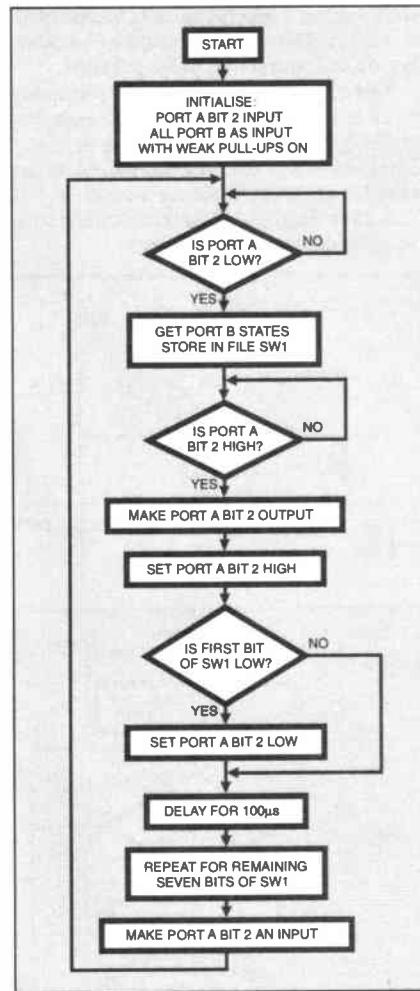


Fig.4. Flow diagram for the second Transmitter PIC, IC2.

A single PIC can only provide eight such inputs however, and this project required sixteen. Since these i.c.s are now available at a cost of less than £2 from some suppliers, the quickest and cheapest way to obtain a further eight inputs is from a second PIC which transmits its inputs serially to the first upon request.

### SOFTWARE OPERATION

An outline of the software operation for the first PIC, IC1, in the Transmitter circuit is shown in the flow diagram Fig.3. The initial setting up includes configuring all of port B as inputs with active weak pull-ups.

This is followed by a brief delay. It is unlikely but quite possible that both transmitters in a bi-directional system might check the line, find it inactive and transmit together in perfect synchronisation. The use of a slightly different delay in each transmitter will quickly break such a pattern to ensure correct operation. Five and ten milliseconds are the values used for this.

Following the delay the PIC monitors the line for a period of inactivity greater than 1.8ms, after which it mutes the input to the local receiver, collects the input states from the second PIC, IC2, and stores them in a register named SW2, and then stores its own input states in register SW1. It then transmits the first clock "pulse" as described earlier and checks the first bit of SW1. If this is clear, corresponding to an

active input, a second pulse is transmitted. If it is set, the input was inactive so a delay lasting the period of a pulse is called.

This action is repeated for the remaining seven bits of SW1 followed by the eight bits of SW2, the whole process taking precisely 32ms. After this the program returns to the start and the entire sequence is repeated.

A flow diagram of the Transmitter software for IC2 is shown in Fig.4.

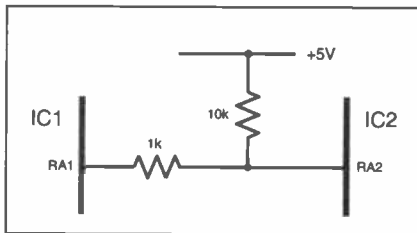


Fig.5. Communication between two PICs.

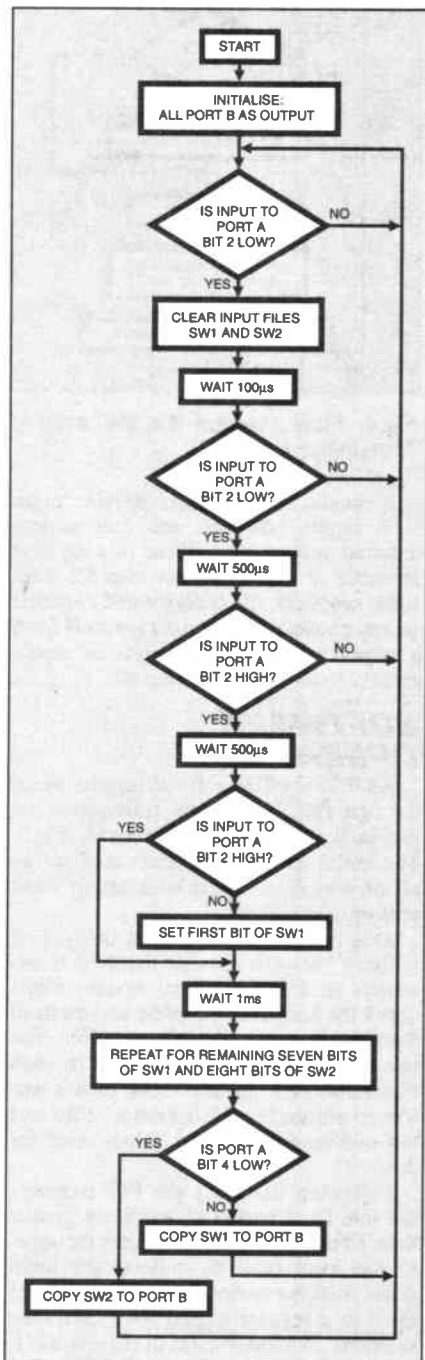


Fig.6. Flow diagram for the Receiver.

## PIC-TO-PIC

From time to time readers have asked how communication between PICs can be achieved so a detailed description of the method used may be helpful. In this circuit two PIC connections (RA1 and RA2) are linked as shown in Fig.5. A 1k resistor is used in case both pins become outputs simultaneously, although this should never be the case.

Initially, both connections are configured as inputs and the 10k resistor pulls them both high. When IC1 requires data from IC2 it's pin becomes an output and is pulsed low for about 400µs before returning to the input state.

Meanwhile, IC2 has been waiting for the low pulse. On seeing this it stores its input states in a register and waits for the input to return to the high state. When this happens it makes its pin an output and sends the eight input states serially at intervals of 100µs. Following this the pin returns to the input state and the program returns to the start to wait for the next pulse from IC1.

In the meantime, 50µs after restoring its connection to input, IC1 commences taking eight readings from it at 100µs intervals and storing the results in register SW2. The whole process takes just over a millisecond and is easy to implement, both in hardware and software. This is serial communication at its simplest and more sophisticated methods are obviously possible but it provides a starting point for anyone wanting to connect two or more PICs together.

One advantage of this method is that for eight-channel operation IC2 can be omitted. IC1 will still request the information but will "see" eight inactive inputs as each time it reads the pin it will see a high state set by the 10k resistor.

## RECEIVER SOFTWARE

Continuing with the Receiver, the flow diagram for this is shown in Fig.6. The program begins by looking for a falling edge in the input signal from the line. When it locates one it clears the two input registers named SW1 and SW2 which will contain the sixteen switch states.

It then waits for 100µs, which should take it into the low portion of a pulse if this was the origin of the edge. It checks the input is still low, if not it returns to the program start. Otherwise, it waits for 500µs and checks that the input is now high, as it will be if a pulse is present. Again, if it isn't the program returns to the start.

After another 500µs, which takes it to the point where the input will be low or high depending on the input state being transmitted, it samples the state of the line and stores it in the first bit of register SW1. A further delay of 1ms takes it to the next clock pulse, where the process is repeated until all sixteen pulses have been checked and their associated data bits read.

Both low and high states of all sixteen clock pulses are checked and if any are missing the program immediately returns to the start. This provides rapid synchronisation to the transmitter and good protection against data corruption as a complete valid sequence must be received before output takes place.

Assuming a complete sequence is received, the program now checks the input to port A bit 4. This is wired "high" for IC1 and "low" for IC2, so the PIC knows which socket it is in and sends the appropriate eight bits of data to port B, SW1 in the case of IC1 and SW2 for IC2.

In contrast to the Transmitter there is no communication between the two i.c.s which both simply check and store all sixteen bits and output the appropriate set. This allows them to use identical software and, as with the Transmitter, if just eight channels are required the second i.c. can be simply omitted.

An examination of the software of this project will reveal that it is written in straightforward "top-down" style with most repetitive operations simply repeated the appropriate number of times in preference to using loop techniques. This tends to improve reliability and is easy to follow, even though it is more tedious to write.

## TRANSMITTER CIRCUIT

As with many PIC projects, the circuits are relatively simple as so much of the work is done by the software. The only complexity is in the Transmitter where the various methods of use make some of the components optional.

These options will be explained in more detail next month. For now the simplest method will be described so that construction and testing can be carried out.

The full circuit diagram of the Transmitter is shown in Fig.7. The two 16F84 PICs, IC1 and IC2, share a common clock using the oscillator of IC1 with a 4MHz crystal X1 and capacitors C1 and C2.

Both IC1 and IC2 have all eight inputs of port B pulled high internally so these are simply brought out to pins to which external connections can be made. The communication between them is through resistor R7 with pull-up resistor R8. A digital output is taken from IC1 port A bit 2 (at pin 1), which is normally high and goes low for clock and data pulses.

The sensing and muting function, only required for synchronised bi-directional use, is performed with port A bit 1 (at pin 18) and operates as follows. When used in this way the signal is coupled to the local receiver through a 10k resistor, and the sense/mute pin is also connected to the receiver side of this resistor.

Initially it is an input, and listens for a continuous "high" signal to confirm that the other transmitter is not sending. Once this is detected it is converted to an output and set high for the duration of transmission, so the local receiver effectively sees a continuous inactive line. Where this facility is not required, resistor R2 holds this pin high so that transmission will take place anyway.

Other optional bits are resistors R3 and R4 which are only required if the unit is used with the Interface circuit to be described next month, and resistors R1, R5, transistor TR1 and diode D1, are needed if it is to be powered through a 2-wire connection from the distant Receiver.

The principle here is that one of the two wires is a common ground (0V), or negative, whilst the other is energised from

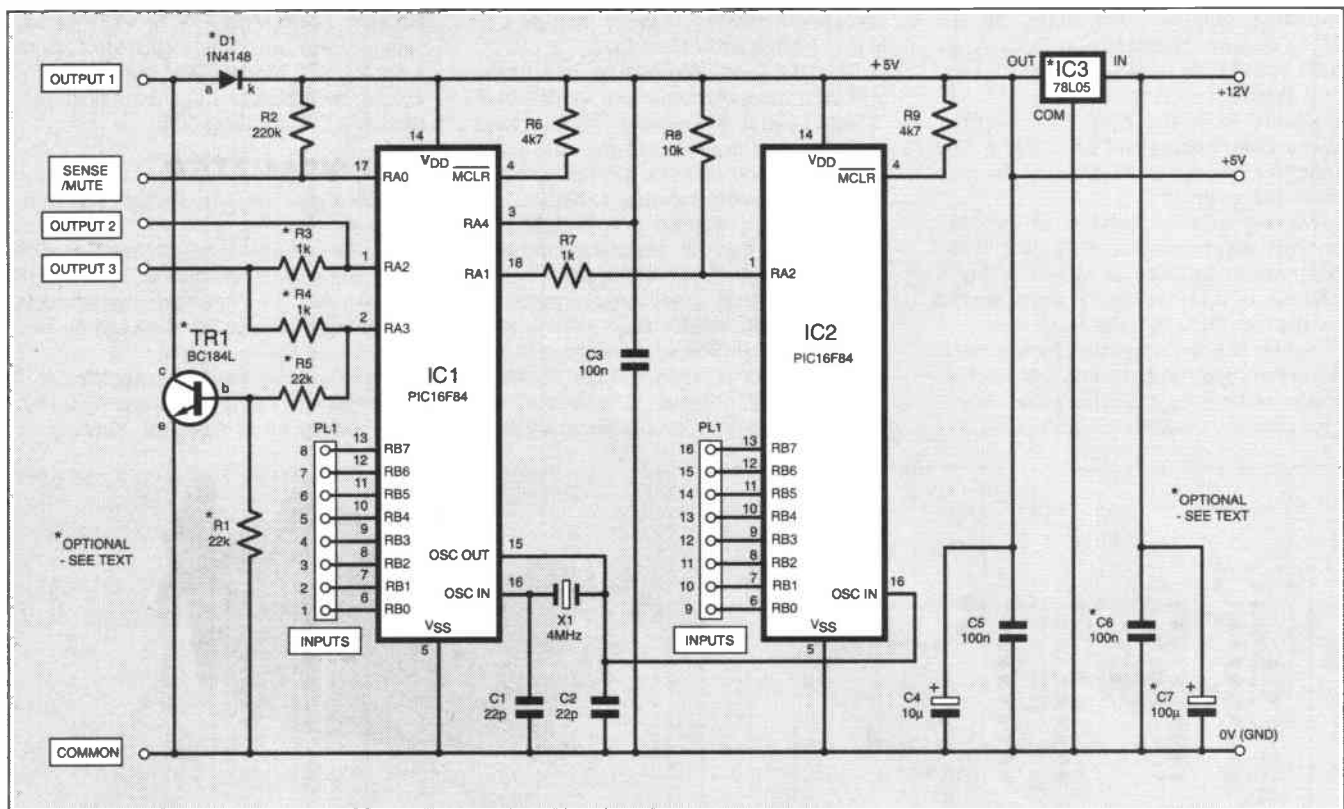


Fig.7. Full circuit diagram for the Transmitter section. Note the items marked with an asterisk are optional – see text.

+5V through a 220 ohm resistor (an option in the Receiver) and charges capacitor C4 via diode D1 whilst the line is high. Then C4 supplies the circuit whilst the line is pulled low for pulses by transistor TR1.

Finally, there is an optional on-board 5V supply regulator, IC3. In most cases the Transmitter will be supplied with +5V from a Receiver, either local for a bi-directional system or remote. However, if an application requires that it should be self-powered for any reason, regulator IC3 can be fitted together with input decoupling capacitors C6 and C7. In most cases these three components will not be needed.

Also, of course, where only eight channels are needed IC2 may be omitted.

### RECEIVER CIRCUIT

The Receiver circuit diagram shown in Fig.8 is even simpler. As with the Transmitter, the two PIC16F84s, IC1 and IC2, share a common 4MHz crystal clock. However, there is no communication between them. Instead the input signal is connected to RA2 (at pin 1) of both PICs.

Each of the sixteen outputs is provided with a resistor supplying an l.e.d (light-emitting diode). These can be omitted if not required although they are useful when

testing. For clarity only one resistor and one l.e.d. is shown for each i.c. in Fig.8, since the others are identical.

The supply regulator IC3 is a robust 1A type mounted on a small heatsink as it has to supply the l.e.d.s and probably also some output circuits and a Transmitter. The only optional component is resistor R10 which is needed if 2-wire operation with the Transmitter powered from the line is intended.

### CONSTRUCTION

Construction of this project is straightforward. The Transmitter and

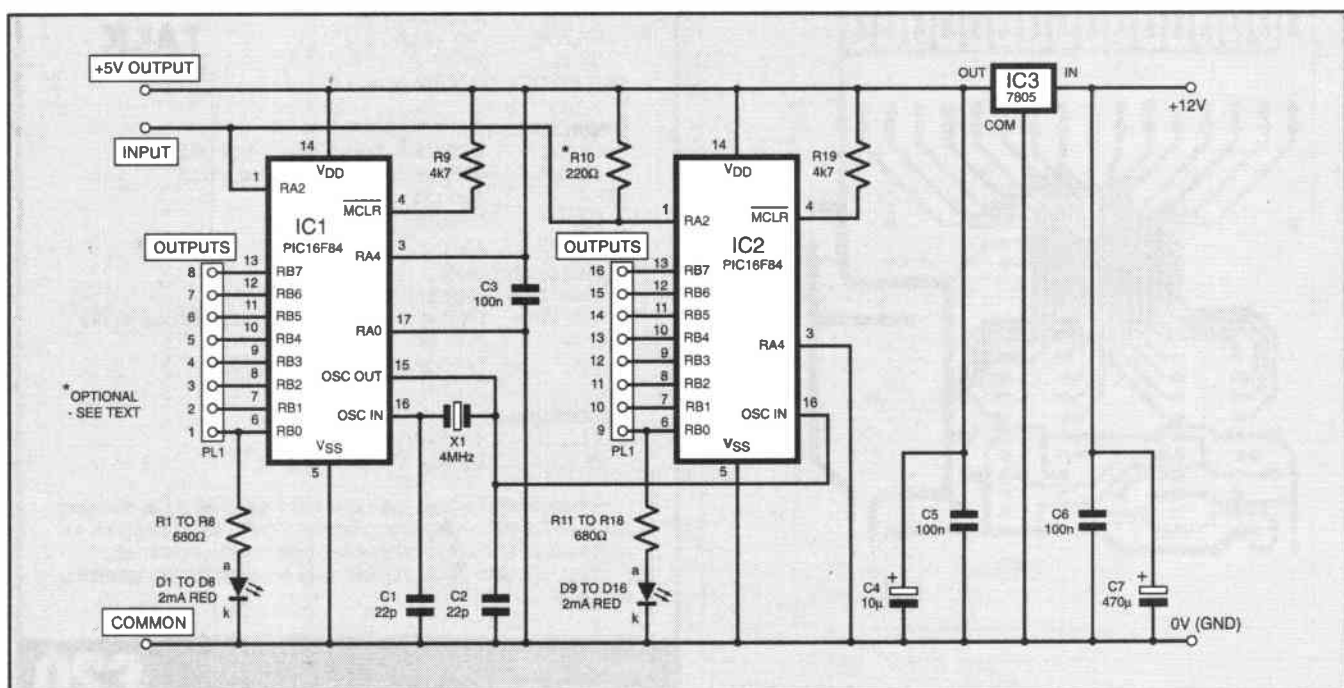


Fig.8. Complete circuit diagram for the Receiver section of the Multi-Channel Transmission System.

Receiver circuits, that make up the Multi-channel Transmission System, are both built up on single-sided printed circuit boards (p.c.b.s). These boards are available from the *EPE PCB Service*, codes 264 (Trans.) and 265 (Rec.). The Interface p.c.b. (next month) is also available, code 266.

Starting with the Receiver all the components except resistor R10, just above IC1, should be fitted as shown in Fig.9. The use of d.i.l. sockets is recommended for the two PICs, IC1 and IC2.

Solder pins are suggested for the external connections as these will then be more robust and can be made from the component side of the board. A degree of force is

sometimes required to insert such pins so it may be best to fit them first.

The l.e.d.s, which should be 2mA types, and their associated resistors are optional. Where fitted it is not too difficult to bend their leads in the required manner, and a little "Blu-Tack" may be helpful for holding them in position during soldering.

Not mentioned so far is the plug PL1. A requirement for the original application was a means of rapid connection and removal for testing and service purposes so 20-way IDC header plugs were included in the design. These are retained in this project but can be omitted if not required.

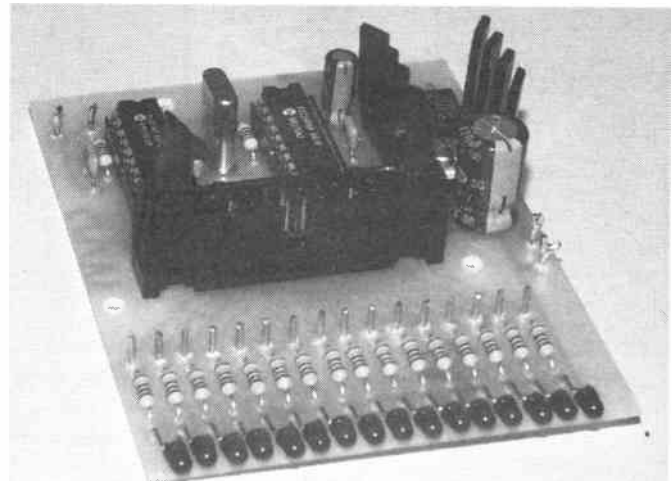
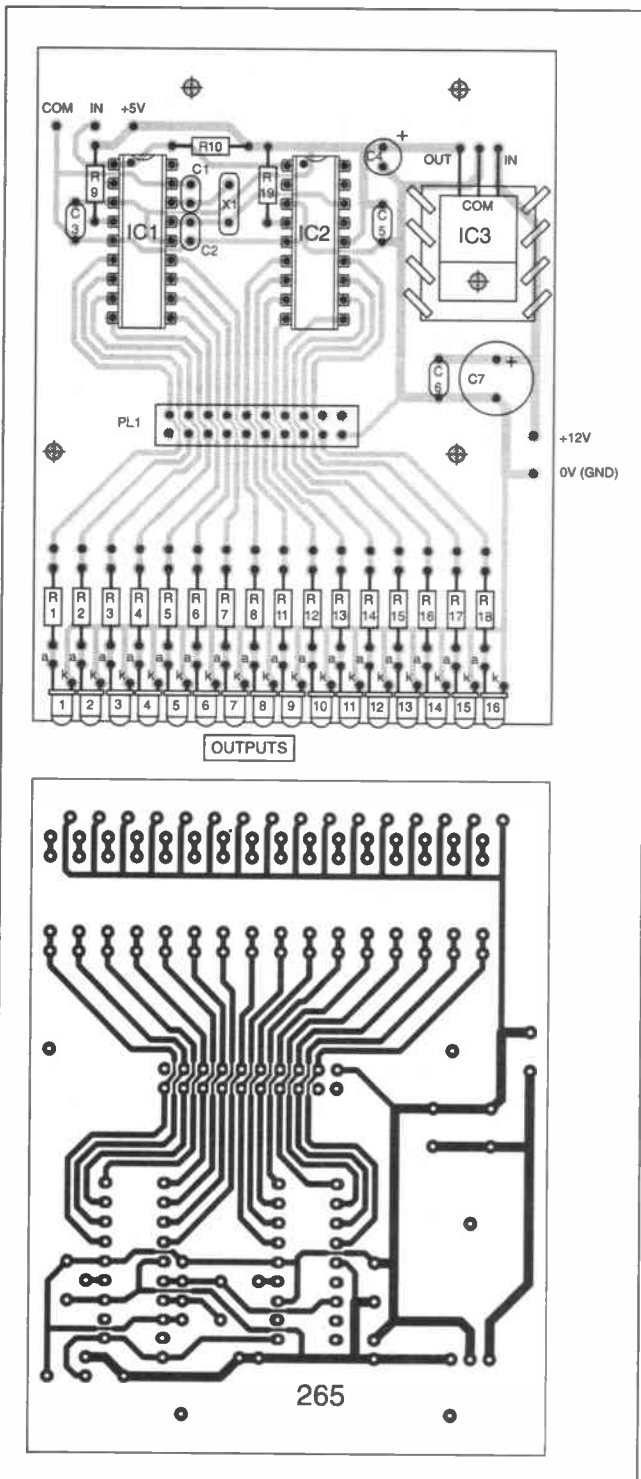
The two PICs should not be inserted yet. An initial test is to supply the completed

Receiver board with +9V to +12V which should result in a supply current of about 4-8mA whilst the regulated output of +5V should be available from the solder pin, marked +5V, just above IC1.

## TRANSMITTER

If the above test is satisfactory construction can continue with the Transmitter p.c.b., the component layout, together with a full size copper foil master, is shown in Fig.10. All the optional components should be omitted at this stage and the two PICs should not be inserted.

Once the board has been completed, it is worth checking initially by powering it with a 5V supply taken from the Receiver. It



Complete Receiver module, including the l.e.d.s. The l.e.d.s, together with their associated resistors, can be omitted if you wish – see text.

## COMPONENTS

### RECEIVER

#### Resistors

R1 to R8  
R11 to  
R18 680Ω (16 off)  
R9, R19 4k7 (2 off)  
\*R10 220Ω  
All 0.6W 1% metal film type

#### Capacitors

C1, C2, 22p resin-dipped ceramic (2 off)  
C3, C5, 100n resin-dipped ceramic (3 off)  
C4 10μ radial elect. 63V  
C7, 470μ radial elect. 25V

#### Semiconductors

D1 to D16 red l.e.d., 2mA type (16 off)  
IC1, IC2 PIC16F84 pre-programmed microcontroller (2 off)  
IC3 7805 5V 1A voltage regulator.

#### Miscellaneous:

X1 4MHz crystal  
PL1 20-way IDC header plug

Printed circuit board available from the *EPE PCB Service*, code 265 (Rec.); 18-pin d.i.l. socket (2 off); small heatsink for IC3; multistrand connecting wire; solder pins; solder etc.  
*Note: Resistor R10, marked with an asterisk, is optional – see text.*

See  
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Fig.9. Receiver printed circuit board component layout and full size copper foil master pattern.

# COMPONENTS

## TRANSMITTER

### Resistors

*R1, R5	22k (2 off)
R2	220k
*R3, *R4,	
R7	1k (3 off)
R6, R9	4k7 (2 off)
R8	10k

See  
**SHOP**  
**TALK**  
page

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### Capacitors

C1, C2,	22p resin-dipped ceramic (2 off)
C3, C5,	100n resin-dipped ceramic (3 off)
*C6	10µ radial elect. 63V
*C7	100µ radial elect. 25V

### Semiconductors

*D1,	1N4148 signal diode
*TR1,	BC184L <i>n</i> p <i>n</i> transistor
IC1, IC2,	PIC16F84 pre-programmed microcontroller (2 off)
IC3,	78L05 5V 100mA voltage regulator.

### Miscellaneous

X1	4MHz crystal
PL1	20-way IDC header plug

Printed circuit board available from the *EPE PCB Service*, code 264 (Trans.); 18-pin d.i.l. socket (2 off); solder pins; multistrand connecting wire; solder etc.

Note: All components marked with an asterisk (\*) are optional – see text.

Approx. Cost  
Guidance Only

**£16**

should draw virtually no current at all since the only components bridging the supply are the three decoupling capacitors. However, short circuits do occasionally occur in construction and electrolytics have been known to be fitted the wrong way round!

## TESTING

If all seems well IC1, programmed with TXIC1\_5 (5ms delay) or TXIC1\_10 (10ms delay) software, can be inserted. This should raise the supply current to about 2mA and the average voltage measured with a meter at Output 2 should be about 4V, indicating that IC1 is operating and transmitting an appropriate pulse sequence.

Next, a PIC programmed with receiver RX software should be inserted into the Receiver board at IC1 position and a connection made from Output 2 of the Transmitter to "IN" of the Receiver as shown in Fig.11. Connecting any of the first eight inputs (1 to 8) to ground (0V) should now illuminate the corresponding output l.e.d.s on the Receiver or take the appropriate outputs high if the l.e.d.s are not fitted.

Finally, if all sixteen channels are required, a second PIC with RX software can be fitted to the Receiver and one with TXIC2 software to the transmitter, after which the remaining eight channels (9 to 16) can be tested. The two boards are now operational and ready for use.

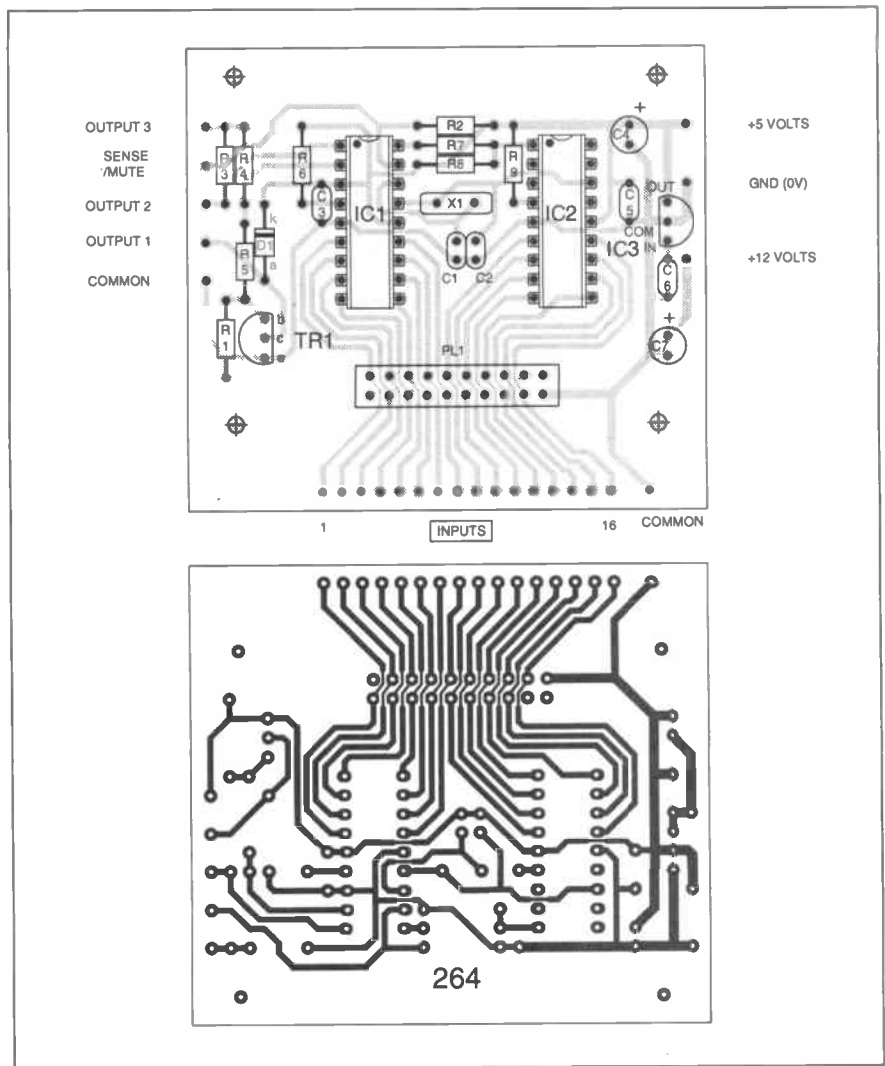


Fig.10. Printed circuit board topside component layout and full size undersided copper foil master pattern for the Transmitter.

## RESOURCES

Software for the Multi-Channel Transmission System Transmitter and Receiver modules is available on a PC-compatible 3.5 inch disk from the Editorial Office, code *EPE Disk 3* (a nominal handling charge is levied). Alternatively, it may be downloaded Free from the *EPE* Web site.

Ready-programmed PICs are also available and full details, including the above

options, can be found in the *Shoptalk* page in this issue.

Next Month: Details of the various ways in which these units can be used will be given, together with the construction of an Interface board for use with internal telephone circuits or similar long lines. This is effective in reducing or eliminating the radiated interference sometimes caused by high-level digital signals in transmission circuits.

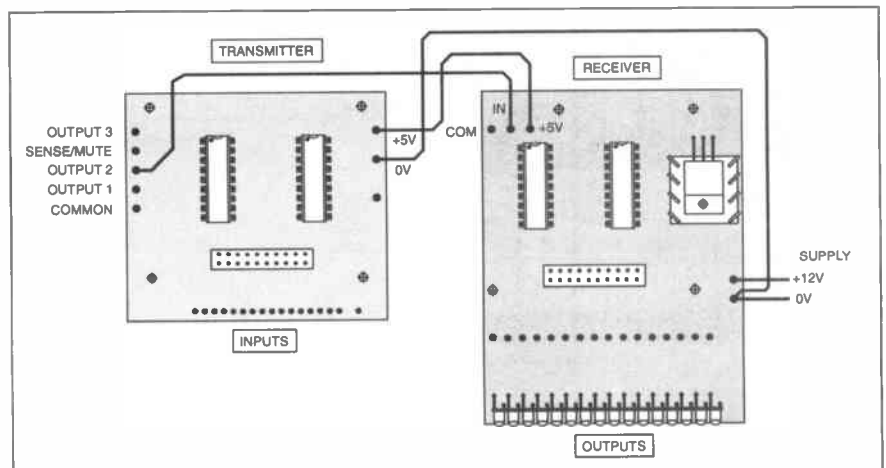


Fig.11. Test set-up for checking out the two p.c.b.s.

We can supply back issues of *EPE* and *ETI* (see panel) by post, most *EPE* issues from the past five years are available. An *EPE* index for the last five years is also available – see order form. Alternatively, indexes are published in the December issue for that year. Where we are unable to provide a back issue a photostat of any *one* article (or *one* part of a series) can be purchased for the same price.

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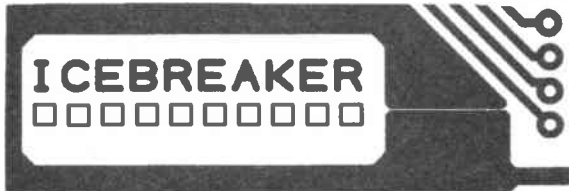
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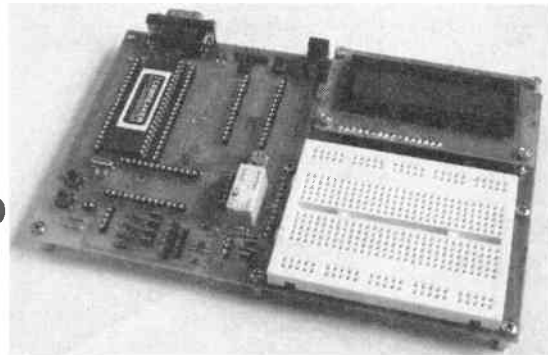
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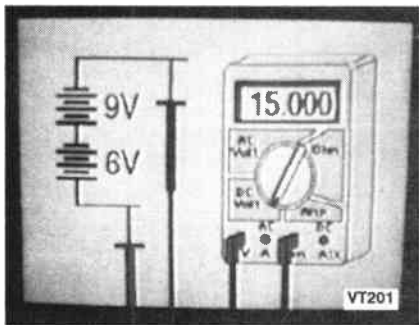
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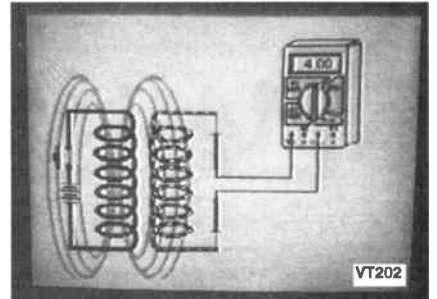
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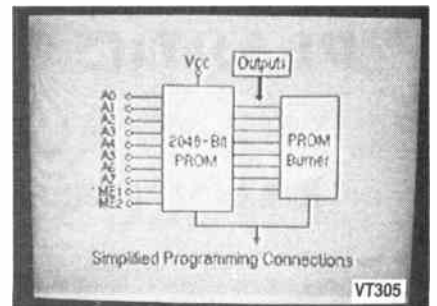
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# READOUT

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

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## ★ LETTER OF THE MONTH ★

### REGENERATIVE RECEIVER

Dear EPE,  
Regarding the *Regenerative Receiver* (March '00 issue):

The use of positive feedback to increase the *Q* of tuned circuits was widely used in commercial wireless receivers in the 1920s and early 1930s; amateurs continued to use the technique until the 1950s. The term commonly used was "reaction" and controls with this label appear on many receivers. The feedback in early sets was inductive with a pivotally mounted "reaction" coil that could be turned towards a static "tuning" coil. In later sets the feedback was fed through a variable capacitor, usually with solid dielectric, to a supplementary reaction winding on the coil used to form the main tuned circuit.

There were disadvantages with using reaction to increase sensitivity. If the feedback exceeded a critical limit the circuit oscillated and, as it was usually coupled to the aerial, became a transmitter. This had disastrous consequences as many receivers in the neighbourhood would be swamped by the radiation and those with critically adjusted reaction controls also burst into oscillation.

The *BBC Handbook* for 1929 has warnings about the problem, leaflets were issued by the Post Office (then the wireless licensing authority) and cartoons on the subject appeared in *Punch*. (In 1929 the *BBC Handbook* carried circuit diagrams to assist potential listeners to construct receivers!). People were branded as bad neighbours if they were suspected of oscillating. The addition of an r.f. amplifier stage alleviated the problem as the oscillating circuit was no longer directly connected to the aerial.

Increasing the *Q* of a tuned circuit also limits bandwidth. In the early days of broadcasting the signals were Morse (CW) and bandwidth limitation was a positive advantage. By the 1950s a.m. broadcast sound quality had reached a standard where this bandwidth limitation was significant.

The oscillation caused by positive feedback in circuits using "leaky grid" detectors was rectified by the grid driving the valve

into cut-off until the charge leaked away, so called "squegging", generating pulses of radiation. This circuit system, as the self-quenching super-regenerative receiver, was also patented by the brilliant Edwin Armstrong. The ratio of signal frequency to squegging frequency needed to be between 100 and 1000 so that audio reception was only possible at Short Wave and higher frequencies.

The circuit was used in the short range "B" set of Wireless Set 19 by the Army, in IFF responders (MkIII) by the Navy and Air Force. The *Lichtenstein* night fighter radar used by the Luftwaffe also relied on the circuit. Super-regenerative receivers, if mistuned, could receive f.m., and Hazeltine "Fremodyne" used a double triode to receive f.m. and provide an audio output.

P.S. In an act of generosity, possibly misplaced, I presented my copy of the *BBC Handbook 1929* to the East Midland Radio Museum in upstate New York. The place is worth a visit if only to see the spark gaps operated and the poster advertising the return trip of the *Titanic*. Possibly there is a copy at Amberley.

A book worth reading is *Super-Regenerative Receivers* by J.R. Whitehead, Cambridge University Press, 1950. (Dr Whitehead was a TRE man so the book is biased towards aircraft equipment.)

**Guy Selby-Lowndes, Patent Attorney,  
Plaistow, Billingshurst**

*Thank you Guy, most interesting information. We assume you refer to Amberley Chalk Pits Museum, near Arundel, West Sussex - it has many historic items relating to radio and electronics and is certainly well worth a visit.*

*Which leads nicely into a sales plug for our sister magazine Radio Bygones! It is the leading magazine for vintage radio enthusiasts, and you can find out more about it through the advert elsewhere in this issue. If you have internet access, have a browse of RB's web site as well, at [www.radiobygones.co.uk](http://www.radiobygones.co.uk), which also allows you to "chat" with other like-minded enthusiasts.*

### PIC LOCATIONS 0 TO 3

Dear EPE,  
*PIC Toolkit Mk 2* (May-June '99) forces the addition of a JMP to location 0005 at the Reset Vector and loads any HEX file from location \$0004 onwards, despite the HEX file address information. Similarly, the decode routine used during disassembly totally ignores ANY CODE in locations \$0000 to \$0003 inclusive.

Note that it is common for an interrupt routine code block to start at 0004 and continue through 0005 until the end of the routine. It is also common for other code such as Subroutines to start at 0005, the Reset vector being a JMP to the relevant location.

**Peter Balcombe,  
via the Net**

*The reason for Toolkit not allowing programmed access to locations 0 to 3 is historical, having adopted the convention used in the Simple PIC16C84 Programmer of Feb '96, as designed by Derren Crome. The same question was subsequently raised by readers and we have replied in various ways since then. The following is Derren's original reply:*

When the PIC is put into programming mode, it sets its internal counter to \$0000, which is the reset vector address. It was decided to have the program set this to \$0005, which is the beginning of the program memory address space.

Addresses \$0001 to \$0003 are not of use to the user. Address \$0004 is the interrupt vector which is set by the first line in the assembly code. The user program starts at \$0005.

### PIC16F87x PROBLEMS

Dear EPE,

I have been experimenting with the new PICs ('876 and '877) and *Toolkit Mk2* hardware and software, mostly using a 3-2768MHz crystal clock rate.

I have problems with Port C bits 0 and 1 as outputs at relatively fast state changes. With "slow" switching, e.g. using your TKTEST4 program, all seems OK. However, if I halve the COUNTs to speed up switching, the bit C0 square wave becomes erratic and the bit C1 square wave gets somewhat noisy. If I output \$00 and \$FF to all ports in a rapid loop, these two bits are a mess, while all other bits, on Port C (and Ports A, B, D and E) are OK.

I am setting PAGE0 and PAGE1 OK using both bits RP0 and RP1, and I have even tried ensuring that TIMER1 is off by setting file T1 CON to all zeros. I assume the problem is something to do with the multi-functional nature of these two bits, and most likely to do with TIMER1.

I have examined the PIC datasheet and recent issues of *EPE* but I am foxed. I note in the *8-Channel Data Logger* (Aug-Sep '99), that you use these two bits for push-button input, which is slow (and not output), so maybe you have not seen this problem yet. Can you offer any help, please?

TK2 is great! Thanks for adding recognition of TABs for spaces. You asked for suggestions for other facilities: are you able to add two useful functions to the assembler (functions which TASM supports), I think many people would find they make for clearer programs:

(a) simple addition in statements, e.g.:

```
HIGHBIT EQU %10000000
```

```
RETLW 'P'
```

```
RETLW 'I'
```

```
RETLW 'C' + HIGHBIT ;end of string 'x' of total 'n' strings
```

I use this for a useful I.c.d. text driver, with top bit set for end of each string, filtered off before displaying. It currently causes an error in TK2.

(b) Multiple components to a #DEFINE statement, e.g.:

```
EQUs for STATUS, RPO, RP1, then:
```

```
#DEFINE SETRPO BSF STATUS,RPO
```

```
#DEFINE CLRRP1 BCF STATUS,RP1
```

```
#DEFINE PAGE1 SETRPOCLRRP1 etc. (at the moment this only codes one statement.)
```

Could you please pass on my appreciation to all your staff for an excellent magazine and a very useful web-site. I find all the PIC stuff extremely clear and very useful.

Incidentally, my first introduction to electronics was *ETI* magazine, back in the mid-seventies. Since then I have built RAM and I/O boards and data loggers for the NASCOM (Z80), the North Star Horizon (Z80 and S100 bus), the dear old BBC (6520) and all the IBM PCs from 1981 to date, within both my professional work and my hobby.

**Roger D. Redman, via the Net**

*I've not come up against your Port C problem. Are you sure that your PIC is fully healthy? I have seen erratic waveforms on other devices when part of them has died for some reason. Buy another PIC and try the program on it.*

*Both your TK suggestions seem useful. Thank you Roger. Perhaps one day . . . !*

## PATENTLY DIFFICULT

Dear EPE,

I have designed a microprocessor-based PC Card for the ISA bus, but no one wants to know. I have tried over 40 UK manufacturers that were specifically selected to do the job of buying the manufacturing rights of my card, and have contacted a telecoms company here as my card uses Distinctive Ring Patterns from them, but not one of them has had the decency to reply.

Are all UK-based inventors of electronic devices treated, this pathetic way all the time? Or is there someone you know out there who would be interested in manufacturing my card? I am made to feel that I am insignificant, a has been, a nobody.

You would not believe the amount of E-mail and snail-mail I have sent out, but, nothing whatsoever has come back. I am so depressed with it all. I think the question is, after the Patent, what now?

I would be ever so grateful to you and your colleagues if you could publish this and your reply, as I feel it would benefit other UK Electronics Inventors in the same situation.

**Jim Delaney, Sheffield**

*Jim's plea was E-mailed to our Online Editor, Alan, who offered the following extremely practical reply:*

I've worked on both sides of the desk, both designing a wide variety of products as a development manager and also receiving proposals from outside designers hoping that my company would take on their idea. It happens all the time, and it's surprising how badly presented the applicant's case can be. Not every manufacturer would be as sympathetic to the aspiring designer as I was, so first impressions count, and a crisp business-like approach can only help as well as setting you above all the other (amateur) applications vying for the same spot.

However, I was one of the few who would always spare a little time to look at an external idea, but my next problem would be selling the merits of the idea to the senior management. If a designer couldn't sell the concept to me, I had no hope selling it up the ladder.

Often designers had no idea of the investments needed in tooling, production and distribution either. No basic market research, no sales projections, no budgeting – a design without such initial marketing research really would need to set the world alight. James Dyson found out the hard way and persevered, now everyone buys his vacuum cleaners (even me!). The Black & Decker Lawnraker and their WorkMate bench are two more examples of products designed by amateur designers. The Bayliss wind-up radio is another.

In my career in product development, I have only come across one really switched-on professional-looking designer (a real "ideas man") who presented a very powerful case, with good quality prototypes and lots of ideas that forced us to sit up and listen. He was immensely enthusiastic and positive, and had really thought of everything and had come up with some very cute answers.

A personal meeting sold us on the concepts. He had all the ideas and we were prepared to develop the product and tool up for mass production, which is what we did (for a special type of tool kit). It would also be true that, sometimes, manufacturers just don't know what they're looking at and are being very short-sighted, so you have no hope with such firms.

Manufacturers usually have their own agenda with their own products currently on the drawing board (CAD screen anyway), so to take on an external design could mean dumping one of their own in-house designs. There would need to be a very good reason to do that.

In the case of electronics, there is also the development cost involved with making the product EMC compatible and gaining CE-approval. Maybe the fact it's an ISA card rather than, say, PCI might also detract from it, I couldn't say. I believe that ISA is being phased out in

the PC2000 spec., though of course ISA slots will be around on legacy systems for some time to come.

It's only worth patenting if you can afford the legal costs of fighting an infringement. A pending patent enables designers to go with an NDA instead and then try to sell All Rights. I think it's not just the treatment of inventors which is the problem, more likely it's the pressure the manufacturers are already under with their own product lines. They get too wrapped up in their own problems to want to go looking for more! But a forward-thinking and progressive company (e.g. Black & Decker) will listen to outside ideas, if only to get the feel for an idea that may subsequently be proposed to their competitors.

You should ask yourself whether it's worth sub-contracting the production yourself, and maybe get a small batch made and sell direct if you have to (e.g. on a web site). CE approval is your next hurdle, then give a few samples away and get the market talking about it. If you can make a big enough nuisance of yourself in the marketplace, it could then be that someone will buy the rights. Just make sure you are fully protected with design rights. There are plenty of good electronic engineers who can CAD up a board and polish off its development.

Try looking at James Dyson's web site ([www.dyson.com/co.uk](http://www.dyson.com/co.uk)), there used to be an inventor's resource there. There is also an alt. newsgroup for inventors where I'm sure you'll get more help. Also you could try a local University – an example in my case would be the new Product Design & Development Centre based at the University of Hull, with whom I'm working.

I'm sorry I can't be of more assistance but hope the above helps – good luck!

**Alan Winstanley**

## REGEN RECEIVER AND F.E.T.S

Dear EPE,

I am writing to you as a subscriber to *EPE* and an electronics construction enthusiast for some 35 years. First, thank you for the superb series of articles on *R.F. Design* by Raymond Haigh, culminating in the *High Performance Receiver* (March '00), which I have decided to construct.

I am not "new" to construction, having built over 23 receivers for short waves over the years, designing and producing my own p.c.b.s for these receivers.

It is the power gain of the 2N3819 f.e.t.s used in Raymond Haigh's design that I wish to query. The problem is that many component suppliers use the same manufacturer for 2N3819s and the spread in characteristics of these devices may affect the receiver's performance. In my own designs I use BF244 and BF245. Your comments are requested.

**John B. Dickinson, Tamworth, Staffs**

*John Dickinson gave a lot more information in his letter and sent an example 2N3819. We forwarded everything to Raymond Haigh, who replied:*

Thank you for letting me read Mr Dickinson's interesting and helpful letter. I should be grateful if you would thank him for having taken so much trouble and for his very kind remarks about my recent series of articles. I would offer the following observations:

He is, of course, quite correct in pointing out the wide spread in f.e.t. characteristics. He is also correct when he says that the specifications for the BF244 and BF245 are tighter than the specification for the 2N3819. Referring to the tables published in Farnell's catalogue, the transconductance spread for the BF244 and BF245 is 3 to 6.5mA/V, whilst the spread for the 2N3819 is slightly greater at 2 to 6.5mA/V.

Unfortunately, the BF244 and BF245 may not be readily available outside Europe, and regard must be had to the world-wide circulation of *EPE*. Because of this, I will have to continue specifying the ubiquitous 2N3819.

I have built about six versions of the circuit

using this transistor as a drain bend detector. They all worked well with the component values quoted and without any selection of the 2N3819s.

I have, however, explored this question. The outcome of the trial was as follows:

(a) Thirty-three 2N3819 transistors were connected into circuit and provision made for monitoring the audio output voltage. Of these, 23 performed in a completely satisfactory way, three were marginally better than the rest, and seven performed badly, or would not work at all, unless the detector source resistor was increased in value. The transistor kindly supplied by Mr Dickinson was one of those which would not work at all.

(b) When the source bias resistor (R5) was increased to 15k, all 33 specimens of the 2N3819 performed in a completely satisfactory way. With the source bias resistor increased, several specimens of 2SK168, MPF102, TIS14 and J310 (about twenty transistors in total) all worked well in the circuit also.

(c) The few transistors which were marginally better than the rest gave a very slightly higher output with the specified 4k7 source resistor. It would seem my earlier endeavours to milk the last drop of performance from the circuit had revealed this. It is unfortunate that I made a chance selection of transistors which would work with this source bias resistor. Had I not done so I would have discovered that the circuit would not suit devices at the other extreme of the characteristic spread.

(d) Working and non-working devices in the test were distributed across a random selection of the products of different manufacturers. Presumably, therefore, the problem is primarily one of characteristic spreads rather than manufacturing differences. However, as suggested by Mr Dickinson, there could well be a tendency for some manufacturer's transistors to drift towards a particular extreme of the tolerance range.

(e) I suggest that the value of TR2 source bias resistor, R5, be increased to 15k to ensure that all specimens of 2N3819 are operated in the non-linear region of their characteristic curve. With this value for the source resistor, most other j.f.e.t.s, including the 2SK88, MPF102 and J310 should also work well.

**Raymond Haigh, Doncaster, S. Yorks**

## BINARY CONVERSION

Dear EPE,

Your *Teach-In 2000* Part 6 (Logic gates, Binary and Hex) brought to mind a system of converting decimal to binary I learnt many years ago.

Dredging through my personal memory-bank and with many false starts, the system is to divide the number to be converted by 2 continuously, ignoring any remainder. Every time the number is odd, put a dash (–) beside it. If it is even put "o". The top "–" or "o" is the least significant figure and the bottom one most significant. For example, decimal 3353 is converted as follows:

```
3353 –
1676 o
 838 o
 419 –
 209 –
 104 o
 52 o
 26 o
 13 –
 6 o
 3 –
 1 –
```

Turn the paper through 90 degrees so that the most significant figure is to the left then read off the binary code. Thus decimal 3353 equals 110100011001 binary.

This method is probably well-known in the "Trade" but it might be new to some readers.

**Harry Nairn, Ashted, Surrey**

*It's certainly new to me as well Harry. It's a form of long division, of course. Many thanks.*

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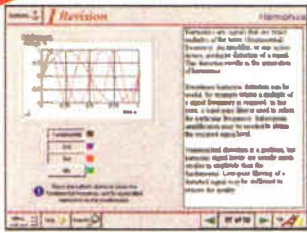
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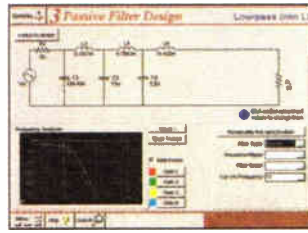
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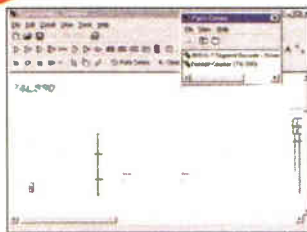
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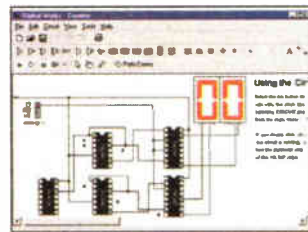
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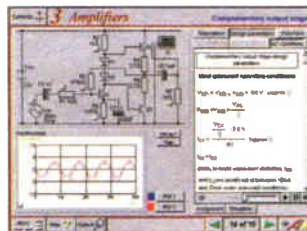


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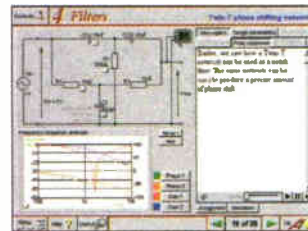
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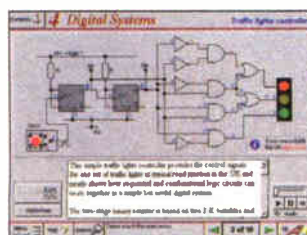


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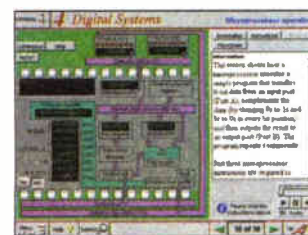
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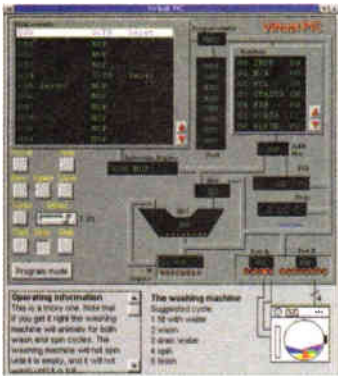
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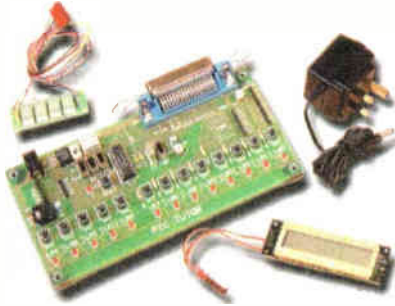
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## Constructional Project

# PIR LIGHT CHECKER

**TERRY DE VAUX-BALBIRNIE**

*Be trigger happy with your outdoor security light system.*

**P**ASSIVE infra-red (PIR) lamps, of the type which may be bought in any DIY store, are now very popular with householders. Mounted on an outside wall, they may be used to improve security or simply to illuminate dark areas when a member of the family passes by.

### JUST PASSING THROUGH

These lamps are designed to switch on for a certain time when someone walks in the detection field. This extends fan-shaped from a "window" in the front of the detector. In simple units, the operating time is fixed at manufacture. However, it is more usual to provide a control which may be used to adjust it over a certain range.

Normally, the lamps operate only when the ambient light falls below a certain level so that they will not switch on during daylight hours. Again, the point at which this happens is often adjustable using a control on the unit.

The working part of a PIR lamp is a sensor which detects the infra-red radiation which is naturally emitted by a warm body. The detector may be contained in a separate unit connected remotely to the

lamp. In most DIY units, however, it is attached to the lamp itself because this makes for simpler installation.

When a warm object moves in the sensitive zone, a signal is given which, after processing, operates a relay and switches on a filament bulb. In the larger security-type lamp, the bulb will be a halogen unit of some 150W to 500W rating. Smaller PIR lamps use an ordinary 60W household bulb.

### BLOWING IN THE WIND

When the PIR unit is properly installed, the lamp does its job well and rarely causes problems. However, when it is not properly set up it may be activated by animals such as dogs and cats passing by.

Any warm object moving in (and especially across) the detection field is likely to cause the unit to trigger – even warm air from a nearby central heating flue. Tree branches and other objects moving in the wind sometimes activate it – presumably because they reflect infra-red from somewhere else.

Any cause of false triggering may be difficult to track down. It can occur even

when the user has taken every precaution detailed in the installation guide. After supposedly "correct" setting-up, there is often a tendency towards occasional false triggering. This will require further adjustment on a "trial and error" basis to eliminate it completely.

Most PIR lamps have a "test" facility which enables them to operate in daylight and this helps with the initial adjustment process. However, it will miss any false triggering which happens only occasionally. There could be considerable difficulty when the lamp is mounted in a position which cannot be seen from the house.

Normally, the only way to check for correct operation would be to stand outside and watch it for a long period of time! Unnecessary operation of the lamp can be a nuisance to neighbours as well as wasting electricity and reducing the life of the bulb. With this PIR Light Checker, however, you can leave the monitoring to automatic electronics!

### CLOCKED

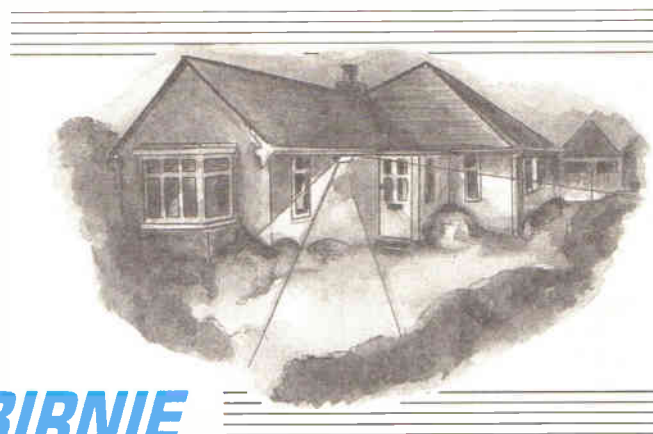
This self-contained battery-operated unit will automatically monitor a PIR lamp over a period of several hours overnight. An l.e.d. (light-emitting diode) display registers the number of times it has been triggered, up to nine. If the count exceeds this, the display will return to zero but the decimal point will light up. This shows the "overflow" – that is, a number greater than nine. When the unit is switched off then on again, the count is reset to zero, ready for a further test.

By adjusting the aim and sensitivity control on the lamp (if one exists), re-siting and cutting away foliage as necessary, any improvement can be easily monitored. Multiple causes of false triggering may then be eliminated one by one over a period of a few days. Note that if the unit is used to monitor the lamp overnight, it will record an extra count at dawn and this will need to be subtracted from the total.

This circuit is only suitable for use at night with the PIR lamp in "normal" mode. There must be no other bright sources of light nearby which could result in false counts.

### BATTERY SAVING

The circuit is housed in a small plastic box. This has a seven-segment l.e.d. display showing through a hole in the lid. There are also two switches (see photograph). One of these is simply an on-off switch while the other activates the





display. This latter switch is operated only when a reading needs to be taken and so saves battery power. A hole in the side of the box allows light from the lamp being monitored to reach a sensor on the printed circuit board (p.c.b.) inside.

The unit draws power from a 6V battery pack consisting of four AA-size alkaline cells. Under standby conditions, the current requirement of the prototype unit is some 400µA.

When the display is operated, the current rises to a value which depends on the number being displayed. This is because each digit is formed by lighting up the appropriate segments in the display. The most current-hungry case is when the number "8" is involved (since this uses all seven segments) together with the "over-flow" decimal point.

Since each segment and the decimal point require 12mA approximately, the total current will be about 100mA. However, this will only be needed for a few seconds during each test and, as stated earlier, it is the "worst" case. In practice, the battery pack should last for at least a year under normal conditions.

## HOW IT WORKS

The full circuit diagram for the PIR Light Checker is shown in Fig.1. Power is derived from a 6V battery pack (4 × 1.5V cell) B1 via on-off switch S2 and diode D1. The diode prevents possible damage if the supply were to be connected in the opposite sense. If this were done, the diode would be reverse-biased so no current would flow.

It will be found that the actual nominal supply voltage is 5.3V taking into account the forward voltage drop of the diode (0.7V approximately). Capacitor C8 charges up almost instantly and helps to provide a smooth and stable supply.

The light sensing section of the circuit is centred on IC1 and associated components. The light detector itself is a light-dependent

## COMPONENTS

### Resistors

R1	56k
R2	sub-min light-dependent resistor (l.d.r.), dark resistance 5MΩ approx. (see text)
R3, R4	470k (2 off)
R5	3MΩ
R6, R7,	
R9 to R11	1M (5 off)
R8, R19	2M2 (2 off)
R12 to R18,	
R20	270Ω (8 off)

All 0.25W 5% carbon film, except R2.

See  
SHOP  
TALK  
page

### Potentiometer

VR1	2M2 min. enclosed carbon preset, horiz.
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### Capacitors

C1	47n metallised polyester, 2.5mm pitch
C2	100n metallised polyester, 2.5mm pitch
C3, C4,	
C6, C7	100n metallised polyester, 5mm pitch (4 off)
C5	1µ radial elect, 63V.
C8	220µ radial elect, 10V

### Semiconductors

D1	1N4001 1A 50V rectifier diode
TR1	2N3903 npn transistor
IC1	ICL7611 micropower op.amp
IC2	ICM7556IPD dual CMOS timer
IC3	40110B decade up/down counter

### Miscellaneous

X1	7-segment, common cathode, l.e.d. display, 12.7mm
S1	min. s.p.s.t. push-to-make or biased toggle switch
S2	min. s.p.s.t. toggle switch

Printed circuit board available from the EPE PCB Service, code 263; 8-pin d.i.l. socket; 14-pin d.i.l. socket; 16-pin d.i.l. socket; 1.5V AA-size alkaline cell (4 off) and holder; plastic case, 138mm x 76mm x 38mm internal; p.c.b. support (2 off); connecting wire; solder, etc.

Approx. Cost  
Guidance Only

**£20**

excluding battery pack

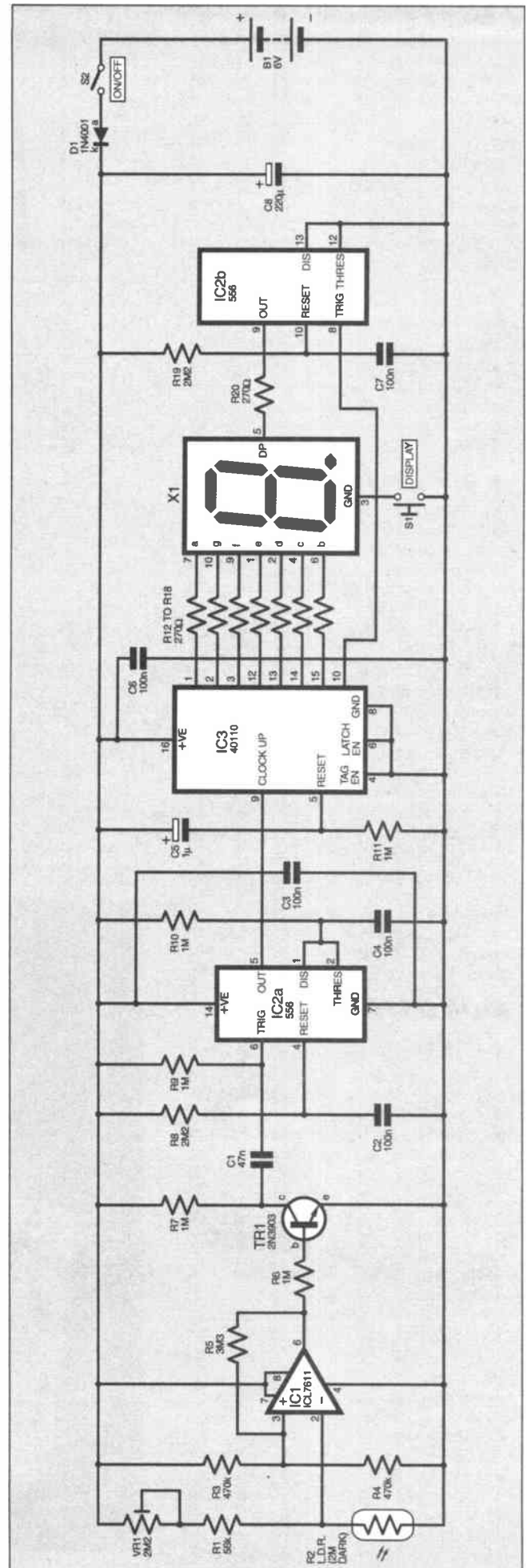


Fig.1. Complete circuit diagram for the PIR Light Checker.

resistor (l.d.r.), R2. The resistance of this device rises as the illumination of its sensitive surface falls.

The l.d.r. works in conjunction with fixed resistor R1 and preset potentiometer VR1 to form a potential divider connected across the supply. Thus, as the resistance of the l.d.r. increases, the voltage across it will rise. This voltage will therefore be greater when the l.d.r. is dark than when it is illuminated. The actual "dark" and "light" voltages can be varied within certain limits by adjusting VR1.

The voltage appearing across the l.d.r. is applied to the inverting input (pin 2) of operational amplifier (op.amp) IC1. The non-inverting input (pin 3) is connected to the mid-point of a further potential divider consisting of fixed resistors R3 and R4. Since these have the same value, the voltage here will be equal to one-half that of the supply – that is, 2.6V approximately.

### A BIT DIM

With preset VR1 suitably adjusted, under dim conditions the voltage at the op.amp inverting input will exceed that at the non-inverting one, so the device will be off with the output (pin 6) low. When the l.d.r. is sufficiently illuminated, the conditions will reverse with the inverting input voltage falling below the non-inverting one. The op.amp will then switch on and output pin 6 will go high. Resistor R5 applies some positive feedback to the system which sharpens the switching action at the critical light level.

Transistor TR1 inverts the output state of the op.amp. When the output is high, current flows into TR1 base (b) through current-limiting resistor R6. This switches the transistor on and its collector (c) goes low. When the op.amp output is low, no current will enter the base and the transistor will remain off. The collector will then take on a high logic state via load resistor R7. The state of the collector is therefore in the opposite sense to that of the op.amp output.

### MONOSTABLE

Transistor TR1's collector is connected to the trigger input (pin 6) of a monostable based on IC2a, which is one half of dual integrated circuit timer, IC2.

When TR1 collector goes from high to low (that is, the l.d.r. is illuminated), the trigger input receives a low pulse through capacitor C1. The monostable output (pin 5) then goes high for a time dependent on the values of resistor R10 and capacitor C4. With the values specified, the timed period is 0.1s, approximately.

While the op.amp output remains low (the l.d.r. dimly illuminated), the high state of TR1's collector has no effect. In fact, in the absence of a low pulse, IC2a trigger input is kept high through resistor R9 and this prevents possible false triggering. Capacitor C3 decouples this section of the circuit.

At the instant of powering-up, capacitor C2 keeps IC2a reset input (pin 4) low and this disables the monostable. The capacitor soon charges up through resistor R8, pin 4 goes high and the monostable then functions normally. The purpose of this is to allow time for the power supply to settle down to a steady state since, otherwise, the monostable could self-trigger and a false count would be registered.

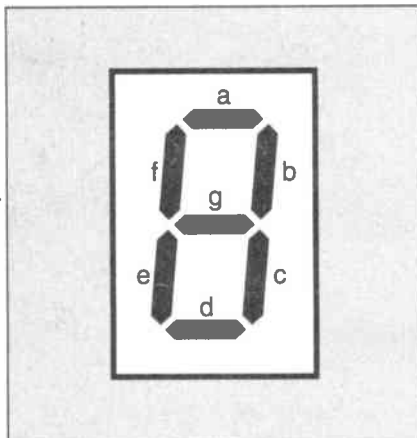


Fig.2. The seven segments of the display are identified by letters (a to g).

### COUNTING PULSES

When the monostable outputs a pulse, this is transferred to the "clock up" input (pin 9) of counter and 7-segment driver IC3. This registers the number of pulses received and decodes the result into a form which will directly drive the 7-segment l.e.d. display X1.

The seven segments of the l.e.d. display are identified by letters a to g as shown in Fig.2. Note that the unit used in this circuit is a common cathode type. In this, all the l.e.d. cathodes (including that of the decimal point) are connected together and taken to pin 3 (GND).

Each segment requires a current-limiting resistor (R12 to R18) as with a conventional l.e.d. With the value specified, each one will draw 12mA approximately when using a new battery.

The display, however, will do nothing until push-to-make "Display" switch S1 is

operated. This allows current to flow through any active segments and complete the circuit via pin 3 to the 0V line. With S1 in the off state, no current is drawn by the display.

At the instant of switching on, IC3's reset input (pin 5) is maintained in a high state while capacitor C5 charges up through R11. During this time, the counter is reset so the display will always begin at zero. After a short time, C5 will charge sufficiently, pin 5 will go low and the counter will function normally. Capacitor C6 decouples this section of the circuit.

When the count passes from 9 to 0, IC3's carry output, pin 10, goes low momentarily. This would normally be used to feed the clock input of a second counter/driver i.c. and a further display would provide a readout up to 99.

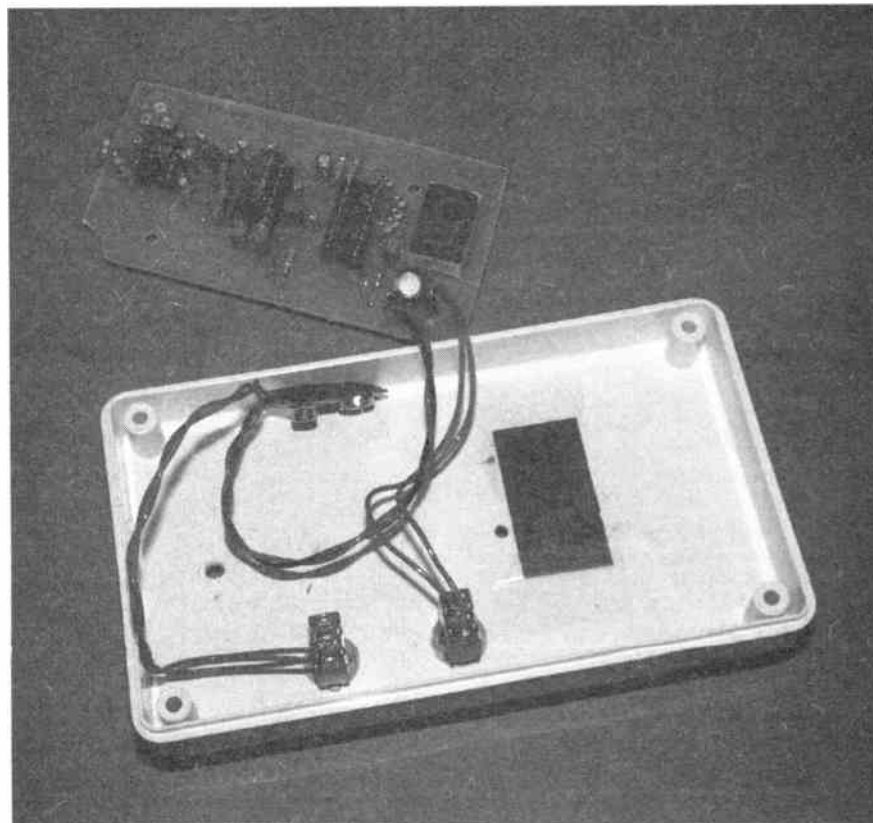
To save costs only one counter and display are used in this circuit. However, the low pulse provides the "overflow" indication by operating the decimal point. This uses IC2b (the second section of dual timer IC2). It is configured as a form of latch by making the threshold and discharge inputs (pin 12 and pin 13) low.

Thus, once triggered by making pin 8 low for an instant, the output (pin 9) will go high and remain high until the supply is interrupted. The output feeds the decimal point via current-limiting resistor R20.

### CONSTRUCTION

The PIR Light Checker circuit is built on a single-sided printed circuit board (p.c.b.). The topside component layout and underside copper foil master pattern are shown in Fig.3. This board is available from the EPE PCB Service, code 263.

In the prototype, one corner of the p.c.b. had to be cut off to avoid a bush in the box,



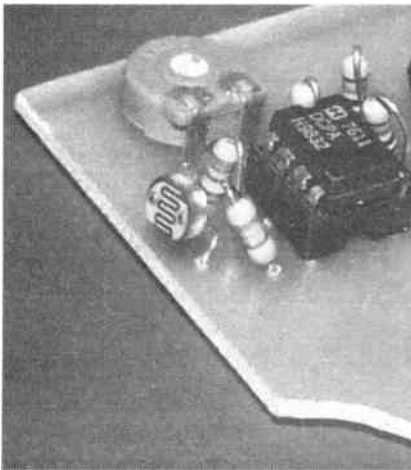
The p.c.b. removed from the case lid to show wiring to the display and on/off toggle switches. The display switch needs to be a "biased" off type. Note the 7-segment display chip must be the highest component on the p.c.b.

see photograph. Begin construction by drilling the two fixing holes and soldering the three i.c. sockets and four link wires into place.

Omit display X1 for the moment. Note that it must end up as the highest component on the p.c.b. Checks should be made at intervals during the other assembly by inserting it into its holes in the p.c.b. (but do not solder it yet).

Follow with all resistors (including preset VR1 but not l.d.r. R2). Note that many of the resistors are mounted vertically (see photo).

Solder electrolytic capacitors C5 and C8 in position taking care over their polarity. If they are not of the sub-miniature type, it may be necessary to mount them flat on the p.c.b. so that they will not be higher than the display.



Close-up of circuit board showing the leads of the l.d.r. carefully bent at right-angles to the p.c.b. to align with "light window" in side of case.

Cut the l.d.r. leads to a length of about 10mm and solder them to the R2 position on the p.c.b. Bend them through right-angles so that the "window" points to the left. Note that the specified l.d.r. is a sub-miniature type having a body diameter of 5mm approximately. If one of these is not readily available, it would be possible to use a standard ORP12 device, but some adjustment may be needed to the end leads to prevent the body getting in the way of anything else.

Add the diode and transistor to the p.c.b., taking care over their orientation. The flat face of transistor TR1 should face to the right as viewed in Fig.3.

Solder the display to the p.c.b. (with the decimal point at bottom right, as shown in the photo) using minimum heat from the soldering iron to prevent possible damage.

Solder 10cm pieces of light-duty stranded connecting wire to the points labelled +6V and S1. Solder the negative (black) battery connector lead to the 0V point. Adjust VR1 to approximately mid-track position.

## TESTING

Immediately before handling the pins of IC1, IC2 and IC3, touch something which is "earthed" (such as a metal water tap). This will remove any static charge which may be present on the body. Insert the i.c.s in their sockets with the correct orientation.

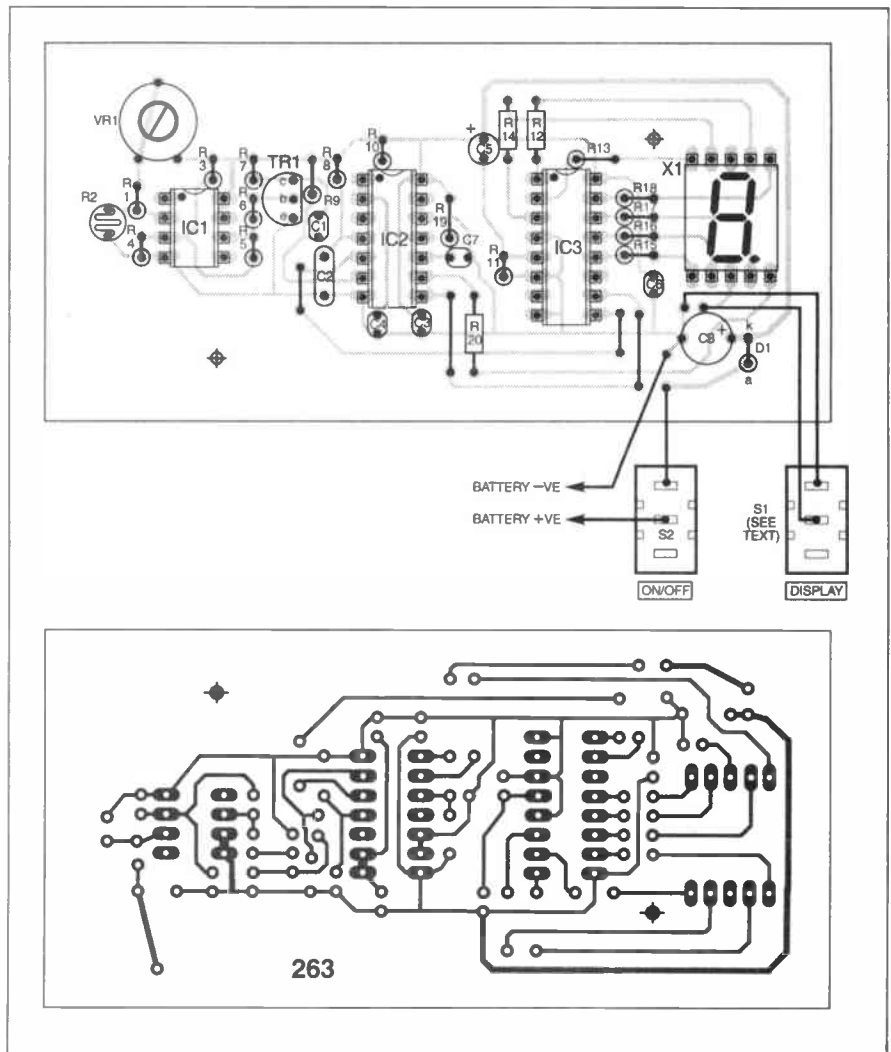


Fig.3. Printed circuit board component layout, full size underside copper foil master pattern and wiring to the two off-board switches.

Before mounting the p.c.b. in its case, perform a basic check so that any minor problems may be resolved more easily.

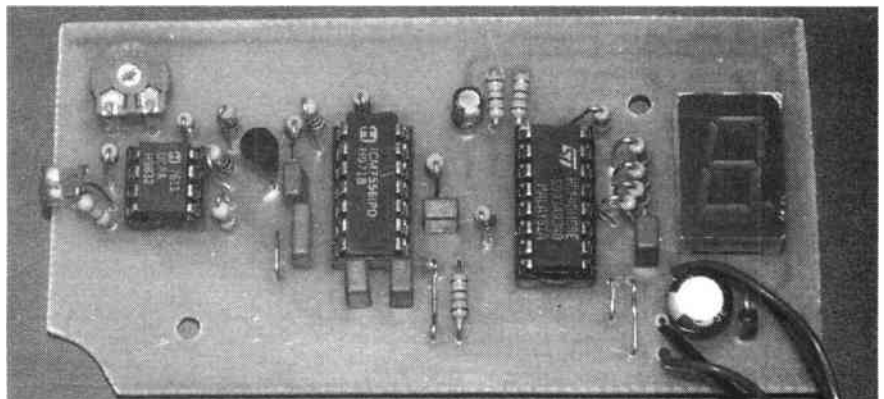
To do this, bare the end few millimetres of the wires for display switch S1 and connect them together. Similarly, bare the end of the +6V wire. Insert the cells for battery B1 into their holder and apply the connector. Twist the battery connector positive (red) wire to the +6V wire from the p.c.b.

The display should light up and read zero. The decimal point should also be off. If it shows some other number, or the decimal point is on, the connection was probably not

done "cleanly", so disconnect the battery, wait for 30 seconds and try again!

Cover the l.d.r. with the hand then remove it to allow light to reach its window. The display should advance to a count of 1. If this does not work, it is likely that the l.d.r. has not been properly covered. Try working in a dark cupboard and open the door slightly to give the flash of light. If this still does not work, re-adjust preset VR1 and try again.

By allowing repeated flashes of light to reach the l.d.r., the counter should increment to 9 and the next flash should return



Layout of components on the completed circuit board. Note, one corner of the board has been trimmed off so it will fit in the case

it to zero. However, the decimal point should now be seen to be lit up. If you wish to reset the display, you will need to wait for up to thirty seconds between disconnecting the battery and re-connecting it again.

## ENCLOSURE

If all is well, the p.c.b. may now be mounted in the box. Note that when using the specified unit, everything may be attached to the lid section. This method places least strain on the battery connecting wires.

First, disconnect the positive supply wire and detach the battery connector. Decide on positions for the p.c.b., battery pack and switches, checking that there is sufficient space for everything to fit. Arrange for the l.d.r. to lie between 5mm and 10mm from the side of the box.

In the prototype, a miniature toggle switch with "make" contacts was used for the on-off switch and a matching biased toggle switch was used for the display. A biased switch is one which springs back to the off position when pressure is removed from the actuating lever. It is best to use either a biased toggle switch or a push-to-make switch to activate the display so that it cannot be left on accidentally.

Mark through the p.c.b. fixing holes. Measure the position of the display and mark around its outline. Mark also the position directly in line with the l.d.r. window and VR1 on the top. Mark the position of the switches. Remove the p.c.b. and drill all these holes.

The hole for the l.d.r. should have a diameter of approximately 4mm (about twice as large if the ORP12 type l.d.r. is used). The hole above the preset VR1 position should be large enough to allow it to be adjusted using a thin screwdriver or trimming tool.

The easiest way to make the hole for the display is to drill small holes within its outline then remove the plastic using a small hacksaw blade, or sharp chisel.



Completed PIR Light Checker front panel layout. The display cutout has been backed with a piece of translucent filter material.

Finally, smooth the edges up to the line using a small file.

Attach the p.c.b. temporarily using nylon fixings and with short plastic stand-off insulators on the bolt shanks. Adjust the length of the stand-off insulators so that the display will end up 1mm approximately below the inside face of the box. When satisfied, re-attach the p.c.b.

Check that the l.d.r. window lies directly in line with the hole drilled for it. If not, adjust the position of its end leads so that it is. Attach the switches. Secure the battery pack using a small bracket or adhesive pads. Refer to Fig.3 and complete the internal wiring.

In the prototype, a piece of red plastic filter was glued over the display hole on the inside of the box. This gives a professional appearance and also improves the contrast of the display. If a piece of real filter is not available, perhaps suitable material could be obtained from a sweet wrapper or something similar.

## INTO SERVICE

With switch S2 off, connect the battery and attach the lid. Find a suitable place for the unit so that light from the PIR lamp will reach the l.d.r. directly through the hole in the side of the box. The fact that the l.d.r. is some distance behind the hole makes the response directional. This is useful because it tends to discriminate against other sources of light which could result in false counting.

Make some tests at night. For initial trials, you may find it helpful to use an elastic band or p.v.c. tape to hold the display switch (S1) on, so that the count may be observed over a period of time. Remember that this wastes the batteries so don't do it for too long.

Adjust preset VR1 for best effect. Remember to protect the unit against rain entering if this is a possibility.

No more disturbed neighbours with this "Trigger Happy" circuit! □

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**HIGHVAC NUMICATOR TUBE.** Highvac ref XN3. Order Ref: 865.  
**DITTO** but reference XN11. Order Ref: 866.  
**QUARTZ LINEAR HEATING TUBES.** 306W but 110V so would have to be joined in series. Pack of 2. Order Ref: 907.  
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**RECHARGEABLE 12V JELLY ACID BATTERIES.** Yuasa 12V 2.3AH. These are 7in. long, 3in. high and 1 1/2in. wide with robust terminals protruding through the top. Price £3.50 or 5 for £15. Order Ref: 3.5P11.

**DITTO,** but 12V 18AH. This is 7in. long, 7in. high and 3in. wide. Brand new with 12 months guarantee, price £12.50 or pack of 4 for £48, including VAT and carriage. Order Ref: 12.5P3.  
**Note** - This battery will start a car and is ideal for golf trolleys, etc.

**CHARGER** for these batteries and other sealed lead acid batteries, £5. Order Ref: 5P269.

**RECHARGEABLE NICAD BATTERIES.** AA size, 25p each, which is a real bargain considering many firms charge as much as £2 each. These are in packs of 10, coupled together with an output lead so are a 12V unit but easily divideable into 2 x 6V or 10 x 1.2V. £2.50 per pack, 10 packs for £25 including carriage. Order Ref: 2.5P34.

**ANSWER-PHONE UNIT.** Brand new, suitable for connection to any BT line, has been currently sold for around £25. You can have one at £12. Order Ref: 12P38.

**LIGHT ALARM.** A circuit for this appears in the February issue, however, we have a rather less complicated model already made up and in a nice case, price only £3. Order Ref: 3P155.

**ULTRA VIOLET VIEWING UNIT.** This is a very neat metal enclosure about the size of a 6in. cube. The lamp and control gear are in the top compartment and an open space with a platform below allows you to inspect paper or other objects under the UV light. Intended for 230V mains operation. Price £12. Order Ref: 12P35.

**TWIN 13A SWITCHED SOCKET.** Standard in all respects and complete with fixing screws. White, standard size and suitable for flush mounting or in a surface box. Price £1.50. Order Ref: 1.5P61.

**VERY POWERFUL BATTERY MOTORS.** Were intended to operate portable screwdrivers. Approximately 2 1/2in. long, 1 1/2in. in diameter, with a good length of spindle. Will operate with considerable power off any voltage between 6 and 12 D.C. Price £2. Order Ref: 2P456. Quantity discount 25% for 100.

**BIG 12V TRANSFORMER.** It is 55VA so that is over 4A which is normal working, intermittantly it would be a much higher amperage. Beautiful transformer, well made and very well insulated, terminals are in a plastic frame so can't be accidentally touched. Price £3.50. Order Ref: 3.5P20.

**SOUND SWITCH.** Can be operated by clapping hands, shouting or almost any other noise. Ready to work but needs casing. Price only £3. Order Ref: 3P246.

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

**VERY THIN DRILLS.** 12 assorted sizes vary between 0.6mm and 1.6mm. Price £1. Order Ref: 128.

**EVEN THINNER DRILLS.** 12 that vary between 0.1 and 0.5mm. Price £1. Order Ref: 129.

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

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

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

**MOST USEFUL POWER SUPPLY.** Rated at 19V 1A, this plugs into a 13A socket, is really nicely boxed. £2. Order Ref: 2P733.

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

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**0-35V + 0-35V at 220VA** would give 35V at 6 1/2A or 70V at 3 1/4A, price £10. Order Ref: 10PG4.  
**0-110V + 0-110V at 220V** would give 110V at 2A or 220V at 1A, price £12. Order Ref: 12PG5.  
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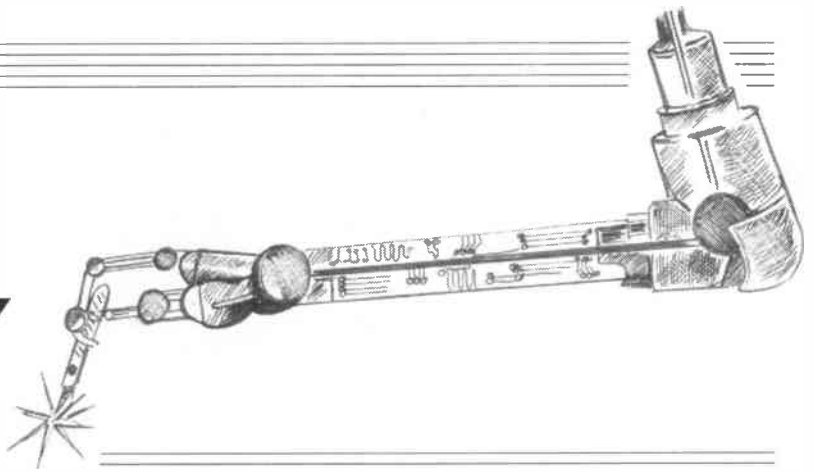


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# CIRCUIT SURGERY



ALAN WINSTANLEY  
and IAN BELL

*Our circuit surgeons provide more advice to help with reader's problems and conclude their mini-series investigating the inner workings of operational amplifiers, looking at output stages and short-circuit protection.*

**T**HIS month we round off our exploration of the op.amp by looking at the level shifter circuits which are used to get the d.c. bias levels correct in different stages of an op.amp. We outline typical short-circuit protection techniques and also output stages, which are power amplifiers that share some of the features of basic audio power amplifier output stages. Some of the principles we'll outline also apply to designs which use discrete transistors instead of integrated circuits.

## Shifty Circuits

No coupling capacitors can be used between stages within op.amps – they have to work with d.c. and very low frequency inputs. Biasing is easy in multi-stage capacitively-coupled amplifiers because the biasing of each stage is isolated by the coupling capacitor.

In an op.amp, life is not so simple. We might, for example, have one stage with an output whose signal varies around a bias point of half the positive supply, which has to be connected to a stage that needs a signal which varies around 0V (ground) instead. Therefore what we would need to do is "shift" the d.c. bias level of a signal.

Ideally, a circuit for this purpose should provide a stable shift in d.c. level without introducing noise, it should not attenuate the signal, and should allow the designer to select any level shift required (within reason). We could achieve a shift using a two-resistor potential divider, but this attenuates the signal. We could use a Zener diode to provide a voltage drop, but these are noisy. We could use diode voltage drops, but these only come in steps of about 0.6V per diode used.

The circuit in Fig.1a acts as a level shifter, changing the d.c. level from  $V_{in}$  to  $V_{out}$  without significant attenuation of the signal. The current source (see *Circuit Surgery*, May and June '99) provides a current  $I$  that flows through  $R$  to give a fixed voltage drop of  $IR$ . The voltage drop is fixed (it does not depend on the signal) because the current source produces the

same current even if the voltage across it varies due to the signal.

The total fixed voltage drop from  $V_{in}$  to  $V_{out}$  also includes the  $V_{BE}$  voltage of the transistor, which will also not vary a great deal as the signal varies. Thus the circuit shifts the d.c. level of the signal down by  $(IR + V_{BE})$  volts.

## Out of the Op.Amp

An op.amp output stage must be capable of supplying sufficient current to the external load (i.e. out of the chip on which the op.amp is fabricated). In order to do this it must have low output resistance and provide *power gain*. It does not have to provide voltage gain as this is done by earlier stages.

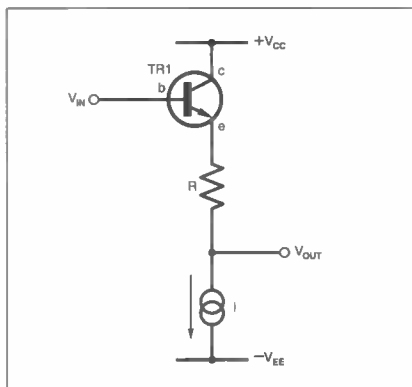


Fig.1a. A level shifter circuit.

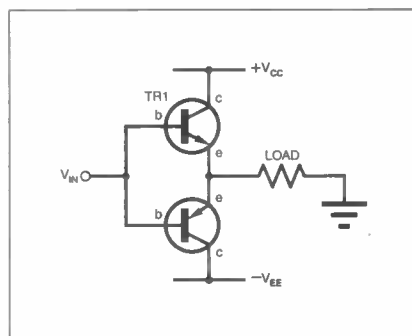


Fig.1c. Basic push-pull amplifier.

The output stage is a power amplifier – a term that conjures images of circuits which deliver many watts of power. This does not have to be the case – it is the fact that power *gain* is provided rather than the *amount* of power available that matters. However, there are, of course, high power op.amps and the op.amp output circuits share features with some types of audio power amplifier.

The well-known *emitter follower* circuit (Fig.1b) has a voltage gain of just less than unity, high input resistance and low output resistance. So it can deliver a relatively high-current version of a "weak" voltage signal. The circuit is called an emitter follower because the *signal* voltage at the emitter, which is where the load is connected, "follows" (is the same as) the voltage at the base. The absolute voltage at the emitter is one  $V_{BE}$  drop (about

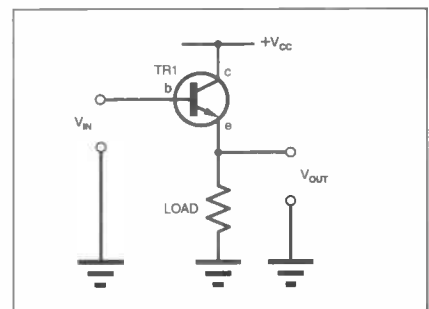


Fig.1b. Emitter follower circuit.

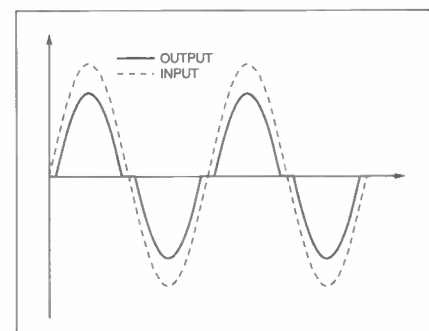


Fig.2. Sinewave with crossover distortion.

0.6 to 0.7V) lower than the base voltage, but this is just a shift in d.c. level.

Our emitter follower circuit of Fig. 1b has the right kind of properties for an op.amp output stage, but is not suitable as it stands because we require the load to be connected to ground and the output signal to be both positive and negative. In this circuit the transistor would turn off with negative input voltages, so we would only amplify half the signal!

To overcome this, two emitter-followers are used in what is known as a **push-pull** amplifier (see Fig. 1c). This type of circuit is also referred to as a **class-B** amplifier because each output transistor conducts for one-half of the waveform cycle. Transistors in class-A amplifiers conduct for the whole cycle, and in class-C for less than half.

The basic push-pull output stage suffers from a problem called **crossover distortion**. Only one transistor can be on at any time, that is: if  $V_{in} > V_{BE}$  then TR1 is conducting, and if  $V_{in} < -V_{BE}$  then TR2 is conducting instead. However, this means that for small inputs, neither transistor is on: if  $-V_{BE} < V_{in} < V_{BE}$  then TR1 and TR2 are both off.

So signals, or parts of signals, in this range are not amplified, which leads to distortion of the output. Fig. 2 shows a sinewave input to a basic push-pull amplifier (dotted line) and the resulting distorted output (solid line). Although this circuit is not suitable for op.amps it may be of use in other applications where the distortion does not matter, for example in a basic motor control circuit.

### Crossover Distortion

To overcome crossover distortion, the output transistors are biased so that with no signal present they are both *just* on the point of conduction. Then when  $V_{in} = 0$  both transistors are just conducting, when  $V_{in} > 0$  TR1 conducts and TR2 is off, and when  $V_{in} < 0$  TR2 conducts and TR1 is off.

This can be achieved using two diodes, or two transistors connected as diodes, to provide the  $2 \times V_{BE}$  difference in bias voltage required between the transistors' bases (see Fig. 3). The diodes are biased with the current required to give the correct  $V_{BE}$  value by means of a current source.

As the input signal varies the diodes maintain a constant  $2 \times V_{BE}$  difference between the two base voltages. The actual base voltages will vary with the signal, but the difference between them is fixed by this biasing arrangement.

The diodes are ideally at the same temperature as the output transistors so that changes in their voltage drop with temperature tracks those of the output transistor. This applies on op.amp i.c.s and for discrete component power amplifiers using this type of circuit.

### Short Circuits

The push-pull amplifier is likely to be damaged if its output is short-circuited to ground, due to excessive collector current in the conducting transistor. A short-circuit protection arrangement may be added to overcome this problem. The protection circuit monitors the current flowing in the output and turns off the output transistor if the current exceeds some pre-defined limit. The current detection is usually achieved by using a small resistor in the output signal path, and a transistor to switch off the output (see Fig. 4); the output current causes a voltage drop across the resistor.

A protection transistor switches on when the resistor voltage reaches about 0.6V to 0.7V. The protection transistor is connected so that when it is on, it effectively short circuits the input to the power transistors, so they have no signal to amplify. The protection resistor values,  $R_{p1}$  and  $R_{p2}$  may be chosen using  $R_{p1} = R_{p2} = V_{be_{TRP1}} / I_{max}$  where  $V_{be_{TRP1}}$  is the turn-on voltage of the protection transistor (typically 0.6V to 0.7V) and  $I_{max}$  is the maximum output current, i.e. the current at which the protection kicks in. This kind of protection circuit is what enables op.amps to have the "infinite output short circuit duration" quoted on many data sheets.

### Audio Power Amp

The circuit shown in Fig. 5 is a discrete component version of the circuit in Fig. 4, which could form the basis of an audio power amplifier output stage. Resistors are used instead of the current sources ubiquitous in i.c. circuits.

Biasing is achieved using what is known as a  $V_{BE}$  multiplier and is manually adjustable using preset VR1 to give the required quiescent current for the circuit (the degree to which the output transistors are "just on" with no signal). The  $V_{BE}$  multiplier circuit consists of TR<sub>a</sub>, preset VR1 and resistor R2. The voltage  $V_{bias}$  is

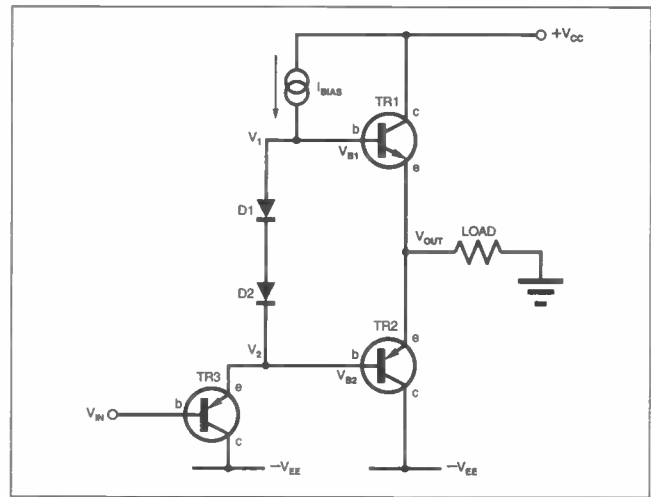


Fig. 3. Output transistors biased to prevent crossover distortion. The diodes may be implemented using transistor base-emitter junctions.

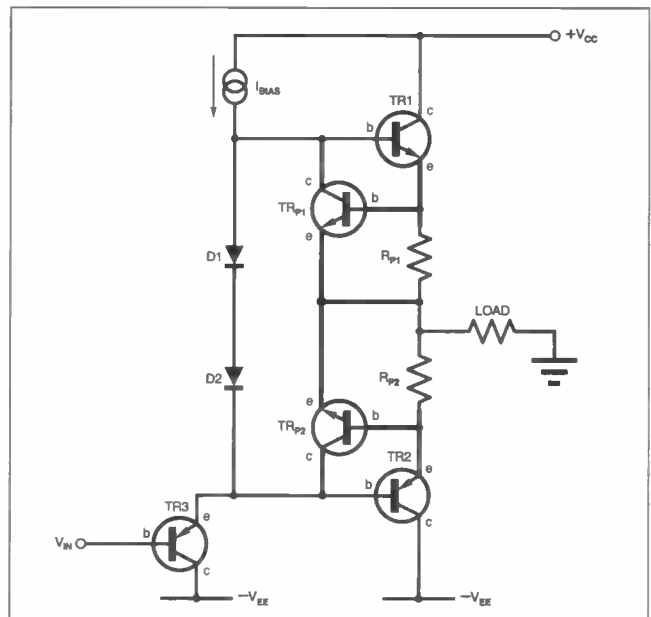


Fig. 4. Output stage with protection circuit (protection components are shown using bold lines).

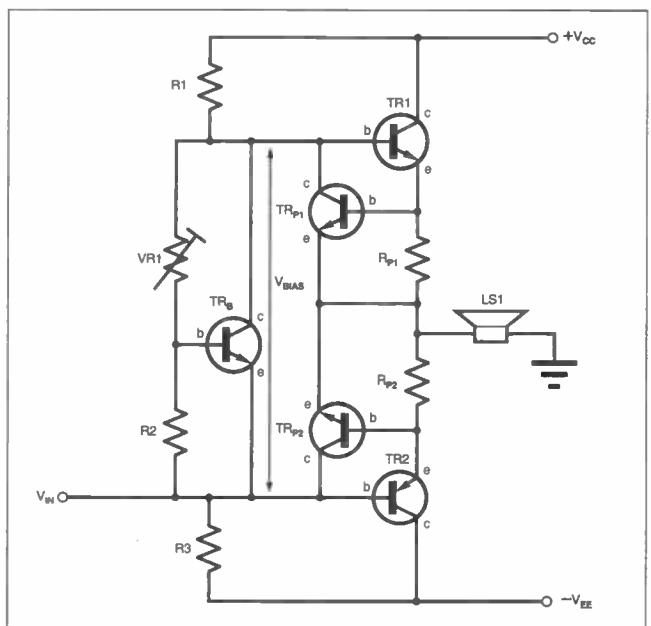


Fig. 5. Audio power amplifier using similar configuration to op.amp output stage.

effectively fixed by virtue of the fact that  $TR_a$ 's  $V_{BE}$  voltage does not vary much, resulting in a fixed voltage across R2 and hence a fixed current through it.

If the preset VR1 and resistor R2 are chosen so that their current is much larger than  $TR_a$ 's base current then we can assume all of the current in R2 also flows in VR1. Thus the total dropped across VR1 and R2 (i.e.  $V_{bias}$ ) is equal to  $V_{BE}$  multiplied by the ratio of the total resistance of VR1 and R2 to the value of R2, i.e.

$$V_{bias} = \frac{V_{BE}(VR1 + R2)}{R2}$$

We hope that our discussion on the op.amp over the past few months has given you some insight into what is inside these chips that get used in so many constructor's projects. Of course, there is a lot more to the circuitry of modern op.amps than we have space to discuss in this series – as a browse through the schematics in manufacturers' data sheets will reveal.

Hopefully, however, you would also be able to recognise at least some of the basic sub-circuits (e.g. differential amplifier) in these schematics, even if there are one or two extra transistors present. We also hope that some of you might find other uses for the circuits we

have shown in your own designs – let us know if you do. *Ian Bell.*

## Battery Flattery

Briefly on the subject of troubleshooting lead acid chargers, *Mr Alister Bottomley* wrote: "Am I correct in assuming that in order to charge a 12V lead acid battery it must receive a voltage greater than 12V across it – the greater the voltage the greater the charging current?"

*My battery charger has suddenly reduced its output to 11.7V as measured on its "high" tapping. I can't find any losses or problems in the circuit."*

A lead acid battery requires something like 2.2V per cell or higher constant voltage to charge. A higher voltage could be used but the battery life will be shortened, and it is true that the greater the applied voltage, the greater the charge current will be. Current gradually reduces to a trickle as the battery charges up.

The reason you are measuring a strange d.c. voltage is because it isn't a smooth level d.c. voltage you are actually testing. Ordinary car battery chargers have a rectified d.c. output which is unsmoothed. However, your multimeter will want to read a pure d.c. voltage, or it will read an r.m.s. voltage on its a.c. range instead. An oscilloscope would highlight the problem.

An electronics mains power supply uses a smoothing or "reservoir" capacitor to iron out the ripple, to produce a higher peak value and much smoother d.c. voltage. The capacitor then charges to the peak value of the rectified d.c. sinewave. In fact, it's the car battery itself which acts as a giant smoothing capacitor across the supply. Hooking this across the battery charger means that the voltage seen across the battery will then increase.

Also, your test equipment may actually cause you to misinterpret the result, and sometimes the very use of test equipment can affect the operation of the circuit as well. Constructors gradually learn to compensate for this with experience.

## CIRCUIT THERAPY

*Circuit Surgery* is your column. If you have any queries or comments, please write to: Alan Winstanley, *Circuit Surgery*, Wimborne Publishing Ltd., Allen House, East Borough, Wimborne, Dorset, BH21 1PF, United Kingdom. E-mail [alan@epemag.demon.co.uk](mailto:alan@epemag.demon.co.uk). Please indicate if your query is not for publication. A personal reply cannot always be guaranteed but we will try to publish representative answers in this column.



## SHOP TALK

with David Barrington

### Versatile Mic/Audio Preamplifier

Todate, we have only traced two sources for the SSM2166P microphone preamplifier i.c. used in the *Versatile Mic/Audio Preamplifier* project. It is currently listed by **Maplin** ([www.maplin.co.uk](http://www.maplin.co.uk)), code GS39N and also carried by **Farnell** (☎ 0113 263 6311 or [www.farnell.com](http://www.farnell.com)), code 114-7249.

If you are going to include the Signal Strength Meter option, the actual selection of the moving coil meter is left to individual choice, hence the small table giving resistor values for meter movements ranging from 50µA up to 1mA. Many of our component advertisers should be able to offer a suitable small panel meter.

### Low-Cost Capacitance Meter

The only item that needs highlighting when buying parts for the *Low-Cost Capacitance Meter*, this month's Starter Project, is the timer i.c.

A low-power version of the 555 timer *must* be used in this project as, due to its low self-capacitance, it gives better accuracy on the 1nF range. Therefore, use the TS555 timer instead of the standard NE version. The low-power version should be widely stocked and readily available.

Once again, the meter is left to individual choice as prices seem to vary quite considerably. The model uses a 100µA movement obtained from **Maplin** ([www.maplin.co.uk](http://www.maplin.co.uk)), code RW92A.

The 12-way single-pole rotary range switch is a Lorlin type which has an adjustable rotation limiting "end-stop" which should be set to 5-ways. This was also purchased from the above, code FF73Q.

### Multi-Channel Transmission System

Most of the components called up for the *Multi-Channel Transmission System* should be stock items, even unprogrammed PIC16F84s are now widely available.

The author is able to supply ready-programmed PIC16F84s. You will need to order at least two microcontrollers, one Transmitter (Tx) and one Receiver (Rx). We understand that the *first two* will cost £6 each and any additional PICs £5 each, inclusive of postage (overseas add £1 per order for postage). Orders should be sent to: **Andy Flind, 22 Holway Hill, Taunton, Somerset, TA1 2HB**. Payments should be made out to *A. Flind*. For those who wish to program their own PICs, the software is available from the Editorial Offices on a 3.5in. PC-compatible disk, see *PCB Service* page 397. It is also available *free* via the *EPE* web site: [ftp://epemag.wimborne.co.uk/pubs/PICS/multichannel](http://ftp://epemag.wimborne.co.uk/pubs/PICS/multichannel).

### PIR Light Checker

Nearly all the components needed to build the *PIR Light Checker* project should be obtainable from your usual local supplier. The miniature light-dependent resistor (l.d.r.) and the 7-segment, common cathode, display both came from **Maplin** ([www.maplin.co.uk](http://www.maplin.co.uk)), codes AZ83E and FR41U respectively. You can, of course, use the good old ORP12 l.d.r.

Details and prices for all of this month's printed circuit boards can be found on page 397.

### PLEASE TAKE NOTE

#### Micro-PICscope

Unfortunately, a digit was missed from the order code of the orange box and it should be: 281-6841. We apologise for this error.

April '00

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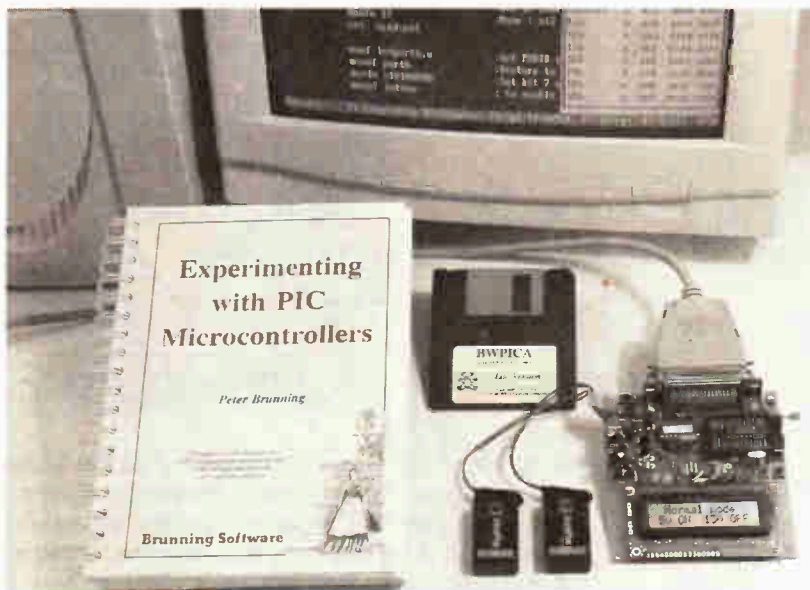
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This Third release in our "Experimenting with....." series concentrates on the PIC16F84 and PIC16C711 microcontrollers, and consists of the book, a programmer/experimental module, and an integrated suite of programmes to run on a PC.

The book with its abundance of flow diagrams and circuit diagrams is the heart of the system, and the software is the brains. A text editor with word processing power is the keystone supporting the assembler, disassembler, simulator, and programming software. As the text is typed in the assembler works in the background testing each line so that errors are immediately highlighted. When the typing is done the simulator can be used to single step or run the programme. Boxes pop up showing the contents of registers and the result of any text written to a standard 2 line by 16 character display. If it works correctly plug the programmer/experimental module onto the end of your printer lead and test it using a real live PIC. All operations work directly from the assembler text in the editor.

The 24 experiments assume no prior programming or electronic experience. These are all performed using the programmer/experimental module which is already wired with LEDs, push buttons, and an alphanumeric liquid crystal display. Flashing LEDs, text display, real time clock, period timer, beeps and music, including a rendition of Beethoven's *Für Elise*. Then there are two projects to work through; building a sinewave generator covering 0.2Hz to 20kHz in five ranges, and investigating measurement of the power taken by domestic appliances. In the space of 24 experiments, two projects and 56 exercises the system works through from absolute beginner to experienced engineer level.

## Programming PICs

The assembler understands normal PIC terminology. This has two distinct advantages for beginners over the usual system; it is not necessary to start programmes with a list of definitions, and the assembler recognises errors such as *call intcon* because it knows that *INTCON* is a register not a subroutine name.

The programmer module itself is a fine example of what can be achieved with PIC microcontrollers. It uses its own PIC to control the timing and voltages required to programme the test PIC. The programming is performed and verified at normal 5 volts, then verified again with  $\pm 10\%$  volts applied to ensure that the device is programmed with a good margin and not poised on the edge of failure. The system is optimised for the PIC16F84 and PIC16C711 and will programme similar PICs (83, 710, 71, 620, 621 etc).

The module is supplied with a test PIC fitted, and requires two PP3 batteries which are not supplied.

## Assembler

The first book *Experimenting with PC Computers* with its kit is the easiest way ever to learn assembly language programming, simple circuit design and interfacing to a PIC. If you have enough intelligence to understand the English language and you can operate a PC computer then you have all the necessary background knowledge. Flashing LEDs, digital to analogue converters, simple oscilloscope, charging curves, temperature graphs and audio digitising.

## C & C++

The second book *Experimenting with C&C++ Programmes* uses a similar approach. It teaches the user to programme by using C to drive the simple hardware circuits built using the materials supplied in the kit of parts. The experimental circuits build up to a storage oscilloscope using relatively simple C techniques to construct a programme that is by no means simple. When approached in this way C is only marginally more difficult than BASIC and infinitely more powerful. C programmers are always in demand. Ideal for absolute beginners and experienced programmers.

## The Kits

The kits contain the prototyping board, lead assemblies, components and programming software to do all the experiments. The 'made up' kits are supplied ready to start the first experiment. The 'unmade' kits require the prototyping board and leads to be assembled and soldered before you can start. The 'top up' kit CP2t is for readers who have purchased a kit to go with the first book, and contains all the components and programming software but not the prototyping board or leads. The kits do not include the book.

## Hardware required

All three systems assume you have a PC (386 or better) and a printer lead.

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# TEACH-IN 2000

## Part Seven – Op.amps

JOHN BECKER



Over the previous six parts of *Teach-In 2000*, which we know you have been greatly enjoying, we have covered passive components and several digital logic circuits. Via the interactive computer programs and the simple interface you assembled, you have also been able to observe the various waveforms generated by the experimental breadboard circuits, showing how a few electronic components can be connected to achieve interesting results.

We now move on from the “interesting” to the “practical”, in terms of describing active components which can be used to amplify and otherwise modify the waveforms generated. It is op.amps we now examine, those simple robust components that feature so frequently in audio and other analogue circuits. This month we demonstrate their basic nature, next month we get you experimenting with some useful applications.

**P**ROBABLY the most important electronic component in the analogue designer’s armoury is the *operational amplifier*. Better known, perhaps, by its abbreviated name of *op.amp* (or *op-amp*, or even *opamp*) this family of devices seemingly has more applications than there are designers who use it!

In this month’s Tutorial we illustrate some of the op.amp’s major features as an amplifier. In next month’s Tutorial we follow on by going into a bit more simple experimental detail, discussing what else op.amps can do, and getting you to try it.

### FIRST DEMONSTRATION

From your components stock, select one of the 8-pin dual-in-line (d.i.l.) devices labelled LM358, call it IC4. Now assemble your breadboard according to Fig.7.1. Any previous components in the area illustrated should be removed (all your counting and logic gate experiments from last month have already served their purpose, we hope!). Leave the oscillator components intact for now.

The equivalent circuit diagram and the component values are shown in Fig.7.2.

Connect the oscillator waveform from the junction of capacitor C1 and IC1a pin 1 (see Fig.4.3 of Part 4) to the point marked “D.C. INPUT”. Use a crocodile-clipped link.

Ignore the points labelled “Buffer Input” and “Buffer Output”, their purpose will be discussed later on in the Tutorial.

The oscillator should have diodes D2 and D3 included; its capacitor C1 value should be 100µF. Set

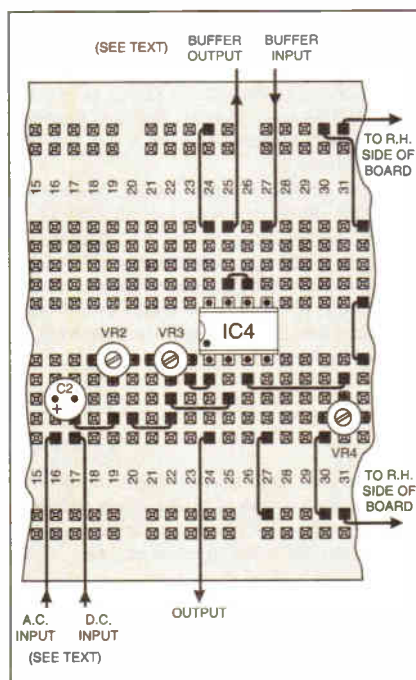
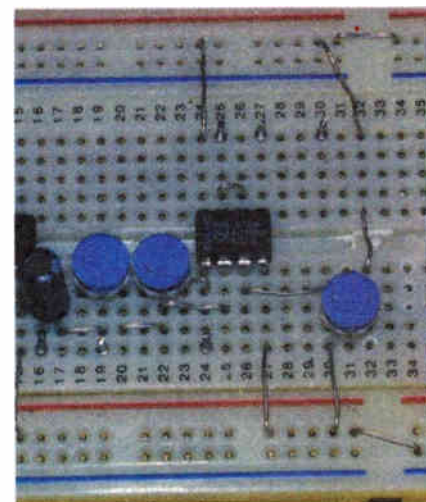


Fig.7.1 Breadboard layout for the first op.amp experiments.



Breadboard showing the components for the first op.amp experiments, part of IC1 is just seen at the left.

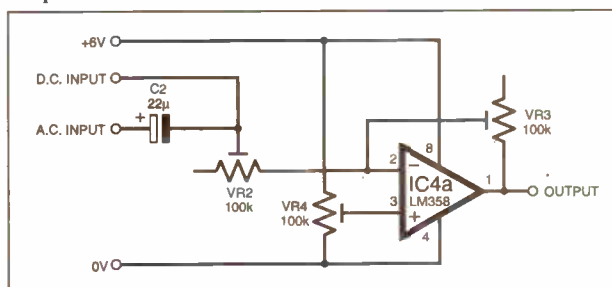


Fig.7.2. Circuit diagram associated with Fig.7.1.

the frequency control VR1’s wiper to midway, so that the generated waveform will be roughly triangular.

Set each of the Fig.7.1 presets (VR2 to VR4) so that their wipers (moving contacts) are also in a midway position, providing approximately equal resistance to either side of the wiper.

Referring to Fig.5.6 of Part 5, connect IC4 pin 1 to the input to the analogue-to-digital converter (IC2 pin 2), and then connect IC2’s output to IN1 of the computer interface section. Run the Analogue Input Waveform Display program.

Connect up your battery to the breadboard (as you’ve done a good few times before – is the battery power still OK?) and observe the computer screen displaying the triangular waveform being generated by IC1a and associated components.

## VARIABLE AMPLITUDE

We are now going to ask you to make various adjustments on the op.amp's three presets and observe the screen responses. We shall discuss what you observe in due course. First, carefully adjust the wiper position of VR4 until the waveform is roughly central on the screen.

Next, slowly adjust the wiper of VR3 in a clockwise direction (to the "right") while observing the screen. This action increases the resistance between the wiper and the end connected to IC4 pin 1, the op.amp's output.

It will no doubt interest you to see that the vertical size of the waveform increases, in other words, its *amplitude* increases the further you adjust VR3. The limit will be reached when you cannot turn the wiper any further. The amplitude will now be about twice that you started with.

Note, though, how the waveform's relative position on the screen probably changes as you rotate VR3. Carefully adjust the wiper of VR4 to set the waveform back to a mid-screen position if it does.

Now rotate VR3's wiper anticlockwise. The waveform amplitude will be seen to decrease, and once the wiper goes beyond the midway position, the waveform amplitude will begin to fall below that at which it started. The waveform is now said to have been *attenuated*.

Towards the far end of the anticlockwise rotation the waveform should be seen just as a straightish horizontal line.

Set VR3's wiper to its fully clockwise position and leave it there.

## PEAK FLATTENING

Turn your attention now to preset VR2. First rotate it clockwise, to increase the effective resistance between its wiper and IC4 pin 2, one of the op.amp's two inputs. Note how an *increase* in resistance here causes a *decrease* in the waveform amplitude.

Next adjust VR2's wiper anticlockwise. Once it goes beyond the original midway position, note how rapidly the waveform amplitude increases. You may also notice a change in the waveform's frequency (fewer cycles per screen-full!). Note also that its top and bottom peaks become flattened the more that VR2's resistance is decreased. The peaks are unlikely to be evenly flattened, however. Carefully adjust VR4 until they become more equal.

As you further rotate VR2's wiper, you will eventually see a waveform somewhat resembling a square wave instead of a triangle. Adjusting VR4 will change the waveform's mark-space ratio (discussed in Part 4). Before VR2 reaches its minimum resistance, and with VR4 set too much to either side of midway, the oscillator might stop functioning.

## WAVEFORM INVERSION

That's the first set of observations – on to the next. Return all three op.amp wipers (VR2 to VR4) to a midway position. If the oscillator had indeed ceased functioning, this action should restart it. If it doesn't, briefly disconnect the power and then reconnect it.

Adjust IC1's preset VR1 so that a rising-ramp waveform is seen (ramps were

## PANEL 7.1. OP.AMP MANUFACTURING CONSTRUCTION

The op.amp type (LM358) used in this *Teach-In* is manufactured using a structure called *bipolar*. In essence, this uses many transistors internally interconnected on the op.amp chip and which require current to flow through them. In most cases the current is not great, but can still place a load on the circuit which is being fed into the op.amp inputs.

Another type of op.amp manufacturing process uses the *field effect transistor* (f.e.t.) technique. F.E.T. devices operate on a different principle to those used in bipolar devices and respond to the voltage (field) on their inputs rather than through their inputs. These devices,

therefore, do not draw current from the circuit feeding into them and so place no load on them.

All the circuits discussed in this *Teach-In* part could probably have f.e.t. op.amps used instead of the bipolar LM358. Such devices include TL062, TL072 and TL082.

Component suppliers' catalogues and manufacturers' data sheets should be consulted for information about the different op.amp types available. Internet access to various manufacturers' web sites and data sheets can be gained via the *EPE* web site at [www.epemag.wimborne.co.uk](http://www.epemag.wimborne.co.uk).

discussed in Part 5). Leave all presets as they are and connect the ADC input to the input of IC1a (pin 1). Look back at the screen. Whereas you had a rising ramp a few moments ago, you should now see a falling ramp – curiously and curiously!

Time, then, to discuss your findings in relation to an op.amp's basic nature.

## BASIC OP.AMP NATURE

In essence, an op.amp is a two-input single-output device which has the capability of *greatly* amplifying a voltage difference between its two inputs. For this reason, it can be called a *differential amplifier*. Within limits, the amplification is according to a *linear* relationship. (You will recall that we discussed linear relationships when we discussed potentiometers in Part 3.) For each unit of change at the input, an equivalent but linearly amplified increase will result at the output.

For some purposes (but not all) the amount of amplification (*gain*) available is far too great to be of use – it can be several hundred thousand times for some op.amps. However, there is a simple technique that can be used to restrict the amplification to a more manageable level.

In Fig.7.3 is shown the basic symbol for an op.amp (no longer cluttered as it is Fig.7.2). The symbol shows that one input is marked as *inverting* (-), and the other as *non-inverting* (+). The different input modes have great significance to the way in which the op.amp can be used and controlled.

Note that the "-" and "+" symbols have nothing to do with power supply connections, they merely symbolise the inverting and non-inverting nature of the respective input.

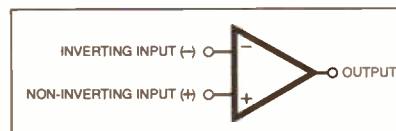


Fig.7.3. Op.amp symbol and connection names.

## INPUT TO OUTPUT

First, suppose that both inputs have the same voltage level applied to them. Because there is no difference between the voltages, the output will be held at the same voltage. If the voltage on the non-inverting

input rises *fractionally* above that on the inverting input, the output voltage will try to rise by the same amount amplified (multiplied) by the gain factor (of, say, 100,000).

Conversely, should the voltage on the non-inverted input fall below that on the inverted input, so the output will try to fall by an equivalently amplified amount.

Obviously, a similar effect will occur, but in the opposite direction, if it is the inverting input voltage that changes while the non-inverting input voltage remains constant.

## NEGATIVE FEEDBACK

Consider, though, what happens if part of the output voltage is fed back to the inverting input, see Fig.7.4. Feedback into this input (via resistor R2 in this case) is known as *negative feedback*. The output will try to swing in the direction prompted by the relative voltage difference across the two inputs, but the effect will be diminished according to the amount of that change which is fed back to counteract it.

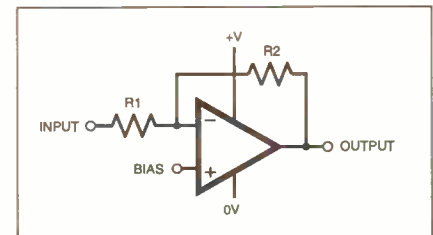


Fig.7.4. Feeding back part of the output voltage to the inverting input.

The output might be trying to change by 100,000 times, but the feedback might be set for 99,990 times. The net difference is thus only 10. Therefore, the effective amplification is only 10 times that of the difference originally fed into the two inputs. The gain is thus said to have a value of 10.

More strictly, when the signal is being applied to the inverting input, the gain should be said to be -10 (*minus* 10) because of the inversion. For the most part here, though, we shall just refer to the gain as a positive value.

Low gain values are of much better use if you want to just slightly raise the amplitude of a waveform, as you have just done with the triangle waveform. In fact, when you first adjusted preset VR3 to its maximum

resistance, the gain you gave to the waveform was about 2, i.e. you doubled the waveform amplitude. So let's explain the mechanism which is used in the circuit of Fig.7.2 to control the signal gain.

## CONTROLLING GAIN

First, assume that the waveform being sent to the inverting input of IC4 via preset VR2 is alternating about a midway voltage level. Let's say the midway level is at 3V (half the voltage applied to the full circuit, as supplied by your 6V battery).

Your initial adjustment of preset VR4 applied just about the same midway voltage (which we refer to as the *bias*) to the non-inverting input (you will recall that you were asked to originally set its wiper to a midway position). This action roughly balanced the two inputs at the midway voltage. The changes in voltage caused by the triangle waveform's swing thus became evenly balanced as seen across the two op.amp inputs.

The voltage being fed into the inverting input, however, passes through the resistance offered by preset VR2. On its own that resistance has no appreciable effect on the voltage actually reaching the input. Preset VR3, though, is connected so that it feeds back part of the output voltage to the inverting input. Jointly, the effect of both resistances, VR2 and VR3, determines the amount of negative feedback that occurs. Respectively, they are the equivalent of R1 and R2 in Fig.7.4.

If both resistances are equal, then the negative feedback amount is the same as the basic input amount, but inverted. The result is that the voltage actually "seen" at the inverting input is the input voltage minus the feedback voltage, i.e. nil! At least, that would be the case if you ignored the non-inverting input.

But you can't and don't. The internal circuitry of the op.amp effectively adds this input's voltage (3V in this case) to the voltage on the other input. Thus both inputs end up with the same voltage on them! Confirm this point using your meter to monitor the voltage on op.amp pins 2 and 3, and that from IC1a pin 1.

What's the good of that? you might ask. Well, there's a lot! In order to achieve that balance between inputs, the output has had to change its voltage level. And that's what we are interested in, the change in output level in response to a change in input level.

## BALANCING ACT

In the above equal resistance example (VR2 = VR3), the output changes by the same amount as the input, but in the opposite direction. An input change of 1V upwards, for instance, causes an output voltage change of 1V downwards.

If, though, VR3 resistance is twice that of VR2 resistance, twice the amount of feedback is required in order to achieve the balance at the op.amp inputs. Consequently, a 1V input change results in a 2V output change in the opposite direction.

Similarly, if VR3 resistance is half that of VR2 resistance, then the output change required to achieve balance is only half that fed into VR1. Thus, a 1V input rise will cause a 0.5V output fall.

Indeed you have already proved the truth

## PANEL 7.2. OP.AMP PACKAGES

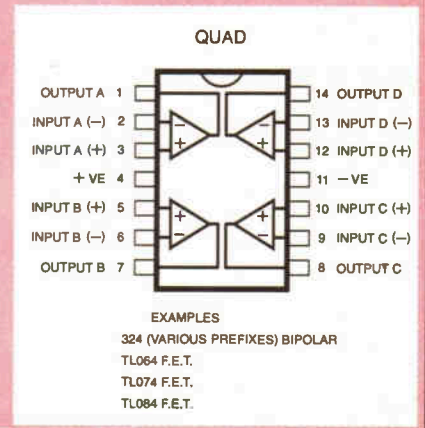
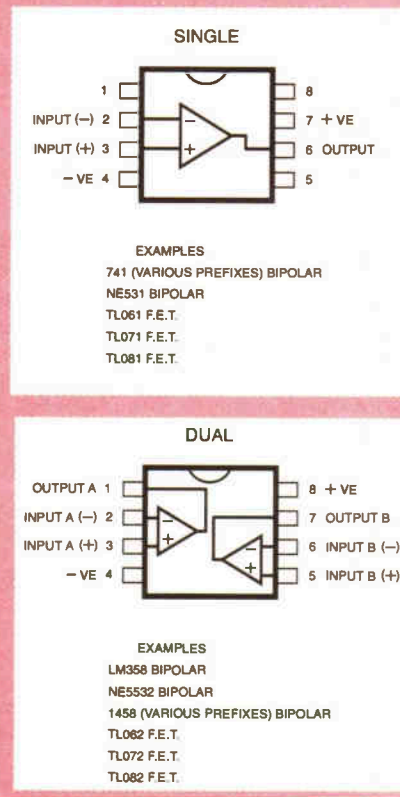
Op.amps are manufactured with encapsulations (packages) containing one, two or four individual op.amps, the packages known respectively as *single*, *dual* and *quad*.

The vast majority of op.amps have

the same pinout configuration per packaging type, as shown here. A few of the op.amp types available are listed below their packages. There are hundreds of other type numbers manufactured. Note that some specialist op.amps do not conform to these pinouts.

With single op.amp types, there are various functions that can be performed via pins 1, 5 and 8. These are too numerous to discuss here and for most simple amplification-type circuits they can be ignored. They can control such matters as, for instance, the fine adjustment of the d.c. output level (*offset*) to match the basic zero-differential input voltage. Manufacturers' data sheets should be consulted for more information.

(ILLUSTRATIONS NOT TO SCALE)



of these statements when observing the affect of changing the values of VR2 and VR3. You have proved both signal gain (amplification) and signal reduction (attenuation).

## INVERTING GAIN FORMULA

There is a simple formula which defines the gain in relation to the value of the inverting input resistance (call it R1, as in Fig.7.4) and the negative feedback resistance (call it R2):

$$\text{Gain} = R2 / R1$$

Thus if R2 is 100kΩ and R1 is 10kΩ the gain is 100k/10k = 10. The output signal will be ten times greater than that coming in through R1 (within certain limits, as discussed in a moment).

Similarly, if R2 is 10kΩ and R1 is 100kΩ then the gain will be 10k/100k = 0.1. The output signal will then be 0.1 (one tenth) of the input signal.

## VIRTUAL EARTH

There is a term used to describe the effect seen at the inverting input when there is a balance of voltage directly at the two inputs when feedback is employed - *virtual earth*. It is not a "true" earth in the sense that applies when referring to the common or 0V line of a circuit, but nonetheless it is one into which voltages can be fed via resistances from many sources without causing a change in the virtual earth

voltage level at the inverting input. Under feedback conditions, only adjusting the voltage level on the non-inverting input will cause a change in level on the inverting input, this occurring due to the op.amp's internal circuitry, as said earlier.

Note that a virtual earth condition does not exist if negative feedback is not employed.

## WAVEFORM CLIPPING

What we have not yet accounted for is the "flattening" of the waveform peaks as the gain is increased beyond a certain point. The term given to this effect is *clipping*.

The clipping has two possible causes. First, the op.amp is powered at a particular voltage, 6V (or thereabouts) in your experiments. Reason must tell you that the op.amp cannot output a voltage greater than its power supply.

In a *perfect* op.amp, the output voltage would be capable of swinging fully between the two power line levels, 0V and 6V in this case. The flattening occurs when the swing can increase no further, irrespective of the amount of amplification available.

There are, indeed, some more-specialised op.amps manufactured whose outputs can swing *almost* completely between the power line levels. The term given is that they have a *rail-to-rail* output capability, where *rail* means *power-rail* (power-line).

Most general purpose op.amps, though, do not have rail-to-rail output. Most will

## PANEL 7.3. OP.AMP POWER LINES

Most op.amps are designed to be run from a dual-rail power supply, i.e. one having positive, negative and zero (ground) output voltage rails, typically  $\pm 15V$  but may not be as high as this with some devices.

As we deliberately demonstrate in this *Teach-In*, op.amps can also be powered from a power supply having only positive and 0V (ground) connections. In this case the middle rail voltage is provided by using the voltage at the centre of an equally-divided potential divider (as used in the demos).

only swing within limits somewhat less than the power rail range. The actual range depends on the op.amp type, the voltage that it is being powered at, and the amount of current that is being drawn from its output by the load into which it is feeding. Under no-load conditions, the LM358 you are using here has a typical swing of about 0.5V to 3.8V for a 5V power supply.

### INPUT CAPACITOR

Earlier, we drew your attention to the likelihood that, when the gain was being adjusted, the waveform position seen on screen would change as well as amplitude. This is in part due to the fact that the triangular waveform tapped from IC1a pin 1 may not be swinging about an exact mid-way voltage level.

Consequently, any d.c. voltage difference between the waveform's midway level and that set by VR4 is amplified by the op.amp, causing the vertical shift observed.

There is a very easy cure for this – to stop the d.c. level from the oscillator reaching the op.amp, just allowing the a.c. voltage change through.

In *Teach-In* Part 2 we discussed capacitors in terms of their ability to be charged and discharged through a resistance. We displayed it via one of the computer demos and gave formulae for it.

Capacitors have another attribute, the ability to stop direct current (d.c.) passing through them whilst allowing alternating current (a.c.) to pass through. We shall discuss this ability more fully in a future *Teach-In* part, but for the moment accept this as a fact. But bear in mind that future discussions will point out that this ability is governed by the capacitance value and the load resistance into which the "output" side of the capacitor is fed. Two other terms come into use in that discussion, *differentiation* and *integration*.

### A.C. COUPLING

So let's prove the point even though we don't explain it. Remove the oscillator connection from the "D.C. Input" point on your breadboard and connect it to the "A.C. Input" point. This now provides the input path with what is known as *a.c. coupling* (as opposed to *d.c. coupling*, which has been the situation so far).

Run the same group of adjustments using op.amp presets VR2 to VR4 as you did earlier and observe the screen results.

You should find that once VR4 has been set midway, there should be no vertical shift of the waveform as you adjust gain, just the amplitude change.

Note that whilst in theory all op.amp circuits shown in this *Teach-In* part can be powered from dual-rail supplies, **on no account should dual-rail supplies be used if the circuit is to be connected to the ADC device or to a computer.** Additional circuitry would be required in order to permit computer connection. Failure to observe this could seriously harm the ADC and/or computer.

For optimum stability of an op.amp circuit, the power supply should be regulated at fixed voltage levels. Power supplies will be discussed in Part 9.

There is, though, a much more pronounced effect that you may observe, that of a reduction in oscillator frequency with the additional capacitor in circuit. Furthermore, the frequency and shape of the waveform are likely to vary when adjusting op.amp preset VR2.

The effect is due to the oscillator now seeing two capacitors in parallel, its own C1, and C2 of the op.amp circuit. The effective value of the latter is also changed by the amount of resistance it sees from VR2.

We have a cure for this as well!

### SIGNAL BUFFERING

There is a scenario that we have not yet explored, that of feeding a voltage into the non-inverting input, and merely feeding the output straight back into the inverting input, but without any additional voltage or current being fed into that input. Such a circuit is shown in Fig.7.5.

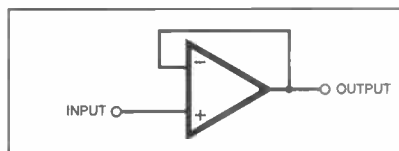


Fig.7.5. Unity gain op.amp buffer.

The interesting thing about this circuit is that the total negative feedback ensures that the voltage applied to the non-inverting input receives neither amplification nor attenuation at the output. Whatever change there is on this input is exactly followed by the output, and in the same direction. In this configuration, the circuit is known as a *unity gain* amplifier, i.e. the gain is 1. The circuit is also said to function as a *buffer*.

What is now worth noting is that inputs to op.amps draw very little current (some

types draw none at all, see Panel 7.1). They are said to have *high impedance* inputs, where *impedance* can loosely be described as *resistance*.

In the earlier experiments, capacitor C2 caused a frequency change at the oscillator because the current/voltage flowing through the resistance provided by VR1 was being partly diverted into C2. If we insert a unity gain op.amp to isolate (*buffer*) the charging process for C1 from the effect of C2, then the oscillator frequency will be unaffected by the presence of C2.

The circuit diagram for this simple improvement is shown in Fig.7.6. Here we now use the second half of the dual op.amp, IC4b, to provide the unity gain buffer stage and then feed its output into the amplifier stage around IC4a, still via C2 and VR2.

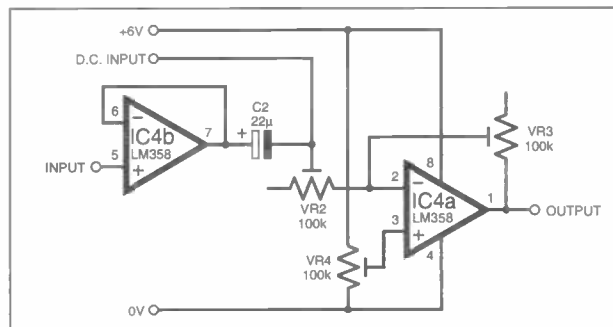
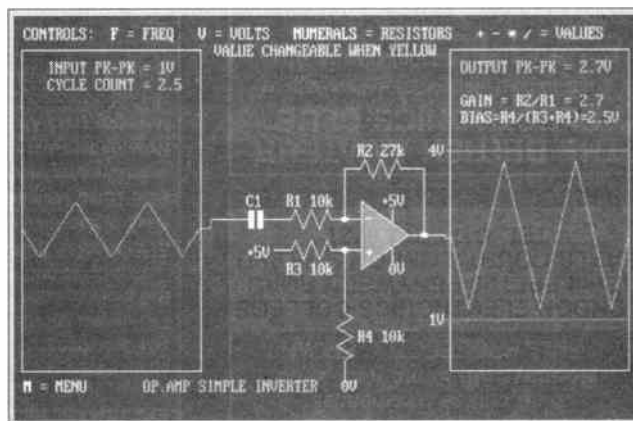


Fig.7.6. Adding a buffer to the circuit of Fig.7.2.



Interactive computer display illustrating an inverting op.amp circuit.

Referring back to the breadboard layout in Fig.7.1, connect the oscillator output from IC1a pin 1 to the point labelled "Buffer Input" and connect "Buffer Output" to "A.C. Input". Ensure that the small link between columns 25 and 26 of row G is inserted.

Having made the changes, observe that the frequency is now unaffected by the presence of the amplifying stage.

### SIGNAL NON-INVERSION

We have not fully discussed the fact the waveform being output from IC4a is an upside down (*inverted*) version of that generated by the oscillator. There are occasions when this inversion might be undesirable, in d.c. voltage amplification, for example.

As another example, in audio amplification involving many simultaneously processed sources, signals must often remain the "right-way-up" with respect to each in order to maintain their correct relationships. Failure to do so could have

severely detrimental effects on the overall sound quality. It could even result in two signals cancelling each other (a principle we shall demonstrate next month).

One way that we can maintain the correct *phase relationship*, as it is known in waveform processing, is to use the amplifier stage in its non-inverting mode rather than its inverting mode. We can still provide the same amount of amplification.

### NON-INVERSION CIRCUIT

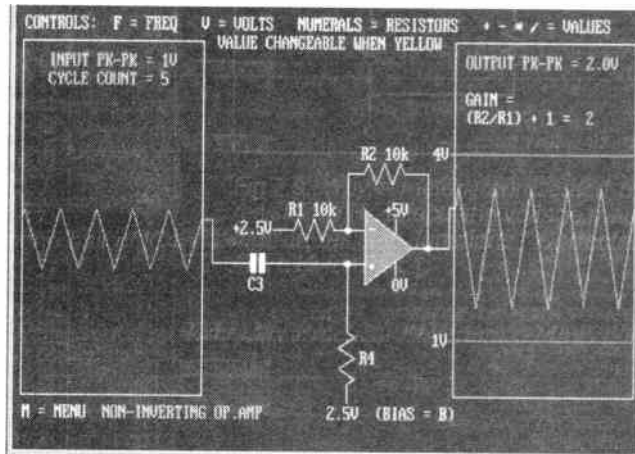
First we need to connect the signal to the non-inverting input of the op.amp. We must then provide the correct midway bias voltage to the inverting input. It is, though, this input that is still responsible for partly controlling the negative feedback, and thus the gain. Consequently, the resistance of the bias setting control must also be taken into account.

There are several approaches to this problem. We shall just take an option that is easy to implement with the breadboard layout we are already using. The circuit is shown in Fig.7.7. Change the breadboard layout to that shown in Fig.7.8.

The signal is still being fed in via capacitor C2 in order to isolate the amplification from the effects of the d.c. bias that might

Note that in the "real world", the discharge resistance value in relation to the value of capacitor C2 affects the frequency range that can be correctly handled (to be discussed when we examine integration in a later part of the series), and should be chosen accordingly. For the sake of this demo, however, we'll ignore such niceties – the relationship is OK for what are trying to show.

We retain presets VR2 and VR3, but have to provide a second midway bias voltage into the now "loose" wiper of VR2. This is provided by the voltage divider formed by resistors R3 and R4. At their junction is added a capacitor (C3) to "smooth" the voltage here, which could otherwise vary significantly with the changing signal levels in the feedback path.



Interactive computer screen illustrating a non-inverting op.amp circuit.

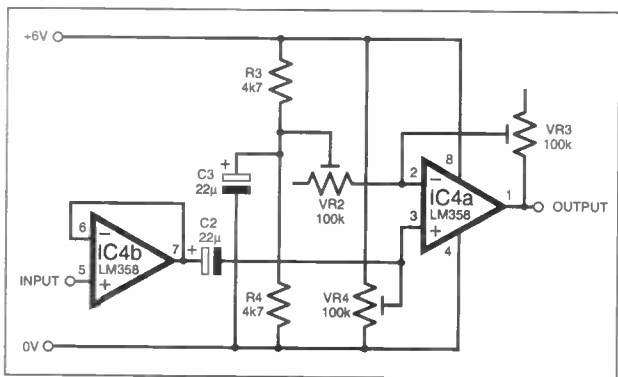


Fig.7.7. Non-inverting op.amp amplifier circuit.

exist from the oscillator. However, we must provide the op.amp side of C2 with a discharge path, as supplied via preset VR4.

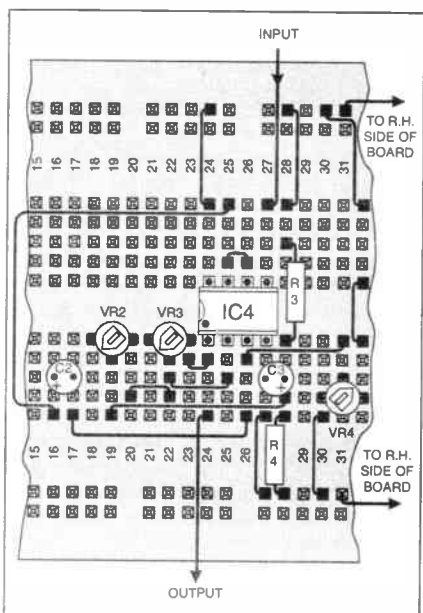
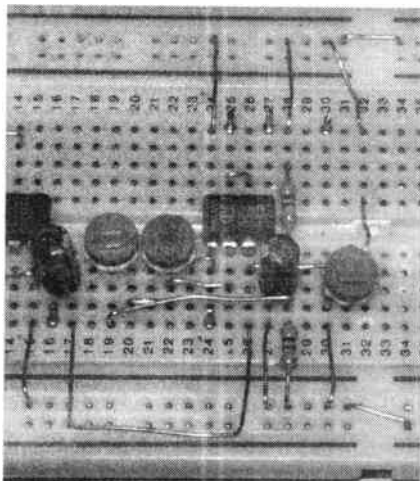


Fig.7.8 and photo. Breadboard layout for Fig.7.7, note that the second half of IC4 is now required to be connected into the circuit.

using preset VR4.

Note that the wrong figure was published for Fig.1.12 of Part 1. The correct figure, which illustrates a voltage divider feeding into another resistance ( $R_m$ ), is shown now as Fig.7.9.

The circuit in Fig.7.7 does not invert the signal output. Examine the output at IC4



pin 1 as shown on your screen (via the ADC) and confirm that it is the same way up as the original. Now that you have a buffer amp in circuit, you can monitor the basic oscillator waveform from its output (IC4 pin 7).

### NON-INVERSION GAIN

Earlier we defined the formula for calculating inversion gain as:

$$R2 / R1$$

where R1 and R2 represented the inverting input and feedback resistances respectively.

Using the inversion configuration, signal attenuation can be achieved as well as amplification.

For the non-inverting amplifier, the lowest level of signal amplification is 1 (unity), *attenuation can never be achieved*. Consequently, the gain calculation becomes feedback resistance (R2) divided by inverting input resistance (R1), as before, but a value of 1 is then added:

$$\text{Gain} = (R2 / R1) + 1$$

You will probably spot that if R2 has a value of zero, then the unity gain condition exists, irrespective of the value of R1.

### D.C. AMPLIFICATION

For the last several paragraphs we have concentrated heavily on an op.amp's ability to amplify waveforms (i.e. a.c. signals). You may not have recognised it, but you

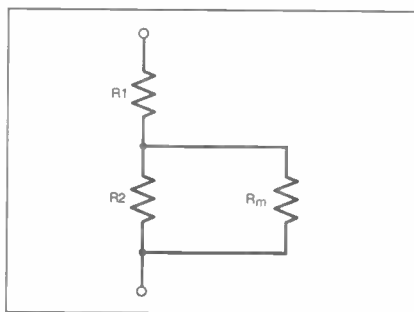


Fig.7.9. Why a meter (represented by resistance  $R_m$ ) affects the voltage reading at resistor junctions. Corrected Fig.1.12 for Part 1.

have already proved that the op.amp is equally suited to amplifying d.c. levels.

When you were initially experimenting with the relationships of the three presets in Fig.7.2, you needed to adjust VR4 in order to compensate for the d.c. bias coming from the oscillator. You may have noticed that the adjustment became more sensitive when the gain was set high by either VR2 or VR3.

This was entirely due to the d.c. bias from the oscillator and VR4 being amplified. At that time the d.c. amplification was undesirable. There are, though, many occasions in which a d.c. level needs to be amplified in order to be useful.

One example that comes to mind is the way in which the thermistor (heat sensor) and light dependent resistor (l.d.r.) you were encouraged to try as part of various oscillator experiments could be used (Part 3). We'll examine how voltage change with temperature or light intensity can be monitored on your multimeter and computer screen as part of next month's Tutorial.

## D.C. STABILITY

We must comment now, however, that amplifying d.c. voltage is not necessarily as easy as one might like. We have said that the values of electronic components can change with temperature, indeed the thermistor is an exaggerated example of this (but intended to do so beneficially).

Unfortunately, op.amp circuits are no exception to this rule. Not only can the components which are used in conjunction with op.amps have their values changed according to temperature, but so too can the characteristics of the op.amp itself.

The subject is actually too complicated to fully discuss or demonstrate as part of *Teach-In*, but it is something of which you should be aware. There are many circuit techniques by which the problem can be overcome, and more sophisticated (and expensive) op.amps in which the situation is less pronounced.

## TEMPERATURE DRIFT

A particular example of an op.amp's temperature dependency affects the d.c. output relative to the input. In a d.c. amplification circuit you can set up a bias level on one input in order to bring it closer to the d.c. level on the other input (i.e. narrow the differential voltage between the two). The resulting d.c. output level, however, may only hold true at the temperature at which the adjustment is made.

As the ambient (surrounding) temperature changes, so the d.c. output level can change, even though the voltage difference on the two inputs seemingly remains the same. Such a change is known as *temperature drift*. It will be far more pronounced at higher amplification settings. Typical temperature drift values are usually quoted in component data sheets, often in the form of graphs.

You should also be aware that an op.amp can heat up internally when the current into or out of its output increases, and that this will affect its characteristics.

For a.c. amplification (waveforms fed in and out via capacitors), though, temperature drift is seldom of any significance.

## COMPUTER DEMOS

We suggest that you now run two of the op.amp demo programs which interactively

## PANEL 7.4. RESISTANCE VALUES

The question of what decade ranges the resistance values should be chosen from for op.amp designs is a slightly tricky one. You will recognise that a uniform potential divider, for instance, can be made up from any two equal resistance values. So, should the values each be 1Ω, 10kΩ or even 10MΩ?

We have to say first that only a text book heavily dedicated to op.amps can really give definitive answers. There are, though, some basic considerations which it is appropriate to mention here:

One consideration is that power economy should always be at the forefront of any designer's mind. Since power consumption is less with higher value resistors, this does not favour very low resistances for the divider.

We have already said that a divider's resistance should ideally be at least ten times less than the load into which it feeds. When the divider is feeding into the non-inverting input simply as bias, its resistance can therefore be comparatively high. When it is providing bias to the inverting input of a feedback circuit, the load is provided by the *effective* input resistance and so the divider resistance should be chosen with respect to that.

The input resistance is chosen in relation to the gain required and the resulting value of the feedback resistor. One matter to consider here is that the gain of an *amplifier* (as opposed to a comparator) is usually best kept below about 200, and preferably below 100.

In d.c. amplification circuits, another factor to be considered is that (again, ideally) both op.amp inputs should have equal current flow, and the resistances should be chosen to meet this condition.

illustrate the functioning of inverting and non-inverting op.amp circuits.

From the main menu select Op.amps – Menu, this will bring up another screen from which five op.amp demo programs can be selected. The two we suggest you play with now are Simple Inverting Amp and Simple Non-Inverting Amp. We shall discuss the other three options next month.

The inverting demo illustrates an op.amp's response to an a.c. coupled input triangle waveform in respect of different resistance values. Resistors R1 and R2 control the gain, while R3 and R4 change the bias on the non-inverting input.

The non-inverting demo also inputs an a.c. coupled triangle waveform. Resistors R1 and R2 control the gain. R4 has a fixed unspecified value; it is the "bleed" resistor required following input capacitor C3. The bias voltage applied via R4 can be changed.

Signal input amplitude and frequency rate (Cycle Count) can also be changed. The power supply voltage is fixed at +5V/0V. Note that the demo op.amp has been given output min/max limits of 1V and 4V.

The controls are stated on screen, press the appropriate keys to activate the function to be changed. Note the varying conditions under which the output signal can become clipped. You can press the <PAUSE> key to

In choosing gain setting values, and those of the dividers, it should be borne in mind that very high values of resistance are prone to causing the circuit to pick up signals from external electrical sources, such as mains "hum", motor-bike ignition, frequency radiation from TV or computer monitors, etc.

Additionally, the relationship between signal capacitors and resistors affects the frequency response of the circuit as a whole. Some of this capacitance can be due to that which exists in the op.amp itself, as well as the proximity of one printed circuit board track to another.

With some op.amps a further problem is that if the load they feed into has quite a low resistance, distortion of the output can occur if the feedback resistance is too high.

As a very rough guide, however, the ranges of input and feedback resistances are usually best kept between about 1kΩ and 1MΩ, but it does depend on the circumstances. It is then usually best if the values are chosen from the "common-place" decade multiples, such as those in the E12 range (see Part 1): 1, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8 and 8.2.

To help you become more conversant with what resistance values can be chosen for different op.amp circuits, study the published circuits of other electronics designers.

Finally, despite this list of considerations, for general experimentation op.amps are *really easy devices to use successfully*. You can play around with component values to your heart's content with an excellent chance of achieving results, even if not perfect. Furthermore, op.amps are such hardy devices that you are highly unlikely to ever kill one!

stop the waveform scrolling, then press any other key to restart scrolling.

## NEXT MONTH

This seems a convenient point at which to end this month's Tutorial. We do not have room for an Experimental section as such, this has been moved forward to next month and becomes Tutorial Part 8.

In reality, Part 7 and Part 8 are both a mixture of Tutorial and Experimental. What we discuss in Part 8, though, is all based on the characteristics we have been describing here in Part 7, and illustrates some interesting ways in which op.amps can be used.

## MORE SOFTWARE

Version V1.1 of the *Teach-In 2000* software is now available on disk and from our website ([www.epemag.wimborne.co.uk](http://www.epemag.wimborne.co.uk)). The software includes all the previous programs (some slightly updated) plus all those needed to see you through to the end of the series.

Copy all the files on to your computer (having unzipped them first). When asked if you wish to overwrite the previous files, say yes to all.

# PRACTICALLY SPEAKING

Robert Penfold looks at the Techniques of Actually Doing It!

IT IS SAID that the simplest inventions are the best ones, and, for the electronics hobbyist, stripboard possibly ranks alongside sliced bread and the wheel in the best inventions stakes.

Stripboard is a proprietary printed circuit board that is noted for its versatility. For most projects it represents the only practical alternative to using a custom printed circuit board (p.c.b.).

A project based on a custom board is actually the best choice for a complete beginner due to the relatively foolproof nature of these boards. However, many small and medium sized projects are based on stripboards, and newcomers to the hobby soon find themselves using this method of construction.

Although stripboard is not quite as straightforward to use as custom p.c.b.s, it is not really that difficult to use either. There are a few traps waiting for the unwary, but once you are aware of the pitfalls it is not too difficult to obtain perfect results almost every time.

## Right Pitch

So what exactly is stripboard? It is based on a board about 1.6mm thick that is made from an insulating material. Presumably the colour of the board varies from one manufacturer to another, but it seems to be supplied in a variety of yellow-brown colours from almost white to virtually black.

The board is drilled with one-millimetre diameter holes on a regular matrix. In the past it was possible to obtain stripboards with the holes spaced at 0.1-inch, 0.15-inch, or 0.2-inch intervals, but these days only 0.1-inch boards are readily available. It is only 0.1-inch pitch boards that are of any real use with modern projects, because many components will not fit onto 0.15-inch or 0.2-inch boards.

One side of stripboard is plain, while the other side has copper strips running along the rows of holes. It is, of course, from these copper strips that the stripboard name is derived. Many people still refer to this material by the old proprietary name of "Veroboard".

Like an ordinary single-sided printed circuit board, the components are mounted on the plain side. The leadout wires are trimmed short on the other side and soldered to the copper strips, which then carry the connections from one component to another. Fig.1 shows the plain and copper sides of two scraps of stripboard.

## Brittle Experience

With a custom p.c.b. there is usually no preparation required. When you are ready to start construction you simply begin fitting the component to the board. With stripboard a small amount of work is needed before the board is ready to accept the components, and the normal first step is to cut out a

board of the required size.

As pointed out previously, stripboard comes in a range of yellow-brown colours, reflecting a range of materials used in the board. Some of these materials are tougher than others, but most stripboards seem to be slightly brittle. It is best to err on the side of caution and assume that all these boards are brittle, and exercise due care when working on them. Use the "hammer and tongs" approach and you may well end up with three or four small boards instead of one large one!

Over the years various suggestions have been made for quick and easy ways of cutting stripboard to size using implements such as glass and tile cutters. The problem with these methods is that they work well with some makes of stripboard, but can produce disastrous results with others.

The only truly reliable method found so far is to carefully cut along rows of holes using a hacksaw. Due to the close spacing of the holes and width of the blade it is not practical to cut between rows. Cutting along rows of holes inevitably produces some very rough edges, but these are easily filed to a neat finish using a flat file.

The finished board might slot into place in the case, but it is more likely that it will be bolted in place. Any mounting holes should be drilled at this stage using an ordinary HSS twist drill. Use a piece of scrap timber, chipboard, etc. underneath the board, and use only moderate pressure. This should give good "clean" holes and avoid any cracking around them.

When drilling any form of copper laminate board it is best to drill the board with the copper side uppermost, as there is otherwise a risk of the copper being torn away from the board.

## Big Breaks

With anything but the most simple of projects it is necessary to make some breaks in the copper strips. Without any cuts each strip can only carry one set of interconnections, but by breaking a strip into (say) three pieces, it can carry three sets of connections.

The article describing the project should include a diagram that clearly shows the positions of the breaks, as in the example of Fig.2. Double-check the posi-

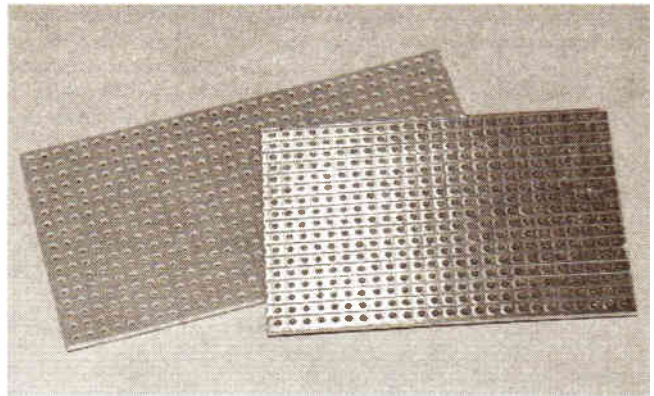


Fig.1. Stripboard only has the copper strips on one side

tion of each break before actually making it. If a mistake should be made it is possible to solder a small piece of wire over the break, but more than the occasional repair will give scrappy looking results and poor reliability.

A special strip-cutting tool is available, and it is often referred to as a "spot face cutter" in component catalogues. This is basically just a drill style cutting tool fitted in a handle. In order to cut a strip the point of the tool is placed in position and the handle is given a couple of rotations while applying moderate pressure (Fig.3).

If you will be producing anything more than the occasional stripboard project it is certainly worthwhile buying this tool. Initially you may prefer to use a handheld twist drill bit of about 5mm in diameter, which will do the job quite well.

Either way, make quite sure that the strips are cut right across their full width. Very fine residual tracks of copper can be difficult to see with the naked eye, so it is worth checking the board with the aid of a magnifier.

Although you need to make sure that the strips are cut properly, do not go to the other extreme and practically drill through the board. With a large number

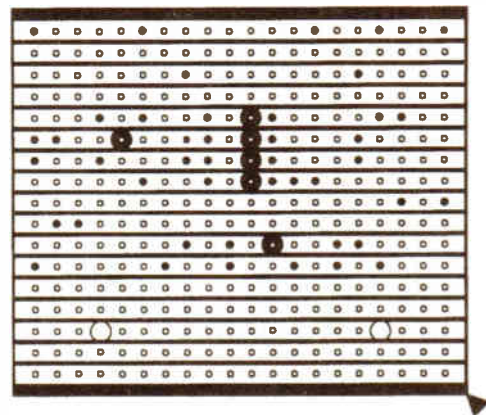


Fig.2. The underside view of the board will clearly show the positions of any breaks required in the copper strips.



of breaks this would seriously weaken it. Brush away any copper shavings as these could otherwise cause short circuits.

### Moving In

At this stage the board is ready for the components to be added. This is one respect in which stripboard is rather more awkward than a custom printed circuit board. With a p.c.b. there is one hole per leadout wire or pin, but with stripboard less than 10 percent of the holes are normally used.

Mistakes with component placement are more easily made, and when they do occur they can be difficult to spot. To compensate for this it is necessary to proceed more carefully and to double-check the positioning before fitting and soldering each component in place.

Having to remove and refit a small component occasionally is not a major disaster, but getting a multi-pin component, such as an integrated circuit (i.c.), in the wrong place can be more difficult to deal with. Removing this type of component requires proper desoldering equipment and risks damaging the board.

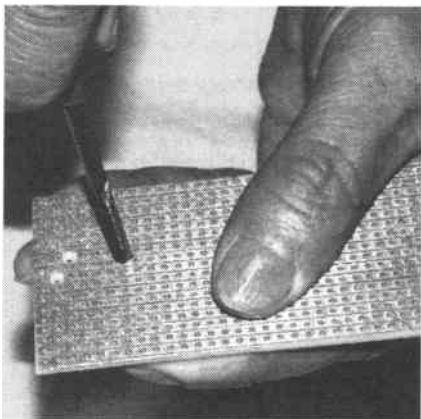


Fig.3. Using the special tool provides the easiest way of making breaks in the copper tracks.

Getting a large number of components shifted out of position is time consuming to correct, and all the soldering and desoldering could take its toll on the board. It is much better to proceed carefully and get things right first time.

### On Your Marks

Stripboard layout diagrams often have letters and numbers to identify the columns of holes, as in the dummy layout diagram of Fig.4. Many constructors find it useful to mark the board itself with these letters and numbers, so that they can quickly and easily match any point on the board with its equivalent point on the diagram.

A fine point fibre-tip pen is required, as there is not a great deal of space available for the labels. Also, it needs to be a type that is capable of writing on glass and other non-porous surfaces. Otherwise it will not mark the board properly, or the labels will rub off the first time you handle the board.

It is difficult to mark numbers for all the columns of holes, but navigating your way around the board should still be easy if only every fifth or tenth column is labelled. Similarly, it is only necessary to label every other copper strip, or even every fourth or fifth strip.

Do not make the classic mistake of getting the orientation of the board wrong so that all the components are fitted in the wrong places. There are usually mounting holes that make the correct orientation obvious, but the diagrams for the two sides of the board normally have a marker that indicates the same corner of the board in both views. This is included in Fig.2 and Fig.4, and leaves no excuse for getting it wrong.

### Missing Link

With the preliminaries out of the way, assembling a component panel is much the same whether it is based on stripboard or a p.c.b. There are a couple of differences though, one of which is the higher number of link-wires encountered when building projects based on stripboard.

The copper tracks of a custom p.c.b. can weave all round the board if necessary, but this is clearly not possible with stripboard. Link-wires provide a means of compensating for the lack of versatility in the track pattern, and enable connections to run from any given point on the board to any other point. Virtually every stripboard layout has at least a few link-wires, and the larger boards can have dozens of them.

The usual way of fitting link-wires is to preform a piece of wire to fit into the layout in much the same way as resistors and axial capacitors are fitted. The ends of the wires are then trimmed to length and soldered to the board in the usual way.

An alternative method is to cut a piece of wire that is slightly over-length and then solder one end of it to one of the holes in the board. Next thread the other end of the wire through the second hole and pull it tight using a small pair of pliers. Finally trim the wire and solder it to the board.

The trimmings from resistor leadout wires are ideal for short link-wires, but for longer wires 22s.w.g. or 24s.w.g. (or about 0.6mm dia.) tinned copper wire is needed. Where a layout has a lot of link-wires be sure to meticulously check that every link has been fitted to the board.

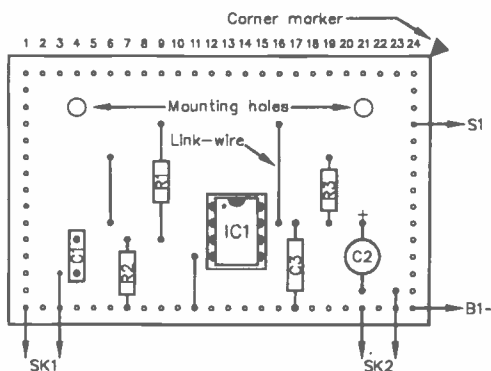


Fig.4. An example stripboard layout diagram.

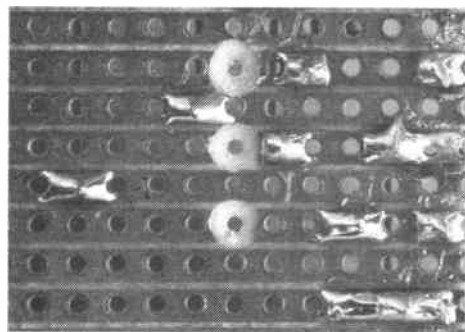


Fig.5. Removing some excess flux rendered this solder bridge fairly obvious.

There is no need to insulate short links, but with wires of around 25mm or more in length there is a slight risk of short circuits occurring, particularly where there are several wires running side by side. In this case, it is advisable to fit the longer link-wires with pieces of p.v.c. sleeving.

### Building Bridges

The second potential problem with stripboard is accidental short circuits due to solder splashes and excess solder on joints. This can be a problem with any form of printed circuit board, but it tends to be more problematic with stripboard due to the very narrow gap between one track and the next. There is actually only about 0.3mm between adjacent tracks.

Usually it is fairly obvious when excess solder bridges two tracks, and remedial action can be taken straight away. Small amounts of excess solder can usually be wiped away with the bit of the soldering iron, but large amounts should be removed using a desoldering pump. The affected joint or joints can then be carefully remade.

The real problems are caused by the tiny trails of solder that are barely visible. In fact, they are sometimes buried under excess flux and can only be seen if the board is cleaned (Fig.5).

Having completed a stripboard it is definitely advisable to clean the copper side of the board and thoroughly check it for solder bridges. Cleaning fluids for removing excess flux are available, but simply scrubbing the board vigorously with something like an old toothbrush seems to do an equally good job.

Any reasonably powerful magnifying glass will provide a good close-up view of the board, but something like an 8x or 10x loupe is best. These are primarily intended for viewing slides and they are available from most camera shops. The cheapest of loupes is adequate for this application.

If a stripboard refuses to work for no apparent reason it is worthwhile making some checks using a continuity tester. Check that there are no short circuits between adjacent copper strips or across any breaks in the strips. Usually, once you know a short circuit is there it will miraculously appear when the board is given another visual check!

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His 1931 Patent for a Binaural Recording System was so revolutionary that most of his contemporaries regarded it as more than 20 years ahead of its time. Even years after his death, the full magnitude of its detail had not been fully utilized. Among his 128 patents are the principal electronic circuits critical to the development of the world's first electronic television system. During his short working life, Blumlein produced patent after patent breaking entirely new ground in electronic and audio engineering.

During the Second World War, Alan Blumlein was deeply engaged in the very secret work of radar development and contributed enormously to the system eventually to become 'H2S' - blind-bombing radar. Tragically, during an experimental H2S flight in June 1942, the Halifax bomber in which Blumlein and several colleagues were flying, crashed and all aboard were killed. He was just days short of his thirty-ninth birthday.

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160 pages Order code T17 £3.95

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### PRACTICAL ELECTRONIC MODEL RAILWAY PROJECTS

R. A. Penfold

The aim of this book is to provide the model railway enthusiast with a number of useful but reasonably simple projects that are easily constructed from readily available components. Stripboard layouts and wiring diagrams are provided for each project. The projects covered include: constant voltage controller; pulsed controller; pushbutton pulsed controller; pulsed controller with simulated inertia, momentum and braking; automatic signals; steam whistle sound effect; two-tone horn sound effect; automatic two-tone horn effect; automatic chuffer.

The final chapter covers the increasingly popular subject of using a computer to control a model railway layout, including circuits for computer-based controllers and signalling systems.

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Bill Mooney

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Whilst the book is mainly intended as an introduction, it is also an invaluable reference book, and the browser should find it engrossing.

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R. A. Penfold

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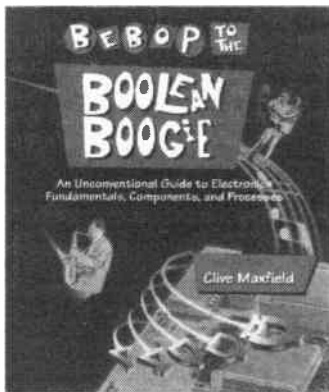
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The Foreword by Pete Waddell, Editor, *Printed Circuit Design*, reads:

"Personally, I think that the title of this tome alone (hmmm, a movie?) should provide some input as to what you can expect. But, for those who require a bit more: be forewarned, dear reader, you will probably learn far more than you could hope to expect from *Bebop to the Boolean Boogie*, just because of the unique approach Max has to technical material. The author will guide you from the basics through a minefield of potentially boring theoretical mish-mash, to a Nirvana of understanding. You will not suffer that fate familiar to every reader: re-reading paragraphs over and over wondering what in the world the author was trying to say. For a limey, Max shoots amazingly well and from the hip, but in a way that will keep you interested and amused. If you are not vigilant, you may not only learn something, but you may even enjoy the process. The only further advice I can give is to 'expect the unexpected'."



This book gives the "big picture" of digital electronics. This indepth, highly readable, up-to-the-minute guide shows you how electronic devices work and how they're made. You'll discover how transistors operate, how printed circuit boards are fabricated, and what the innards of memory ICs look like. You'll also gain a working knowledge of Boolean Algebra and Karnaugh Maps, and understand what Reed-Muller logic is and how it's used. And there's much, MUCH more (including a recipe for a truly great seafood gumbo!).

Hundreds of carefully drawn illustrations clearly show the important points of each topic. The author's tongue-in-cheek British humor makes it a delight to read, but this is a REAL technical book, extremely detailed and accurate. A great reference for your own shelf, and also an ideal gift for a friend or family member who wants to understand what it is you do all day. . . .

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By Clive "Max" Maxfield and Alvin Brown

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The Foreword by Lee Felsenstein reads:

"1. The more time you spend with this book and its accompanying CD-ROM, the more you'll get out of it. Skimming through it won't take you where you want to go. Paying serious attention, on the other hand, will teach you more about computers than you can imagine. (You might also see a few beautiful sunrises.)

2. The labs work on two levels: on and under the surface. When you're performing the labs you'll need to look for patterns that build up from individual events.

3. When you're done, you won't look any different. You won't get a trophy or a certificate to hang on your wall. You'll have some knowledge, and some skill, and you'll be ready to find more knowledge and develop more skill. Much of this will be recognisable only to someone who has the same knowledge and skill."

This follow-on to *Bebop to the Boolean Boogie* is a multimedia extravaganza of information about how computers work. It picks up where "Bebop 1" left off, guiding you through the fascinating world of computer design . . . and you'll have a few chuckles, if not belly laughs, along the way. In addition to over 200 megabytes of mega-cool multimedia, the accompanying CD-ROM (for Windows 95 machines only) contains a virtual microcomputer, simulating the motherboard and standard computer peripherals in an extremely realistic manner. In addition to a wealth of technical information, myriad nuggets of trivia, and hundreds of carefully drawn illustrations, the book contains a set of lab experiments for the virtual microcomputer that let you recreate the experiences of early computer pioneers.

*If you're the slightest bit interested in the inner workings of computers, then don't dare to miss this one!*



## Audio and Music

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R. A. Penfold

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Ian Waugh

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Robert Penfold

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Topics covered include: the PIC register set; numbering systems; bitwise operations and rotation; the PIC instruction set; using interrupts; using the analogue to digital converter; clock circuits; using the real time clock counter (RTCC); using subroutines; driving seven segment displays.

166 pages

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A. Flind

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Various circuits using inductors and capacitors are covered, with emphasis on stable low frequency generation. Some of these are amazingly simple, but are still very useful signal sources.

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Fourth Edition, Ian Sinclair

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Contents: Passive components, Active discrete components, Discrete component circuits, Sensing components, Linear I.C.s, Digital I.C.s, Microprocessors and microprocessor systems, Transferring digital data, Digital-analogue conversions, Computer aids in electronics, Hardware components and practical work, Standard metric wire table, Bibliography, The HEX scale, Index.

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## OPTOELECTRONICS CIRCUITS MANUAL

R. M. Marston

A useful single-volume guide to the optoelectronics device user, specifically aimed at the practical design engineer, technician, and the experimenter, as well as the electronics student and amateur. It deals with the subject in an easy-to-read, down-to-earth, and non-mathematical yet comprehensive manner, explaining the basic principles and characteristics of the best known devices, and presenting the reader with many practical applications and over 200 circuits. Most of the i.c.s and other devices used are inexpensive and readily available types, with universally recognised type numbers.

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## OPERATIONAL AMPLIFIER USER'S HANDBOOK

R. A. Penfold

The first part of this book covers standard operational amplifier based "building blocks" (integrator, precision rectifier, function generator, amplifiers, etc), and considers the ways in which modern devices can be used to give superior performance in each one. The second part describes a number of practical circuits that exploit modern operational amplifiers, such as high slew-rate, ultra low noise, and low input offset devices. The projects include: Low noise tape preamplifier, low noise RIAA preamplifier, audio power amplifiers, d.c. power controllers, opto-isolator audio link, audio millivolt meter, temperature monitor, low distortion audio signal generator, simple video fader, and many more.

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## A BEGINNERS GUIDE TO CMOS DIGITAL ICs

R. A. Penfold

Getting started with logic circuits can be difficult, since many of the fundamental concepts of digital design tend to seem rather abstract, and remote from obviously useful applications. This book covers the basic theory of digital electronics and the use of CMOS integrated circuits, but does not lose sight of the fact that digital electronics has numerous "real world" applications.

The topics covered in this book include: the basic concepts of logic circuits; the functions of gates, inverters and other logic "building blocks"; CMOS logic i.c. characteristics, and their advantages in practical circuit design; oscillators and monostables (timers); flip/flops, binary dividers and binary counters; decade counters and display drivers.

The emphasis is on a practical treatment of the subject, and all the circuits are based on "real" CMOS devices. A number of the circuits demonstrate the use of CMOS logic i.c.s in practical applications.

119 pages

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# AUDIO AND MUSIC

## INTRODUCTION TO DIGITAL AUDIO

(Second Edition)

Ian Sinclair

Digital recording methods have existed for many years and have become familiar to the professional recording engineer, but the compact disc (CD) was the first device to bring audio methods into the home. The next step is the appearance of digital audio tape (DAT) equipment.

All this development has involved methods and circuits that are totally alien to the technician or keen amateur who has previously worked with audio circuits. The principles and practices of digital audio owe little or nothing to the traditional linear circuits of the past, and are much more comprehensible to today's computer engineer than the older generation of audio engineers.

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## PROJECTS FOR THE ELECTRIC GUITAR

J. Chetwin

This book is for anyone interested in the electric guitar. It explains how the electronic functions of the instrument work together, and includes information on the various pickups and transducers that can be fitted. There are complete circuit diagrams for the major types of instrument, as well as a selection of wiring modifications and pickup switching circuits. These can be used to help you create your own custom wiring.

Along with the electric guitar, sections are also included relating to acoustic instruments. The function of specialised piezoelectric pickups is explained and there are detailed instructions on how to make your own contact and bridge transducers. The projects range from simple preamps and tone boosters, to complete active controls and equaliser units.

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104 pages

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## PRACTICAL ELECTRONIC MUSICAL EFFECTS UNITS

R. A. Penfold

This book provides practical circuits for a number of electronic musical effects units. All can be built at relatively low cost, and use standard, readily available components. The projects covered include: Waa-Waa Units; Distortion Units; Phaser; Guitar Envelope Shaper; Compressor; Tremolo Unit; Metal Effects Unit; Bass and Treble Boosters; Graphic Equaliser; Parametric Equaliser. The projects cover a range of complexities, but most are well within the capabilities of the average electronics hobbyist. None of them require the use of test equipment and several are suitable for near beginners.

102 pages

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## LOUDSPEAKERS FOR MUSICIANS

Vivan Capel

This book contains all that a working musician needs to know about loudspeakers; the different types, how they work, the most suitable for different instruments, for cabaret work, and for vocals. It gives tips on constructing cabinets, wiring up, when and where to use wadding, and when not to, what fittings are available, finishing, how to ensure they travel well, how to connect multi-speaker arrays and much more.

Ten practical enclosure designs with plans and comments are given in the last chapter, but by the time you've read that far you should be able to design your own!

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PIC-project source code files: /pub/PICS

PIC projects each have their own folder; navigate to the correct folder and open it, then fetch all the files contained within. Do not try to download the folder itself!

EPE text files: /pub/docs

Basic Soldering Guide: solder.txt

EPE TENS Unit user advice: tens.doc and tens.txt

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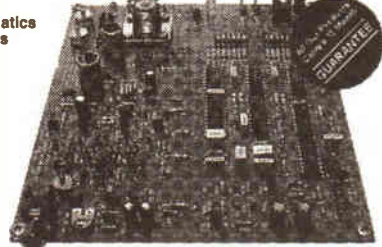
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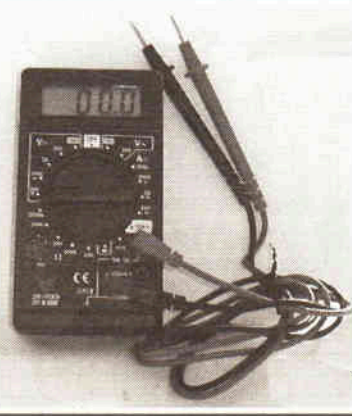
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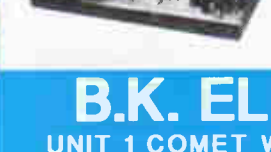
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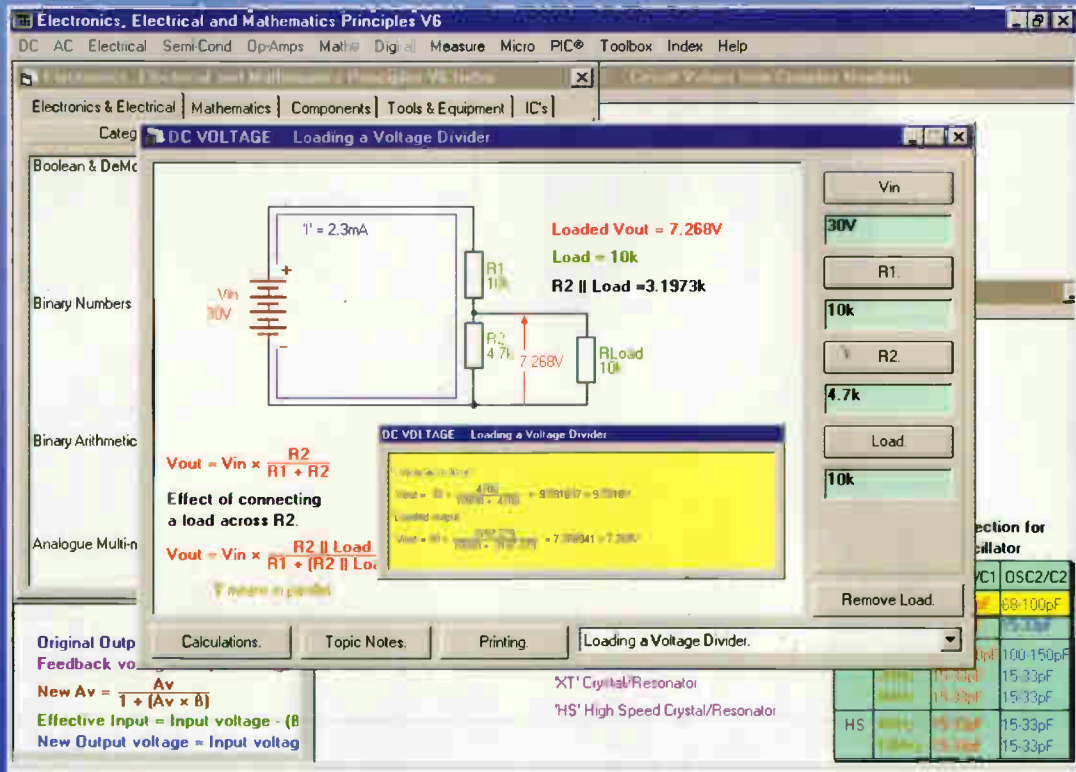
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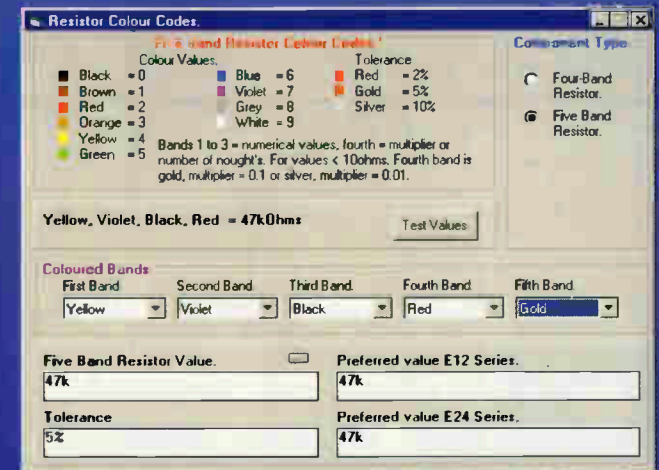


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