THE No.1 MAGAZINE FOR ELECTRONICS TECHNOLOGY & COMPUTER PROJECTS

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MAY 2002

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**180R.P.M. MAINS MOTOR.** Induction type, 90mm x 70mm, 50mm x 5mm shaft, 12A continuous rating, thermal protected. £22, Ref MGM1.
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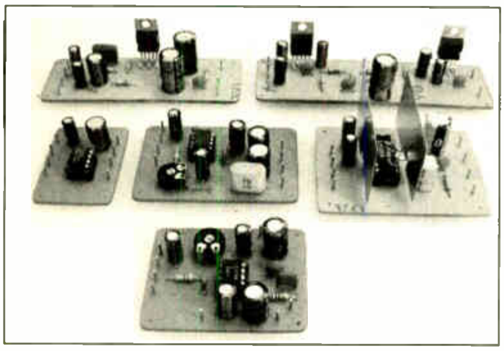

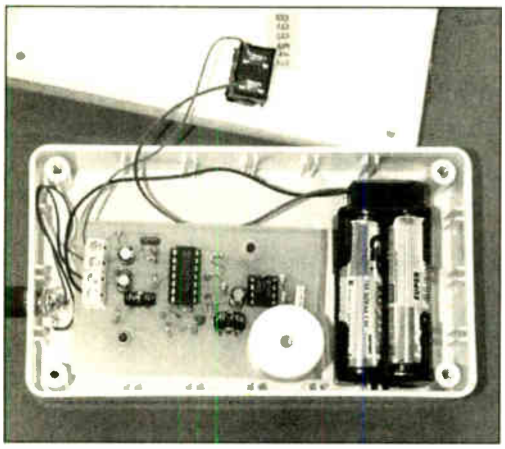

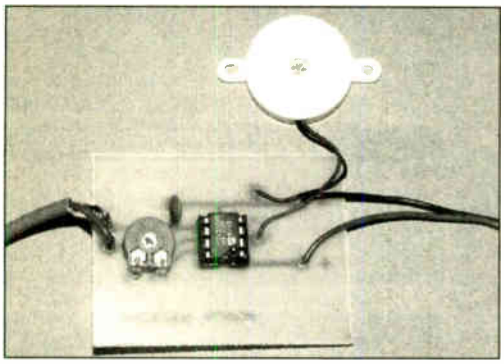

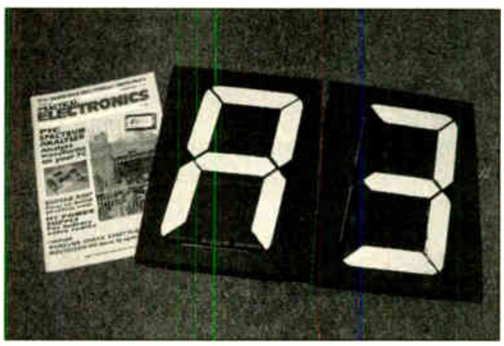



***Our June 2002 issue will be published on Thursday, 9 May 2002. See page 307 for details***

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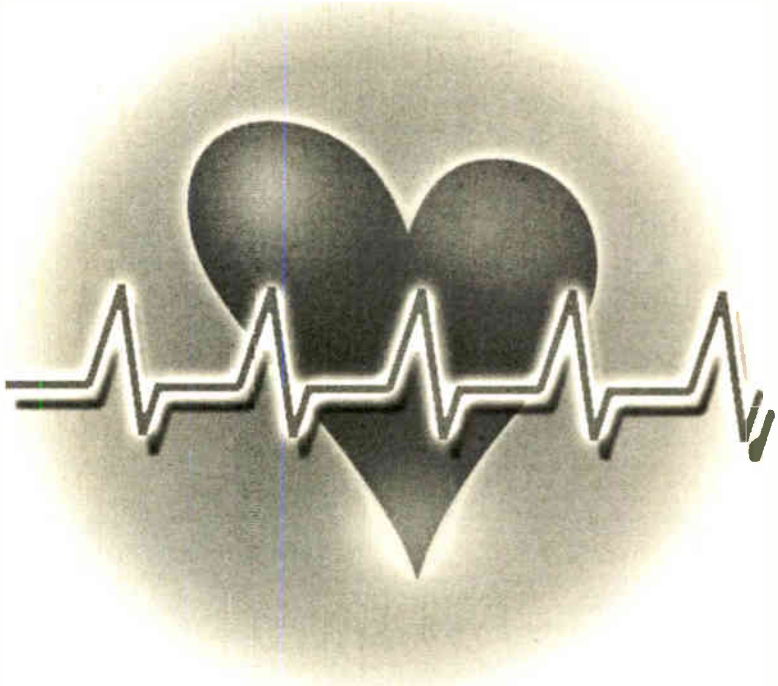
# NEXT MONTH

## BIOPIC HEARTBEAT MONITOR

The Biopic monitors heartbeats across the chest using simple electrodes and outputs the display to a PC-compatible computer via an electrically-isolated serial data link. Pulse rates can be monitored separately by a handheld sensor that detects the opacity of the thumb, which changes as blood pulses through it.
Based on a PIC16F876 microcontroller, the design uses only five i.c.s. The probes and contact pads used are those sold inexpensively by major chemists for use with proprietary TENS (pain relief) machines.
It can also be used as a handheld unit without a PC. In this role, an l.c.d. shows the heart rate as a graphical waveform, and provides a beats per minute count, plus a real-time pulse beat via a flashing asterisk.
The Biopic's PC software is written in QBasic, but is self-contained and does not require QB itself to be installed. It can be run in DOS mode or under Windows 3.1, 95, 98 and ME.



## WORLD LAMP

THE quest for a battery-powered lamp for lighting in poorer areas has presented an interesting and important design challenge for many years. Such a lamp should ideally be cheap, simple, efficient, and flexible – all at the same time.
With this in mind, the authors have designed a lamp that is made from inexpensive readily-available stock parts and runs off a nominal 12V d.c. supply. This is converted to a p.w.m. (pulse width modulated) a.c. supply which will power any ordinary fluorescent lamp between 100mW and 15W. It will power the equivalent of a 60W incandescent lamp for about 80 hours off a standard 12V car battery and can provide low cost lighting whenever or wherever there's no mains supply available.

## FREQUENCY STANDARD GENERATOR

A high-precision selectable 1kHz to 100kHz frequency source derived from BBC Radio Four's transmission signal which has a Rubidium frequency source as its reference and has an accuracy of one part in $10^{11}$.
The primary virtue of this design is its phenomenal accuracy and stability. There will not usually be many really accurate standards of any kind in the workshop of a home constructor since they are usually prohibitively expensive. This design provides an exception to this rule by bringing a national frequency standard right onto the amateur's bench. It should prove useful for checking and adjusting the calibration of frequency meters, oscilloscopes, and any other equipment used for measuring or generating frequency of any kind.

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# MAGIC POWERS

The start of this month's new series on *Simple Audio Circuits* raises a question that always annoys me – I guess it is a pet hate of mine. To put it in simple terms, I hate to see audio output powers quoted by manufacturers that are frankly fairy tales. If you see a set of small computer speakers with internal amplifiers quoted as having 100W or greater output then I suggest you simply buy from a more honest manufacturer.

How do manufacturers dream up these totally unrealistic figures? Well this is how it's done, courtesy of Jake Rothman writing for our *Modern Electronics Manual:*

Say the true r.m.s. output of an amplifier is 10W (this expresses the power of an unclipped sinewave as a d.c. voltage producing the same power into a given – say 8 ohm resistance). The first stage of the trick is to use the term "peak power" which derives the power from the peak voltage so our 10W becomes 20W. The next stage is to specify the output into 4 ohms so now we have 40W (note that 90 per cent of speakers are 8 ohm impedance). Step 3 is to call it music power which, because music is not continuous (like a sinewave), allows the output to be doubled again giving 80W. Finally, the two stereo channel outputs are added together to give 160W peak music power (stereo) you will usually see this quoted simply as 160W PMPO (peak music power output).

As you can see, it's a con, try dividing it by 16 to get the true output! In some cases manufacturers have gone even further and I have seen claims like 480W PMPO qualified by 12W + 12W r.m.s. output – at least they quoted the r.m.s. figure.

So if you see audio output specifications that are not based on continuous sinewave r.m.s. figures at a stated level of distortion then I suggest that you simply do not believe them.

You can tell the quality manufacturers by the way they quote their output figures. There is basically no way that miniature amplified computer speakers will provide a true 100W (or more) output, if you don't believe me just take a look at the output available from the plug top power supply they normally use and ask yourself if you can get 100W output with less than 10W (12V, 800mA) input? Nice trick if you could really do it.

It is, of course, all a marketing con. trick.

Mike Kenward

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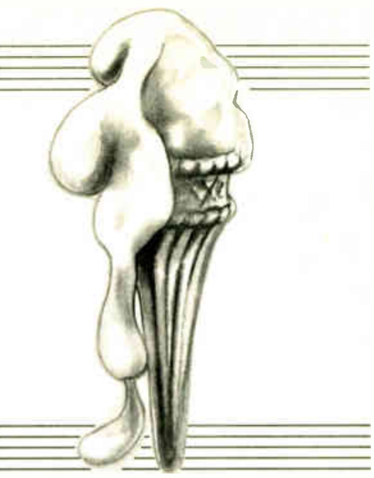
Constructional Project

# FREEZER ALARM

## HUMPHREY BERRIDGE



*Simply protect your food, learn about using the 8-pin PIC12C508, and about applying the Watchdog Timer.*

SOME modern freezers contain alarms which sound if you leave the door open and allow the internal space to warm up. However, they do not work if the freezer suffers a power failure, which is a bit of a drawback.

Making a temperature-sensitive circuit which can sound an alarm is not too difficult (a typical example was the *Ice Alert* in Feb '01) but what is required here is a low-cost circuit which can run on batteries for a very long time.

This design uses a circuit based on a PIC, using a feature about which little has been written, namely the ability to send it to sleep! The circuit is extremely simple, and the software uses several techniques which could be useful in other projects.

### BABY PIC

The design uses the "baby" of the PIC family, the PIC12C508. This is an extraordinarily versatile device, and in its OTP (one-time-programmable) version is very inexpensive. It is housed in an 8-pin d.i.l. package (see Fig.1), and has the same set of 33 RISC instructions as its big brothers.

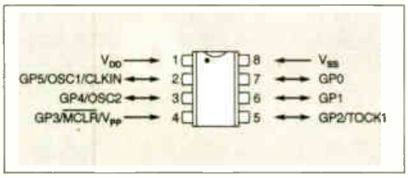



*Fig.1 (above). The pin diagram for the PIC12C508 microcontroller.*

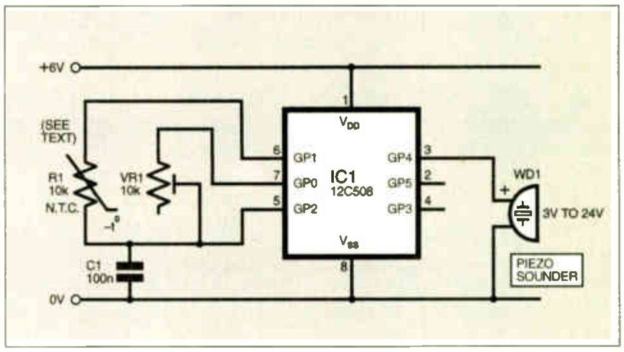
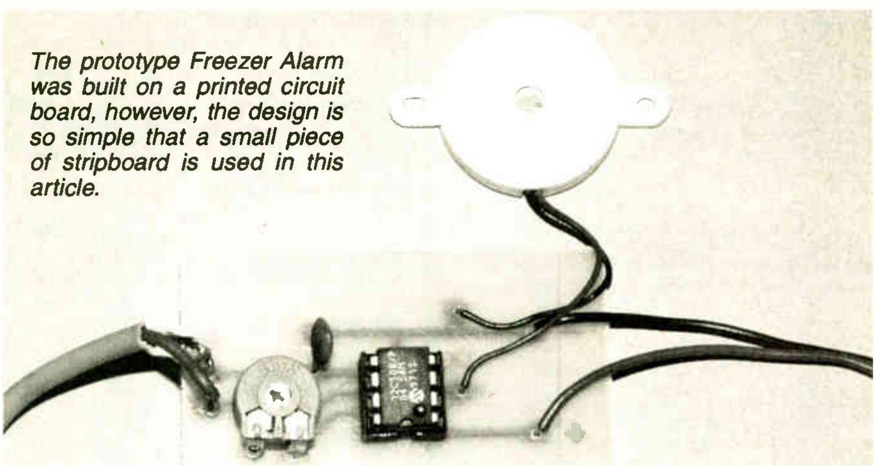



*Fig.2 (right). Circuit diagram for the Freezer Alarm.*

Two pins are used for power (between 2·5V and 5·5V), the remainder can be configured as five I/O (input-output) pins and one input-only pin.

An in-built oscillator runs at 4MHz – i.e. an instruction every 1$\mu$s. It has 25 bytes of data RAM available, program memory is 512 bytes. There are two internal timers, one of which is a "Watchdog", and it can drive output devices with currents up to 50mA.

This little PIC is extraordinarily versatile, and for many applications provides adequate microcontroller power. Of course, the more powerful versions such as the PIC16F84 can be programmed to operate in just the same way with few changes to the software, but why use a sledge-hammer to crack a nut?



*The prototype Freezer Alarm was built on a printed circuit board, however, the design is so simple that a small piece of stripboard is used in this article.*

### CIRCUIT DESCRIPTION

If you are the sort of person who enjoys the challenge of constructing complex circuits, you will be disappointed! The complete circuit contains only five components, as shown in Fig.2. The clever stuff, of course, is provided by the PIC.

The temperature sensor used is a low-cost disc thermistor, R1, which can be attached via a length of 2-core cable. A small preset variable resistor, VR1 is used to set the operating point, the temperature threshold at which the alarm sounds.

Capacitor C1 is used to make the input circuit time-dependant, as described in the next section. For the alarm, a piezo sounder (WD1) is used because it can make a relatively large amount of noise whilst using a very small amount of electrical power. The whole circuit will conveniently run off a 6V battery.

### HOW IT WORKS

Thermistors are basically temperature sensitive resistors – normal n.t.c. (negative temperature coefficient) ones have a high resistance when cold, and a low resistance when hot, and the change of resistance is a very large effect.

An easy way to test a thermistor is to place it in a freezer (which is normally at about –18°C) and connect it to a multimeter via leads of suitable length. After a few minutes the thermistor will reach the temperature of the freezer, and with the meter on its resistance range you will be able to measure the approximate value of resistance at this temperature.

The thermistor used here has a resistance of around 1kΩ at room temperature (see Table 1). Other types of N.T.C. thermistor could equally well be used with minor alterations to the circuit which are explained later.

**Table 1. Thermistor temperature/ resistance**

| | *Temperature* | *Resistance* |
|---|---|---|
| Room | 22°C | 900Ω |
| Fridge | 2°C | 2k3 |
| Freezer | –20°C | 11k2 |

The microcontroller circuit needs to "measure" this resistance in order to evaluate whether the thermistor is too warm – we do not need to know its actual value, just whether it is higher or lower than a preset value. This can conveniently be done by comparing the resistance of the thermistor to that of a preset resistor, VR1.

The PIC12C508 is basically a digital device, so we need a cunning plan to make it capable of measuring resistance. The method is to use the PIC as a timer which can count how long it takes a small capacitor C1 to charge up to a certain voltage.

If we consider a very simple circuit (Fig.3) consisting of just a capacitor C and a resistor R, we can see that if the switch is closed, the voltage V across the capacitor is zero and it is uncharged. As soon as the switch is opened, the capacitor charges via the resistor, and the voltage rises along an exponential curve (Fig.4).

In our circuit, we time how long it takes to go from zero to the logic threshold of the PIC (the point at which a logic 0 changes to a logic 1), which is about 3·0V, say.

The mathematics of this charging process produces a very simple relationship, namely that the time taken to reach a certain voltage is directly proportional to the value of R, so the time we have counted out until the voltage rises to 3·0V is an accurate representation of the value of the resistor. So all we need to do is to time how long it takes for the capacitor to charge via the thermistor, then time how long it takes to charge via the preset resistor. If the first time is shorter than the second, the thermistor is too warm and we ought to sound the alarm!

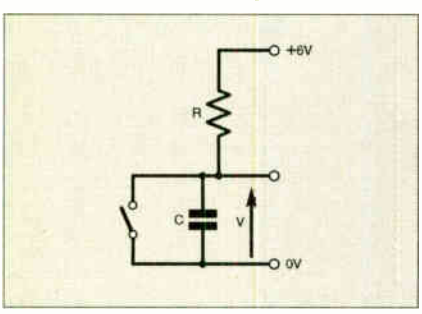



*Fig.3. Simple circuit to demonstrate capacitor charging.*

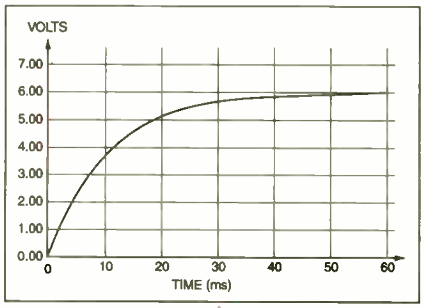



*Fig.4. Capacitor charging curve.*

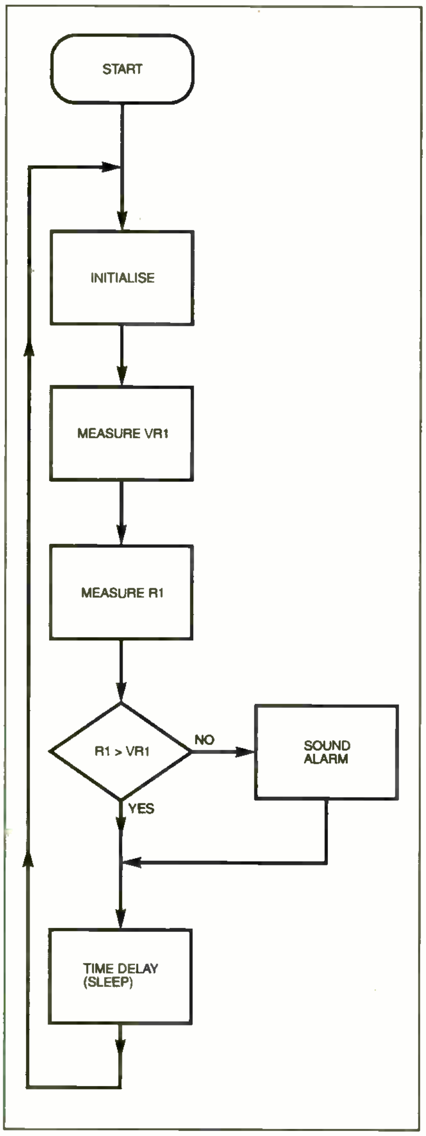



*Fig.5. Flow chart for the main program.*

What makes it possible for the PIC to do this is that not only can we force pins to go high or low, but we can also change whether a pin is an output or an input as the program is running. Using this fact we can both switch between the two resistors, and discharge the capacitor between our readings. This is described in the section on programming.

## MAIN PROGRAM

The way the program operates is straightforward, as illustrated by the flow-chart in Fig.5. First the PIC is initialised in that pins are set up either as outputs or inputs. We then have to measure the charging times of the capacitor first for the preset resistor VR1, then for the thermistor R1.

In order to give a reasonable number of steps to do the counting and improve the range of accuracy of the measurement, two registers are used together to form a 16-bit value.

The technique used for measuring resistance is shown in Fig.6, and involves the following:

1. First the capacitor needs to be completely discharged. To do this, pin 5 is set as an output, and then set at logic 0 (zero volts). This effectively shorts the capacitor. A delay of approximately 5ms makes sure it is fully discharged.
2. Next the two registers used to store the count time for the thermistor are set to zero.
3. Then pin 6 is set as an output, and reset to logic 0. Pin 5 is swapped to being an input pin, and then pin 6 taken to logic 1. At this moment the capacitor begins to charge up.
4. The program now starts to loop, incrementing the counter registers as it goes. Each time around the loop pin 5 is checked for having reached the voltage threshold at which it is considered to be at logic 1.
5. As soon as this happens, the routine ends, and the counter registers then contain the final time count. This process is repeated for the variable resistor VR1 using a different set of counter registers and pin 7 instead of pin 6.

After both measurements have been made, the two answers are compared: all we need to do is to subtract one number from another – we just want to know which process took the longer. Depending upon the outcome, we either go directly into the Sleep mode, or sound the alarm for a short time before again going to sleep.

## ALARMING

Generally speaking, a piezo device is not a buzzer – it has to be driven by an oscillating signal to make the alarm

## COMPONENTS

**Resistor**
R1 n.t.c. disc thermistor, 10k (1k at room temperature)

**See SHOP TALK page**

**Potentiometer**
VR1 10k min. enclosed carbon skeleton preset, horiz

**Capacitor**
C1 100n ceramic disc

**Semiconductor**
IC1 PIC12C508 preprogrammed microcontroller (see text)

**Miscellaneous**
WD1 piezo sounder, 3V to 24V

Stripboard, 10 strips x 17 holes; plastic case, size and type to choice; battery holder; AA-size batteries (4 off); battery clip; 8-pin d.i.l. socket; connecting wire; solder, etc.

*Approx. Cost Guidance Only* **£9** *excluding case & batts.*

sounds. There are two reasons for using a "swept frequency" alarm sound using the software:

a. Changing sounds such as beepers, sirens, etc. stand out much better from background noises, and

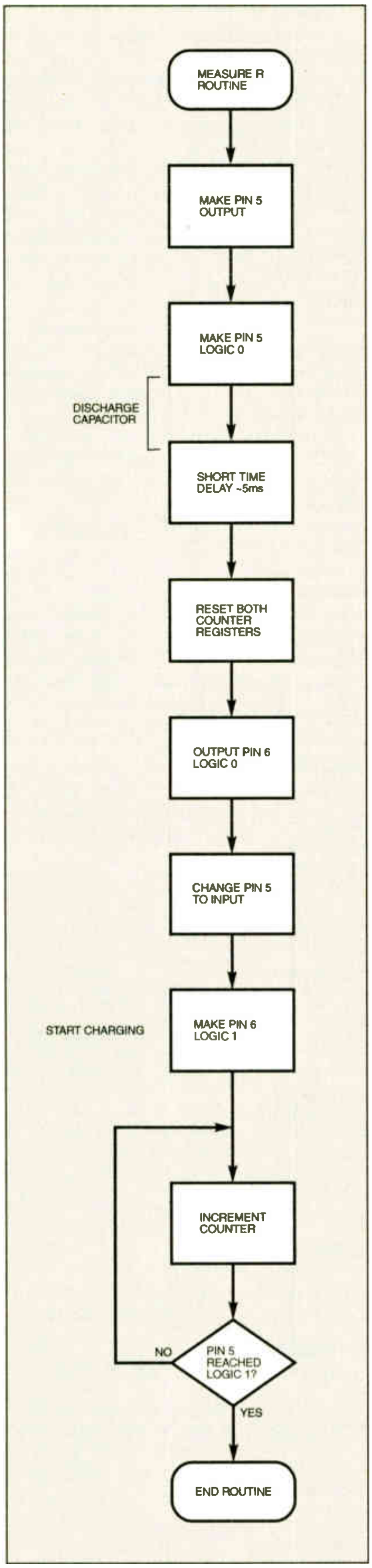



*Fig.6. Measuring the resistance of the thermistor.*

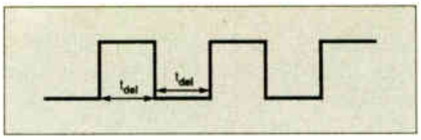



*Fig.7. Output waveform.*

b. the piezo device used here has a very sharp resonance – i.e. the sound output is very much higher at a specific frequency than at others. Different devices have different resonances, and even those tested of the same type had frequencies which varied quite a bit. By sweeping the frequency through the resonance one can be sure of making the most irritating noise! In this design, the frequency sweeps from approximately 2kHz to 8kHz.

To make a PIC generate an oscillating signal is quite simple. Referring to the waveform in Fig.7, you take the output high, wait for a short time ($t_{del}$), take the output low, wait for a short time ($t_{del}$), and then repeat the process.

The result is a square wave driving the piezo sounder. If, for instance, we made $t_{del}$ = 0·5ms, the period would be 2 × $t_{del}$ = 1·0ms, and the sound would have a frequency of 1kHz.

Sweeping the frequency may be accomplished by gradually changing the value of $t_{del}$ which can be done using the fact that delays in microcontroller systems are often made by "time-waster" loops where a counter counts down to zero.

By changing the value loaded into a register in the first place, the time taken can be varied. Fig.8 shows the program segment responsible. For each specific frequency, eight cycles are generated. The whole process takes approximately 130ms.

## WATCHDOG

Not many published projects seem to use a PIC's Watchdog Timer (WDT), but when it comes to conserving power using the Sleep mode, it is very useful. Information can be found in Microchip's data sheets and other publications.

When a PIC is given the Sleep command, it shuts down nearly all its functions and as a result consumes a very tiny amount of power – it only draws about 4$\mu$A from the supply.

There are three ways in which it can wake up again:

a. by a logic change on a pre-defined pin
b. when the WDT times-out, and
c. by an external master Reset

It is the second of these options that is used in this project. Inside the PIC12C508, the WDT function has its own internal oscillator and counter, and these continue to run even if the PIC is asleep. When the WDT times out, a system Reset is generated, and the program restarts.

It should be noted that one bit of the configuration word of the PIC enables or disables the WDT, and this bit must be set when the chip is programmed.

So, if we reset the WDT, it will then start counting and when it times-out (18ms later), the program goes through a Reset and starts again. That is not a very long time, but fortunately we can use the internal pre-scaler which can be used in conjunction with the WDT. To do this, we use the OPTION register to extend the time-out period to approximately 2·3 seconds.

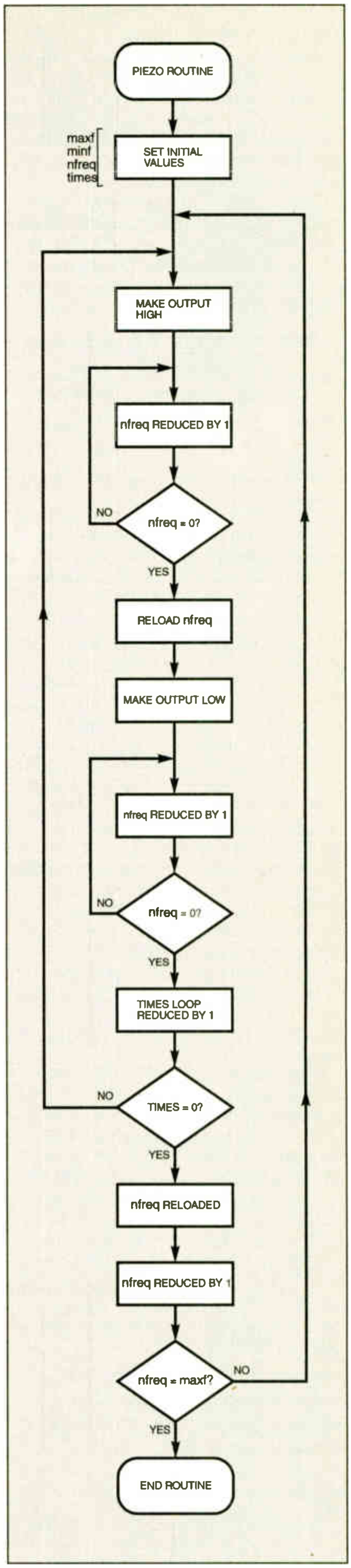



*Fig.8. Flowchart for the piezo sweeper. The whole sequence takes approximately 130ms.*

This may not seem very long, but what matters in conserving power is the ratio of the time taken to run the measurements compared and the time remaining asleep. If, for instance, it takes 50ms to take the measurements, the circuit is asleep for 98 per cent of the time with a resulting extension of battery life.

The OPTION register has eight bits which must be set up in order to control the WDT and prescaler. The functions are shown in Table 2. For this application, the OPTION register must be set to contain the binary byte 11001111. The short main program section is shown in Fig.9.

Note that during a Sleep period, the I/O ports maintain the same conditions that they had immediately beforehand. Therefore, to minimise the current drawn, all the pins are made inputs (high impedance) before the Sleep command.

## CONSTRUCTION

Construction is very simple. The suggested stripboard component layout and track cut details are shown in Fig.10.

The thermistor can be soldered to a short length of wire such as thin audio coax. An improvement would be to waterproof the thermistor connections by dunking it in polyurethane varnish. The wire can be fed into the freezer via the door seal.

It is important to resist the temptation to add a light emitting diode as a battery indicator – the l.e.d. would take about a thousand times more power than the rest of the circuit!

The PIC should be plugged into the board via an 8-pin d.i.l. socket. The circuit and batteries can be housed in a plastic box to sit outside the freezer, a small hole being provided to glue the piezo sounder behind. You should not need to replace batteries very often.

Software and pre-programmed PICs are available as stated in this month's *Shoptalk*.

## TESTING

The circuit will work quite happily at room temperature. Once the batteries are connected (it seems to work well on 6V although this is higher than the maximum recommended).

Gently rotate preset VR1 until the threshold is found between the alarm bleating or not. Set it so that the alarm is just off. Then hold the thermistor in your fingers to warm it up, and the alarm should sound; let go to allow the thermistor to cool again to room temperature, and the alarm should stop.

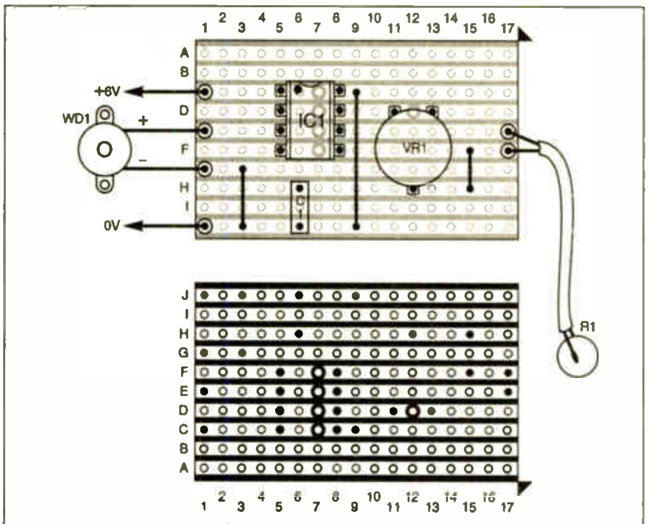



*Fig.10. Stripboard layout for the Freezer Alarm.*

**Fig.9. Main program**

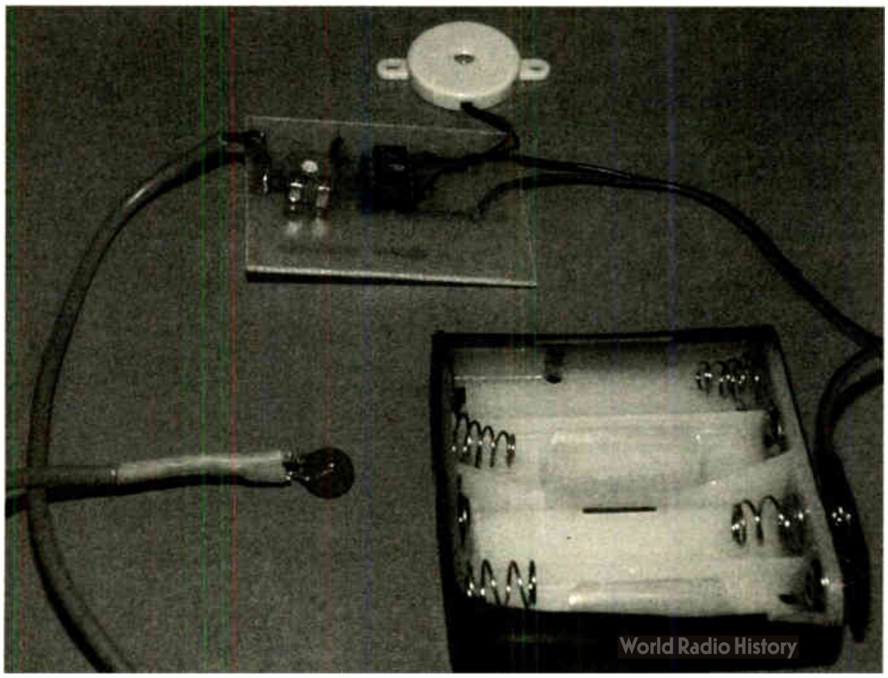
```
; Main program start
start
   clrwdt
   clrf     gpio          ;initialise I/O
   movlw    b'00000111'
   tris     gpio
   movlw    b'11001111'
   option                 ;wdt and prescaler
                           setup

   call     delay         ;settle down
   call     measureR
   call     measureT
   call     compare
   xorlw    0FFH          ;check if resT <
                           resR
   btfsc    z             ;If so, set off alarm!
   call     alarm
   movlw    b'11111111
   tris     gpio          ;all pins high
                           impedance

   clrwdt
   sleep                  ;until reawakened
                           by wdt
                          ;with a reset kiss

   goto start             ;should never reach
                           here!
```

Once you are convinced all is well, put the thermistor in the freezer, and after allowing time for the temperature to stabilise, increase the resistance on the preset so that the alarm threshold is set where you would like it.

In fact, the best way to find out if the batteries are OK is to let the thermistor warm up a bit when you open the freezer – if it is working and the alarm sounds, the batteries are fine!

**Table 2. Option Register Bits**

| | | |
|---|---|---|
| Bit 7 | GPWU | Enable (0) or disable (1) wave-up on pin change |
| Bit 6 | GPPU | Enable (0) or disable (1) weak pull-up resistors |
| Bit 5 | T0CS | Timer 0 clock source |
| Bit 4 | T0SE | Timer 0 edge select |
| Bit 3 | PSA | Prescaler assignment: Assigned to WDT (1), or to Timer 0 (0) |
| Bits 2-0 | | Prescaler rate – division ratio (111 for WDT ratio of 1:128) |




## MODIFICATIONS

As mentioned earlier, the techniques explained allow simple modifications to change how the circuit operates:

a. To make the alarm work if something is too cold rather than too warm (for example as a greenhouse frost alarm), simply swap over the connections to pins 6 and 7. Alternatively, make the appropriate swaps in the software.

b. The method can be adapted for any resistance changes – for example, the alarm could be made light-sensitive by using an l.d.r. (light dependent resistor) instead of a thermistor. Whatever thermistor or other device is used, VR1 needs to have a resistance which can be set to the same that the device has at its operating threshold.

c. An important design consideration concerns the value of the capacitor C1. Once the resistance of the appropriate sensor is known, the variable preset resistor needs to have the same value. However, the counter which waits for the capacitor to charge to its threshold must not overflow. This will happen after 320ms with this design's value for C1. Therefore, ensure that $C(\mu F) \times R(k\Omega) < 320ms$.

d. The circuit is remarkably accurate and stable. Because of the timing method of comparing the two resistors, any changes in the supply voltage (within the parameters above), or changes in the capacitance value caused by temperature or ageing, have virtually no effect.


## ACKNOWLEDGEMENTS

The author expresses his thanks to Mrs Jan Edwards for her help in this project. □

# New Technology Update

*With a growing awareness of global warming, scientists are looking at ways of using dye molecules to produce more efficient solar cells, reports Ian Poole*

Solar cells might seem to be an ideal way of generating electricity. They convert the plentiful supply of sunlight that is freely available in many areas of the world into useful electricity.

Whilst this may seem to be an excellent idea in theory, reality has been quite different and very few solar cells are used. The main reason for this is that a large area needs to be covered by solar cells to enable a useful amount of electricity to be generated. This means that the costs are prohibitively high for most applications.

The raw silicon from which the solar cells are made is plentiful and cheap. Unfortunately the processing costs mean that the completed cells are expensive, especially considering the areas that have to be covered to collect a useful amount of light for conversion. If solar generated electricity is to become common, then cheaper methods of converting the sunlight into electricity are needed.

## Photosynthesis

In the search for more efficient and cost effective methods of converting sunlight into electrical energy, scientists have investigated the way in which plants convert solar energy into chemical energy to explore any leads that could be followed and utilised for electrical energy conversion. This line of research was first investigated in the 1970s.

The basic idea that was adopted was to use a layer of dye molecules that are highly absorbent to light. This is placed onto the surface of a semiconductor and once the dye is excited it delivers an electron into the conduction band. By adopting this approach the operation of the device is no longer dependent upon the absorption level of the semiconductor but the dye, over which there is more control.

The drawback of using this approach is that the electrons move very slowly through the dye layer, and this reduces the efficiency of these devices considerably, even if the dye layer is made very thin. Initially efficiency levels of only 0·01% were achieved, and this is far less than that achieved by the traditional semiconductor techniques.

## New Concept

To overcome this problem a new approach was adopted by the Swiss Federal Institute of Technology. Using their method they believe the new cells will offer the possibility of a significant reduction in the cost of solar generated electricity due to the very simple construction of the cell.

In the new cell, light absorption occurs in what is termed a mono-layer of dye. This is adsorbed chemically at the surface of a semiconductor forming a layer that is only 1μm thick. Instead of using one continuous layer, the new cell uses small particles that are held in a colloidal solution.

When the dye is excited by a photon of light, the dye is able to transfer an electron to the semiconductor. If an external circuit is connected to the cell a current will flow as a result of the potential that is created by the transfer of the electrons. The potential is a function of the structure of the semiconductor and of the dye.

## Cell Structure

The solar cell itself consists of two conducting glass electrodes in a sandwich configuration with an electrolyte separating the two, see Fig.1. During the fabrication of the cell a layer of titanium dioxide is deposited onto one of the electrodes. This is achieved by using a colloidal preparation of monodispersed particles. The resultant layer of titanium dioxide is very porous and has a high surface area. This allows the distribution of dye molecules into the titanium dioxide.

The layer is heat treated to enable the resistivity of the film to reduce to a sufficiently low level to ensure resistance losses are within acceptable limits. Then the electrode with the oxide layer is immersed in the dye solution for several hours. The porous oxide absorbs the dye very efficiently giving an intense colour to the film.

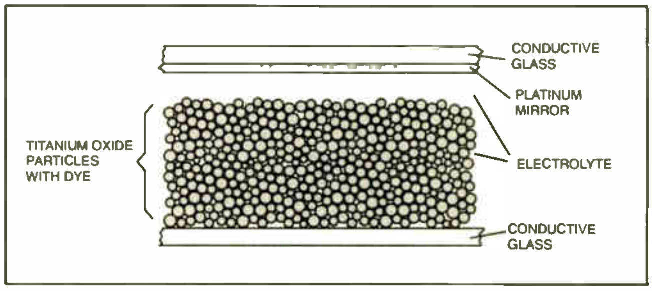



*Fig.1. Structure of the solar cell using organic dye and titanium oxide particles.*

The dye coated electrode is put together with another conducting glass electrode and the space between them is filled with an organic electrolyte. This second glass plate has a reflecting platinum plate to ensure light reaching it is reflected back into the cell. After making provision for the electrical contacts with the two electrodes the assembly is sealed.

## Greater Efficiency

The absorption of light using only a single molecular thickness of dye would be very low if it was not for the construction technique used. The fact that a very rough porous structure is used instead, allows for much greater levels of efficiency to be achieved because there is a far higher surface area presented to the light. A further advantage is gained from the fact that the semiconductor structure is nano-crystalline and this spreads the light over the whole area, further increasing the efficiency.

It might be thought that the heterogeneuos structure of the semiconductor would lead to a high level of resistance within the device and large losses. However, the reverse is true and electrons are able to diffuse in the bulk matter towards the supporting conductor with almost no energy loss.

Also, it does not suffer the same problem of a reduced percentage efficiency under low light conditions that traditional semiconductor cells suffer. Traditional cells suffer from hole-electron recombination in the semiconductor, and this reduces the efficiency, particularly when light levels are low.

## Other Research

Now that the basic idea has been proven, more research is ongoing to find some solid-state substitutes for the liquid electrolyte as this will make its manufacture much easier. It will also enable the complete solar cell to be far more robust than it can currently be made. Some ideas have already been tried and results using conductive polymers such as those used in light emitting diodes may prove to be promising.

Another problem that is facing the researchers is that purifying some of the materials used in the new processes is neither cheap nor easy at the moment. After ten years of research into the new cell there is still plenty that needs to be done. However, success will bring with it large returns because there is a growing awareness of global warming and new initiatives like these are likely to pay off the research and development costs many times over.

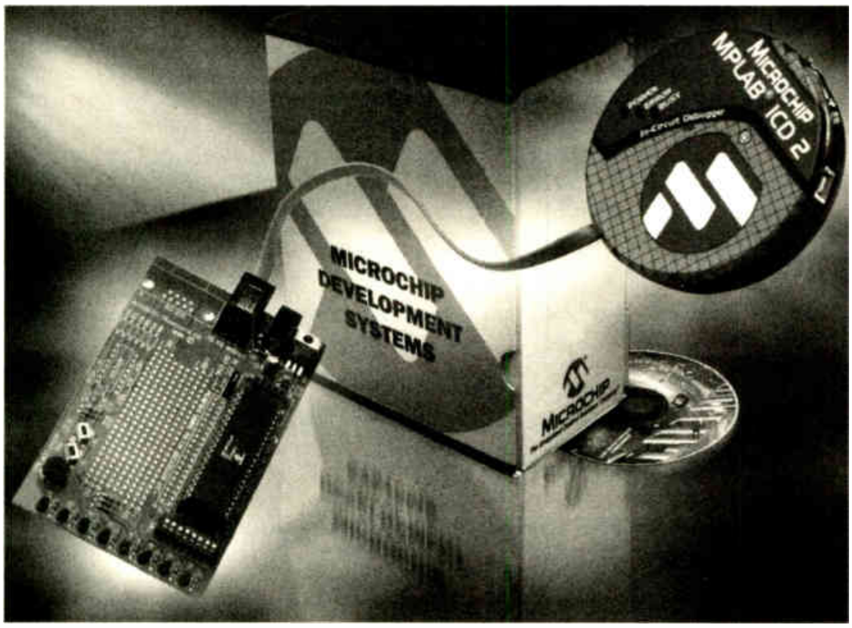
Other groups are also investigating similar technologies. For example, Bell Labs have produced a solar cell that is based around pentacene, an organic semiconductor. Reports indicate that this achieved efficiency levels of around 4%, but they still need to investigate many aspects such as the effect of ultraviolet light on the organic semiconductor.

These new developments often take ten to fifteen years to be completed but reports indicate that the new solar cells could be available in five years or so.

# News . . .

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

## PICS BREAK 1MB BARRIER.




MICROCHIP'S new Flash microcontrollers are the first the break the one megabit memory barrier. The PIC18F6620, PIC18F8620, PIC18F6720 and PIC18F8720 offer field programmability, larger memory, a higher pin count and the most feature-rich peripheral set that Microchip has produced so far.

Programming times allow a 1-megabit array to be fully erased and programmed in under two seconds. The '620s feature 64K bytes of Flash memory, while the '720s have 128K bytes (1Mbit). The '8620 and '8720 also have a linear address capability of 2Mbytes.

Microchip has also released a low-cost, in-circuit debugger and programmer. The PC-based MPLAB ICD 2 supports the PIC16F and PIC18F devices. As new devices become available, users will be able to download new software into MPLAB ICD 2, at no cost, creating a highly adaptable tool.

MPLAB ICD2 is available as a stand-alone unit or as an evaluation kit that includes a demonstration board and samples of the '18F452 and '16F877. The board features a 2 x 16 l.c.d., temperature sensor, EEPROM memory, l.e.d.s, piezo sounder and RS232 interface.

For more information browse **www.microchip.com**.

## FARNELL COMBATS OBSOLESCENCE

COMPONENT distributors Farnell have launched Product Watch, an "obsolescence service", which gives customers advance notice of when components are about to become obsolete, and of any end-of-line and end-of-stock items.

It sounds an excellent innovation. Few of us can claim to have never been afflicted by designing a circuit whose components become obsolete or no longer attainable on the day the design is completed!

For more information email Farnell at **productwatch@farnell.com**.

## WCN SUPPLIES CAT

THE 32-page catalogue from WCN Supplies is another that enterprising hobbyists should have in their library. Component categories run from audio, batteries, cables, chargers and connectors, through the alphabet via models (including some delightful ones from Humbro), motors, passive components (resistors, etc), power supplies, relays, semiconductors, and right on to Zircon drill sets.

For more information contact WCN Supplies, Dept EPE, The Old Grain Store, Rear of 62 Rumbridge Street, Totton, Southampton SO40 9DS.

Tel/Fax: 023 8066 0700.

Email: info@wcnsupplies.fsnet.co.uk.

## EPSON RADIO FAIR

SUNDAY 16 June 2002, is the date for *Epsom Radio and Electronics Fair*, at Epson Downs Racecourse Grandstand, 10am to 5pm. The organisers, Radio Fairs, tell us that it had been perceived that there was a need for a major radio rally to be staged south of the Thames in the North Surrey area, ostensibly to replace the Sandown Rally which is no longer held due to commercial restrictions.

The Epsom fair is a one day event and will consist of private and trade stalls with added attractions throughout the day. Epsom Downs is considered to be an excellent venue as it is easy to get to from any direction.

A car boot sale and a bring and buy sale will be incorporated into the rally. Ken Macintosh and his band will provide entertainment during the day. As an added attraction to the event, morse testing facilities will be available. It is hoped that Dr Bob Whelan, president of the RSGB, will open this new style event. Refreshments and light meals are available. Car parking is free.

Free admission tickets will be made available to schools and colleges in the south east, to encourage new people to come into the hobby. Normal entry is £3, although concessions for wheelchair disabled and children will be priced at £2.50.

For more information contact Brian Cannon G8DIU, 38 Sandringham Road, Worcester Park, Surrey KT4 8UJ. Tel: 020 833 0092 (10am-6pm Mon-Fri).

Fax: 01737 279108 (24 hours).

Email: Brian.Cannon@btinternet.com.

## MAPLIN'S C3 CAT

MAPLIN Electronics have introduced a mini-variant of their large paper-based catalogue. It is free and is described as being their new specialist catalogue focusing on their most popular lines from the world of components, cables and connectors. The C3 is said to contain all the essential items for your hobbyist projects or commercial applications.

David O'Reilly, Maplin's Marketing Director, says "I would like to draw your attention to a number of new features: firstly the extended price breaks for volume enquires . . . plus the launch of our new information centre which will help you with some key technical principles and calculations for your specific application".

For more information contact Maplin Electronics through any one their nationwide stores, or telephone 0870 264 6000. Fax: 0870 264 6001.

Email: customerservice@maplin.co.uk.

Web: www.maplin.co.uk.

# R.F. SOLUTIONS


RADIO communications modules in various forms are at the heart of the product range for R.F. Solutions Ltd. Their latest catalogue consists of 70 A4-size pages in a ring-binder, and details a broad selection of remote control systems, including Microchip's Keeloq encoders and decoders, radio telemetry systems, pager control, r.f. modems, and radio modules principally based on the standard frequencies of 315/433MHz, although modules operating at other frequencies are available.

Amongst the other products offered are Microchip PIC emulator tools, compilers and programmers, an r.f. pocket meter and radio evaluation boards. There is also a 150-page book entitled *An Introduction to Low Power Radio*, which is aimed at the practical engineer and concentrates on discussing theoretical radio matters in an easy to understand manner.

It is interesting to note that R.F. Solutions has complimented its range of PIC emulation products with the introduction of a compact low-cost programmer. The MEL-EPICA enables quick and easy programming of 8-pin and 18-pin mid-range PIC devices. It runs within Win95/98/NT or DOS and is able to integrate with MPLAB. There is also a C compiler for "quick and easy coding" of PICs.

For more information, contact R.F. Solutions Ltd., Unit 21, Cliffe Industrial Estate, South Street, Lewes, E.Sussex BN8 6JL. Tel: 01273 488880. Fax: 01273 480661. Email: sales@rfsolutions.co.uk. Web: www.rfsolutions.co.uk.

## BUBBLE-TIME

**By Barry Fox**

CALTECH, the Californian Institute of Technology, is patenting a new, eye-catching method of billboard advertising, using bubbles (W0 01/35379) which is sure to set constructors thinking.

The system can be scaled down to display time on a domestic clock. A container, like a very thin fish tank, is filled with transparent viscous liquid. On the rear side of the tank, a matrix of piezoelectric pump holes release globs of coloured liquid with slightly different viscosity. As the globs escape they float slowly up or down, like bubbles.

The pump holes are in groups, like the light sources of a digital display, to create alphanumeric characters or graphics. Caltec says the system works well with coloured detergents. Experimenters will doubtless come up with their own variations on the new theme.

## PLUG IN AND FLASHGO

**By Barry Fox**

THE computer industry uses five different miniature memory card formats for digital cameras, handheld computers, PDAs and MP3 players; Compact Flash, Smart Media, Multimedia Card, Secure Digital and Memory Stick, as well as IBM's tiny Microdrive hard disk. Users must use proprietary leads and software to connect each device to a PC. The law of cussedness ensures the right lead for the job is the one lead you have not got.

Imation – a spin-off from 3M – is now selling a reader with a single slot and matrix of contacts that mates with any known card. The reader connects to a PC by single USB lead and all-purpose control software. FlashGo costs around £60. If more formats emerge, Imation will sell matching adaptors that plug into the reader slot.

## Music On Time

**By Barry Fox**

RECORD companies want radio and club DJs to have new releases ready to play on official release day. But if records go out in advance, some DJs break the embargo. So Warner Music in the US has patented a system for enforcing the embargo electronically (W0 01/15428). A batch of music CDs for DJs will be encrypted so they play back only on a modified player.

The encryption is time-coded and the key tied to the official release date. To stop DJs cheating by advancing the player clock, the time code comes from GPS satellites. So everyone in the world gets to play their records for the first time, at the same time.

## National Vintage Communications Fair

THE *National Vintage Communications Fair* will be held at N.E.C. Birmingham on Sunday 5 May 2002. It is the Tenth Anniversary Special and doors open from 10.30am to 4.00pm at an entry price of £5. Do come and have a chat with our sister publication *Radio Bygones* on their stand!

All visitors will receive a free copy of the *Sound & Vision Yearbook's Collector's Guide*. This useful directory is really "the book of the show" but contains information that will be useful long after the show has closed.

For more information contact N.V.C.F., 13 Belmont Road, Exeter, Devon EX1 2HF. Tel: 01392 411565.

Email: sun.press@btinternet.com.

Web: www.anglefire.com/tx/sunpress/index.html.

## Mainline's Cats

THE latest Jackson Brothers catalogue of variable capacitors and drives has been received from Mainline Electronics. These 30 pages will be a highly useful source of information when looking for that vital radio component. Prices are quoted as a separate 4-page supplement.

Also received is Mainline's "Flyer", a 32-page catalogue of over 850 new products on offer. They say they have bought over 250 pallets of new surplus stock and have "many very unusual items, plus the usual freebies". The components are varied too categorise here, so get a copy of the two cats!

Contact Mainline Electronics, Dept EPE, Unit 1A Cutters Close, Coventry Road, Narborough, Leicester LE19 2FZ. Tel: 0116 286 5373. Fax: 0116 286 7797. Email: surplus@mainlinegroup.co.uk.

## Smaller DVD Cassettes

**By Barry Fox**

SONY thinks the world needs a new video format. At the IFA electronics show in Berlin, Sony unveiled MicroMV, a tape cassette 70 per cent smaller than existing Mini DV digital video cassettes. The tape runs for an hour and the cassette has 64KB of onboard solid state memory that automatically indexes every shot and tells what is on a tape by instantly displaying still images taken from the start of the shots.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Constructional Project

# PIC BIG DIGIT DISPLAY



## JOHN BECKER


*Microcontrolling giant 7-segment displays*

RECENTLY Dave Fisher of Display Electronics told *EPE* that he had acquired several thousand electro-mechanical "big digits". These had previously graced the platforms of British Rail as 6-digit 7-segment clocks. Yes, they were the familiar "*click... click...*" digits that surely any would-be passenger has watched mesmerised while waiting for that (*where IS it?*) train to arrive.

In the course of conversation, the question of *EPE* designing a suitable electronic interface for these digits came up. Would Tech Ed be interested? *Certainly*, was the author's timely response to a novel design idea.

### DISPLAY RESULTS

The resulting basic design is capable of driving from one to eight digits, with expansion up to 64 digits possible, as discussed later. They can be controlled via a standard 4 × 4 data entry keypad, or via a PC-compatible computer running under MS-DOS or Win95/98/ME.

A PIC16F84 microcontroller is the controlling device between the PC or keypad and the multiplexed digits. The PC software is written in QBasic/QuickBASIC but can be run as a standalone program without the need for QB to be installed.

The digits are ideal for use in any situation that requires a large electronically controlled display where the data is to be input intermittently. Applications that come to mind are sporting scoreboards, ticket draw results, display of outdoor temperature in public arenas – well, you've seen where large digits can be used, think up your own applications!

### MONSTERS

Since the digits were only large versions of 7-segment displays, reasoned the author before starting the design, they could be simply driven by a PIC through a minimal bit of multiplexing. No problem – or so it seemed until two arrived!

The digits are monsters in several senses. Overall, they measure 12in high, 9in wide and 2·25in deep (30·5cm × 23cm × 5·5cm). The angled display area is effectively 10in high × 7in wide (25·5 × 18cm) and comprises seven bright-yellow hinged segments.

In the absence of fully informative data, the first task was to establish some criteria about controlling the display segments. Basically all that was known from a rudimentary data sheet was that a pulse of 12V d.c. for about 0·25secs was required to turn segments on and off, and that the pinouts of a built-in connector were shown. There was no mention of the current required, although there was a warning not to connect d.c. to the segments for long periods otherwise damage/heating will occur.

The original manufacturer's name was printed on the rear of the digits, Bodet,

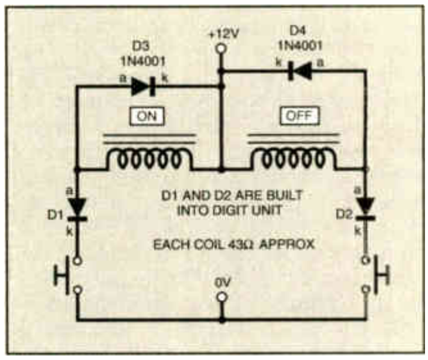



*Fig.1. Basic circuit for controlling one segment.*

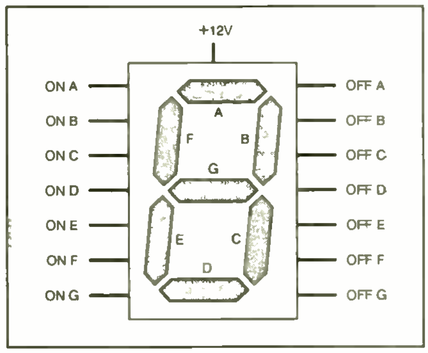



*Fig.2. Each digit has 15 connections, 12V power input and two on-off controls for each segment.*

along with the message Made in France. Doing a **www.google.com** search revealed the company at **www.bodet.com**, but no electronic specifications could be located, other than a schematic for one segment (see Fig.1 and Fig.2). An email to Bodet for data produced no response. Time for experiments!

Briefly connecting an ammeter between a segment and a 12V power supply revealed the current required to activate the mechanical flap – around 280mA. What?! Surely not? An ohms check across the various controlling coils showed a typical d.c. resistance of 43Ω. Wow, yes indeed, that unscientific test had shown a current figure in the right ball-park!

Furthermore, there were seven segments to be controlled – about 2A per digit, and users would probably need several digits. More used to dealing with liquid crystal displays needing only a handful of milliamps, rather than two thousand milliamps, the

author recognised that the digits were more than just monsters in size.

## RESEARCHING DESIGN

Having numerous data books and CD-ROMs is always to be recommended. These days, so is Internet access. Using a mixture of sources, a couple of evenings were spent researching the type of semiconductors that were available to handle such currents in a multiplexed situation. It was a foregone conclusion that they needed to be capable of being PIC-controlled.

Any idea of using any form of discrete transistor, power-FET or otherwise, was rejected. Such techniques were fine years ago, but hardly today's technology when multiplexing – even less so regarding any suggestion of relay control. No, it had to be semiconductors in integrated circuit form.

Anyone familiar with controlling 4-digit 7-segment light emitting diode displays will know that they can easily be controlled by multiplexed signals – a common 7-line "bus" feeding identically to all segments of all digits, and then separate power supply lines, each feeding to its own digit. The technique required then is to send out segment control data along the common bus, and to only turn on digit power lines individually at the appropriate moment.

However, data sheet browsing suggested that switching seven segments simultaneously at a total of 2A or so could present a significant problem. Perhaps switching segments individually at about 280mA would be more sensible?

There are many chips that can provide 1-of-8 output selection in response to a 3-bit control code. Such chips include the 74HC138, whose outputs are normally high, but go low individually when selected by the appropriate control code. The 74HC237 operates with the opposite output logic, normally low but going high when selected.

Although the outputs of these devices cannot handle the sinking or sourcing of 280mA, or a voltage of 12V, they are capable of driving intermediate high-current buffers. The question then became one of which buffers were available?

## LINE DRIVER

After considerable research, it was decided to use the 7-stage line driver type ULN2004A to activate the segments. It can sink 500mA per stage, and is capable of handling voltages up to 50V.

This device also has the benefit of having built-in diodes across each output which inhibit back-e.m.f. generation when switching inductive loads, such as the segment coils (see Fig.3).

It is a bipolar-fabricated Darlington device that requires a positive voltage at each input to turn on the respective open-collector output. Conveniently, each input has its own 10·5kΩ series resistor, removing the need for external resistors (such as required in the control line feeding into the base of a "normal" discrete transistor). The inputs are also diode-protected.

Using a 74HC237 multiplexer, the seven segments can readily be controlled directly through the ULN2004A driver.

## COMMON ANODE

That took care of current sinking through the segments. The problem then became that of providing multiplexed power to each digit. If you relate the concept to a common-anode 7-segment l.e.d. matrix, the individual segment cathodes had now been catered for – it was the common-anode current control that was now required. In other words, a current *source* was needed, at a minimum of 280mA.

It had been expected that as multiple high-current sinking paths were available in one i.c., as with the ULN2004A, so multiple high current sourcing devices would be equally common.

It was found that there were many options available if a source current of no more than 100mA were required, especially as the current would be pulsed intermittently. However, the requirement for at least 280mA presented a seemingly unsolvable problem, unless discrete transistors were used – which the author was determined not to resort to. Quite simply, no *ideal* i.c. devices could be found.

Briefly, power op.amps such as the L272 dual device seemed a possible solution, but that was not deemed "tidy"! Eventually, it was decided to accept a less-than-optimum option, to use an L293DN quadruple Half-H driver.

This has four devices that can each be set to sink or source a current of up to 1A at a voltage from 4·5V to 36V. It also has two enable inputs which allow pairs of drivers to have their outputs placed into a high-impedance state (see Fig.4). Additionally, it too has in-built diode protection.

The device is intended for reversible motor and solenoid control. The term Half-H refers to the bridge configuration in which the pairs of drivers can be operated. It seemed suitable for this application since no other appropriate device format could be found. Consequently, two L293DN devices are used in the main circuit, each providing power for four multiplexed digits. They are under combined control of another 74HC237 1-of-8 controller.

The L293DN, however, has the unfortunate side effect of consuming around 20mA even when the outputs are in a high impedance state. The "enable" inputs do not place the device into a quiescent state in high-impedance mode, unlike many logic devices that you may be familiar with. Regrettably, it is not cheap.

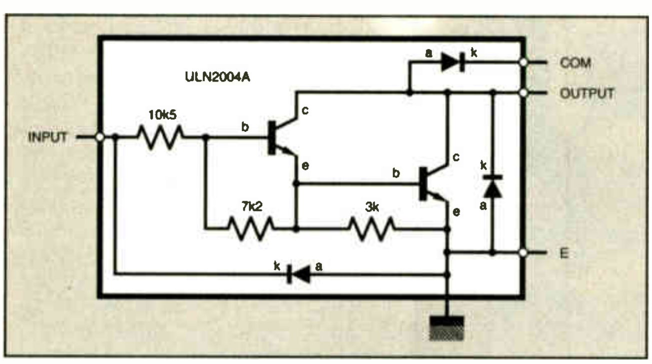



Fig.3. Schematic of one stage within a ULN 2004A 7-stage line driver.

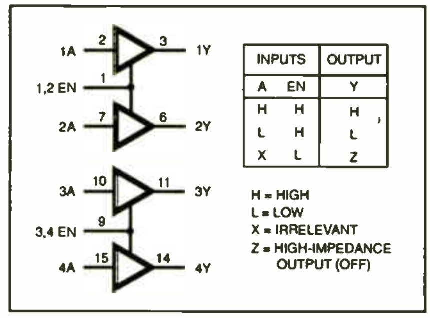



Fig.4. L293DN pinouts and logic table.

***Do not*** use any other type of L293 device. The L293DN (note the DN suffix), is a 16-pin device with diode protection. Other L293 device types may not have the same characteristics (the L293E, for instance, has 20 pins and cannot be used).

## MULTIPLEX CIRCUIT

A simplified block diagram of the control requirement is shown in Fig.5.

The circuit diagram showing the multiplexing and digit drive devices is given in Fig.6. Control data originates from a PIC16F84 microcontroller (discussed presently in relation to Fig.7). Through multiplexer IC1, 3-bit control data selects which digit is to be powered via source drivers IC2 or IC3.

As shown in Fig.6, and designed on the printed circuit board to be described later, eight digits (one "bank") can be controlled by these two drivers. Additional digit source drivers can be added separately if required (on stripboard for example, although no constructional details on this are offered).

If fewer that five digits are to be controlled, IC3 can be omitted.

The eight outputs of IC1 are common *to all* digit drivers, and IC1 does not need to be repeated if additional banks of drivers are added.

The software allows two additional banks of eight digits (a total of 24 digits) to be controlled without modification to the program. Readers who are familiar with PIC and QB programming could modify the software to cope with multiplexing up to 64 digits if an additional 74HC237 multiplexer is used (see later).

Segment selection is provided by a 3-bit code fed to multiplexers IC4 and IC5. These in turn control segment sink drivers IC6 and IC7, respectively. Only seven outputs of these multiplexers are used.

The two multiplexers are under "chip select" (CS) control by separate CS1 lines (pins 6), so that segment On or Off control is achieved not only in respect of the 3-bit code, but also in terms of current-sinking pulse duration (more later).

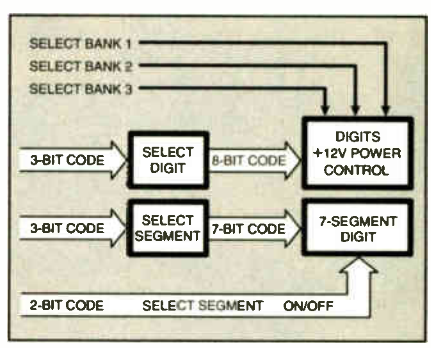



Fig.5. Multiplexed control logic.

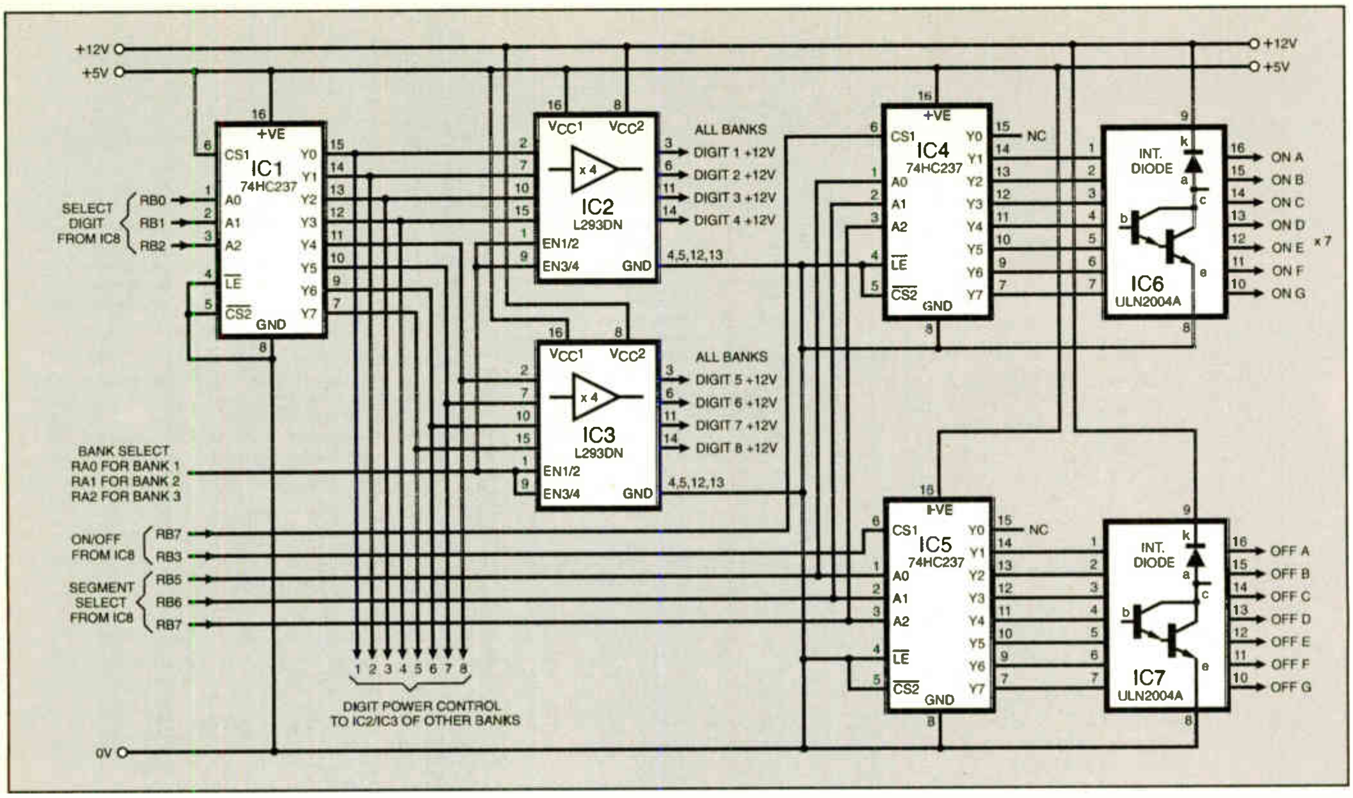



*Fig.6. Circuit diagram for the multiplexed control of the digits, basically for eight, but can be modified to control 64 digits.*

## MICROCONTROLLER

Because of the multiplexing arrangement, a PIC16F84 microcontroller is readily suitable for this design, see Fig.7. It is capable of being user-controlled either via a 16-key (4 × 4) data entry keypad, or via a PC-compatible computer, running under MS-DOS or Win95/98/ME.

The PIC is run at 4MHz, as set by crystal X1. Port pins RB0 to RB2 control digit selection via IC1 (Fig.6), pins RB4 to RB6 control segment selection via IC4 and IC5, RB7 controls selection of IC4 (segment On control), and RB3 controls selection of IC5 (segment Off control).

Port pins RA0 to RA2 perform "bank" selection. As shown, they can control up to three banks of eight digits. If they are used to control another 74HC237 1-of-8 multiplexer, however, they could control eight banks (with suitable software modification).

Port B pins are also used for inputting data from a 16-key keypad, *or* from a PC. Note that it is unwise to connect a keypad and PC simultaneously since one might adversely affect the other. The PIC itself is protected against its Port B pins being undesirably affected by external PC/keypad control by the inclusion of buffer resistors R1 to R8.

Pins RA3 and RB7 are used by the software to achieve "handshaking" with the PC when the unit is under computer control.

Pin RA4 is used in a manner possibly not seen by readers before. It is used in oscillatory mode under software control and at a rate set by preset VR1 and capacitor C5. It allows the segment control pulse width to be varied. The controlling software routine will be discussed towards the end of this article.

As usual with the author's PIC designs, on-board programming can be performed via a 4-pin connection (TB1). Adverse effects on the +5V power line are prevented during programming control by the inclusion of resistor R9 and diode D1.

## POWER SUPPLY

Power for the digits needs to be 12V d.c. This may be provided from any source capable of supplying at least 500mA (to provide "headroom" when a segment is activated). It does not need to be stabilised. A 12V car battery is suitable.

The prototype was found to operate with a supply voltage as low as 9V (with resultant reduction in current consumption).

Whilst the 13·5V (or so) of a fully charged battery seems acceptable, it would appear to be unwise to allow the supply to significantly exceed this voltage. The voltage, current and pulse duration limits for the digits are not known since Bodet did not respond to the author's request for information.

The digital control i.c.s require to be powered at +5V d.c. (which *must not* be exceeded). This is provided from the 12V line via regulator IC9, which can supply up to 100mA of sustained current. Be aware, though, that on the prototype it was

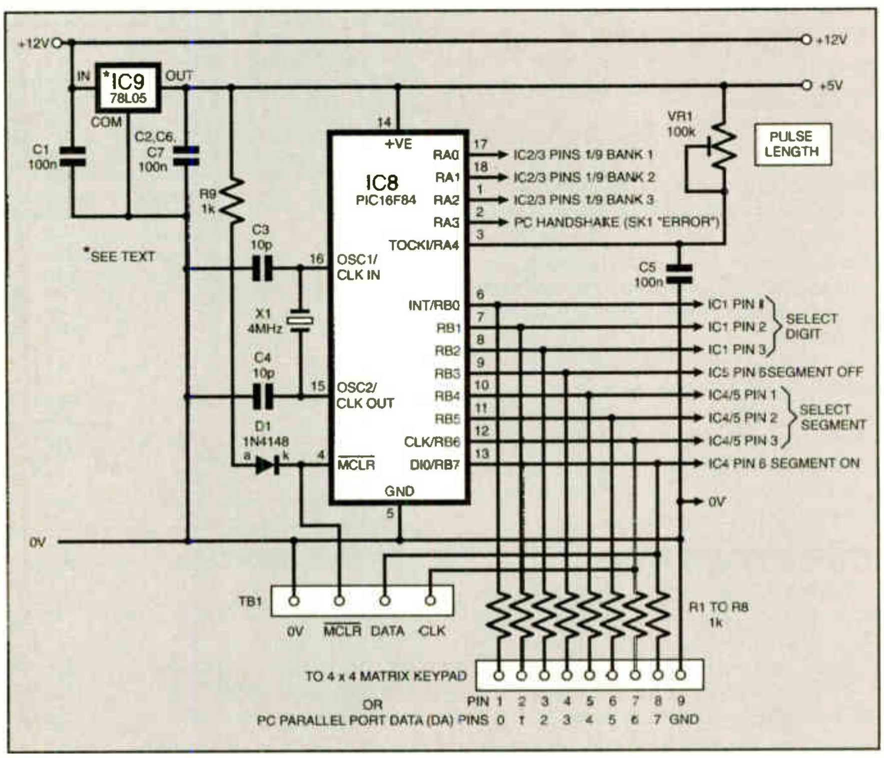



*Fig.7. Circuit diagram showing the PIC16F84 control connections, plus power supply.*

# COMPONENTS

**Resistors**
R1 to R9 1k (9 off)
All 0·25W 5% carbon film

**Potentiometer**
VR1 100k min. preset, round

**See SHOP TALK page**

**Capacitors**
C1, C2, C5 to C7 100n ceramic, 0·2in pitch (5 off)
C3, C4 10p ceramic, 0·2in pitch (2 off)

**Semiconductors**
IC1, IC4, IC5 74HC237 1-to-8 multiplexer (see text) (3 off)
IC2, IC3 L293DN 16-pin Half-H driver (see text) (2 off)
IC6, IC7 ULN2004A 7-way Darlington line driver (see text) (2 off)
IC8 PIC16F84 microcontroller, preprogrammed (see text)
IC9 78L05 +5V 100mA (or 7805 +5V 1A) regulator (see text)

**Miscellaneous**
X1 4MHz crystal

Printed circuit board, available from the *EPE PCB Service*, code 341; RW44 10-inch 7-segment electromechanical display (big digit), quantity to suit (see text); 4 × 4 data entry keypad (optional – see text); stranded colour-coded connecting wire (individual wires or ribbon cable); 12V d.c. power source, min. 500mA output; 1mm terminal pins or pin headers; 16-pin d.i.l. socket (7 off, see text); 18-pin d.i.l. socket; printer port connectors to suit (optional – see text); solder, etc.

*Approx. Cost Guidance Only* **£20** *excluding hardware*

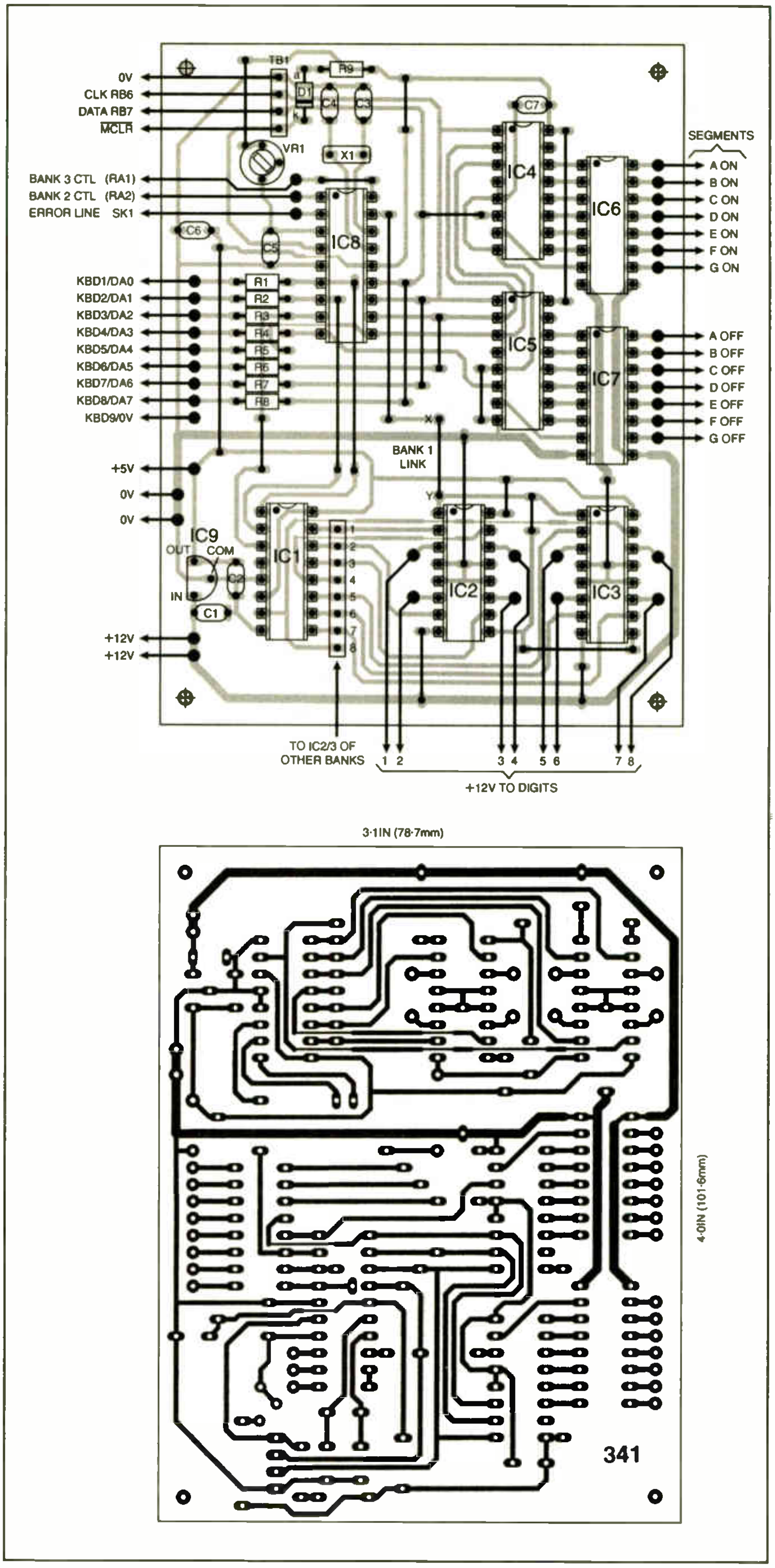



*Fig.8. Component layout and full-size underside copper foil master track pattern.*

required to constantly provide around 40mA (due to the two L293DN devices). It is thus likely to get a bit warm, especially if the source power is 12V or greater.

If it is found to shut down through excessive heat (it is thermally regulated), change it to a standard 7805 +5V 1A device. It is perhaps prudent to switch off power during long periods of digit inactivity.

Note that the digits themselves only consume power during the brief pulse that changes their segment display position.

Capacitors C1, C2, C6 and C7 help to maintain powerline stability.

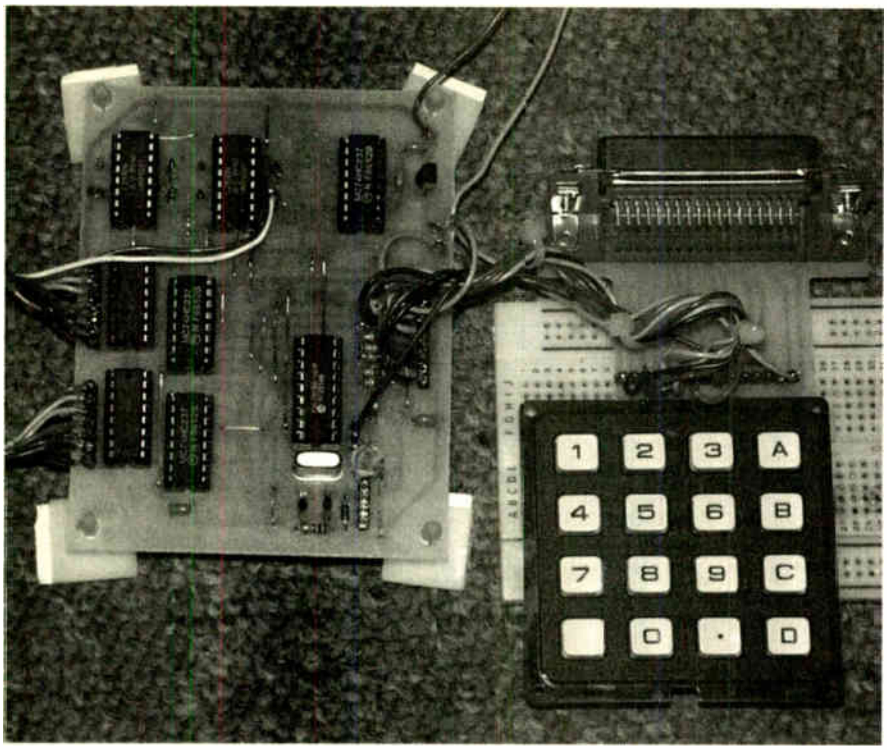
## CONSTRUCTION

Printed circuit board component and track layout details are shown in Fig.8. This board is available from the *EPE PCB Service*, code 341.

Assemble in order of link wires first, including the one marked "Bank 1 Link" – this will be discussed under "Expansion". Note that some links go under the i.c. positions. Follow with the d.i.l. (dual-in-line) i.c. sockets and then continue in any convenient order. Insert 1mm terminal pins at the external connection points, but omit those alongside IC1 which are only needed if more than eight digits are to be controlled.

There are two choices of data input, as said earlier. They are connected to the board at the pins to the left of resistors R1 to R8.

If using the data entry keypad, connect its pins, as shown in Fig.9, to the similarly numbered points on the board. Keyboard




*Prototype display controller board during development testing using a plug-in breadboard to temporarily connect a data keypad and a PC via a Centronics connector (mounted on the p.c.b. used with* Teach-In 2000 Part 4 *– Feb '00).*

pin 9 is a ground (0V) connection for the pad's frame.

If using a PC as the data source, it needs to be connected from its parallel printer port to the board. The easiest way is to use a standard printer cable with pre-attached connectors. The "printer end" of the cable has a 36-way male D-type Centronics connector which requires a matching female type at the unit end. The latter should be hardwired to the board at the designated points using short lengths of insulated stranded wire. The pinouts for a right-angled female connector are shown in Fig.10.

Alternatively, the unit can be hardwired to a separate 25-way D-type male connector plugged into the back of the computer – 10-way ribbon cable would be ideal. The connector's pinouts are shown in Fig.11. Note that the "Error" line connects to the board pin situated near IC8. ("Error" is the name given in respect of that line's normal purpose when interfaced to a printer.)

Before inserting the d.i.l. i.c.s, do a thorough examination of the board for faulty assembly and soldering. Then only insert them after you have established that regulator IC9 is correctly supplying +5V at its output. Check this again once the i.c.s have been inserted.

Be aware that they are CMOS devices and require the normal handling precautions, discharging static electricity from your body by touching the bare metal of something earthed before handling them.

Adjust preset VR1 to a fully-clockwise setting (maximum pulse length) before testing the system.

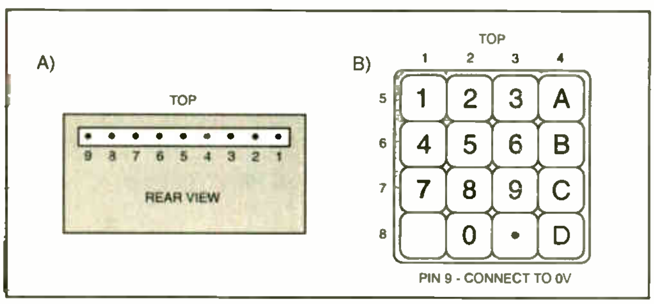



*Fig.9. Keypad connection details.*

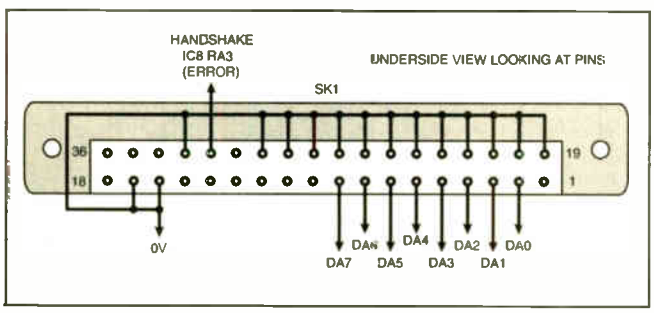



*Fig.10. Connections to a 36-way D-type Centronics female connector used in conjunction with a standard PC parallel port cable.*

| PIN | FUNCTION |
|---|---|
| 1 | NC |
| 2 | NC |
| 3 | D OFF |
| 4 | D ON |
| 5 | E OFF |
| 6 | C ON |
| 7 | E ON |
| 8 | C OFF |
| 9 | F OFF |
| 10 | B ON |
| 11 | F ON |
| 12 | B OFF |
| 13 | G ON |
| 14 | A ON |
| 15 | G OFF |
| 16 | A OFF |

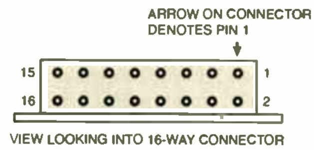



*Fig.12. Pinouts for the connector mounted as part of the digit assembly.*

## DIGIT WIRING

*Monstrous* is again a term that can be used in respect of the digit connection requirements. The digits need to be wired in parallel back to the control board. However, although the manufacturers have provided a *single* connector on each digit, this only allows for one set of the 15 connection wires needed.

One would have expected two connectors, one for the cable harness arriving from the control board, another for the harness that then has to be connected serially to the next digit.

The author offers no recommendations about using the digit's own connector, although for the sake of good order, its pinouts are shown in Fig.12.

It was decided that it was easier to hardwire the connections to solder pads at various positions on the back of the digits. They are the pads to which the manufacturer's rectifier diodes (mounted inside the digit box) are soldered. The correct connection points were found experimentally and are shown in Fig.13. Ignore the unused pads.

Whereas the 14 segment wires of each harness are connected in parallel to each digit, each digit needs its own separate +12V power supply wire, originating from the control unit p.c.b. as shown in Fig.8. Make the +12V connections in numerical order in relation to the digit positions in the proposed display.

Before you fully interwire the digits, though, it is recommended that you just wire-up for the first one and check out the system.

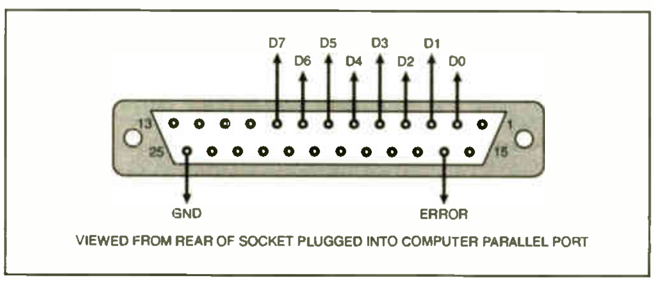



*Fig.11. Alternative connections via a 25-way male D-type connector.*

## KEYPAD OPERATION

The software has been written so that on power being switched on the PIC sets its Port B for input with the input pull-up resistors active. A check is then made to see if the inputs are connected to any source that pulls them low.

Under keypad control (with no keys pressed) there is nothing to pull the pins low and so the PIC assumes that a keypad is the data entry source.

Having established that fact, the software goes into a perpetual loop scanning the keypad for keypresses. The software routine used is a variant of that described in the author's *Using PICs with Keypads* of Jan '01.

In response to any keypresses, look-up tables are used to relate that input value to the data to be sent to the digits. The first table (VALUE) allocates the keypress data to a numerical value between 0 and 15. Another table (TABLE) then relates that value to a binary sequence in respect of the digit segments to be turned on.

The sequence is in the right-to-left order (bit 0 to bit 7) of segment *A* to segment *G*. For example, binary 01111111 turns on all segments, resulting in the 7-segment display of numeral 8. Binary 00000110, on the other hand, only turns on segments *B* and *C*, resulting in numeral 1 being displayed. The full table is shown in Listing 1.

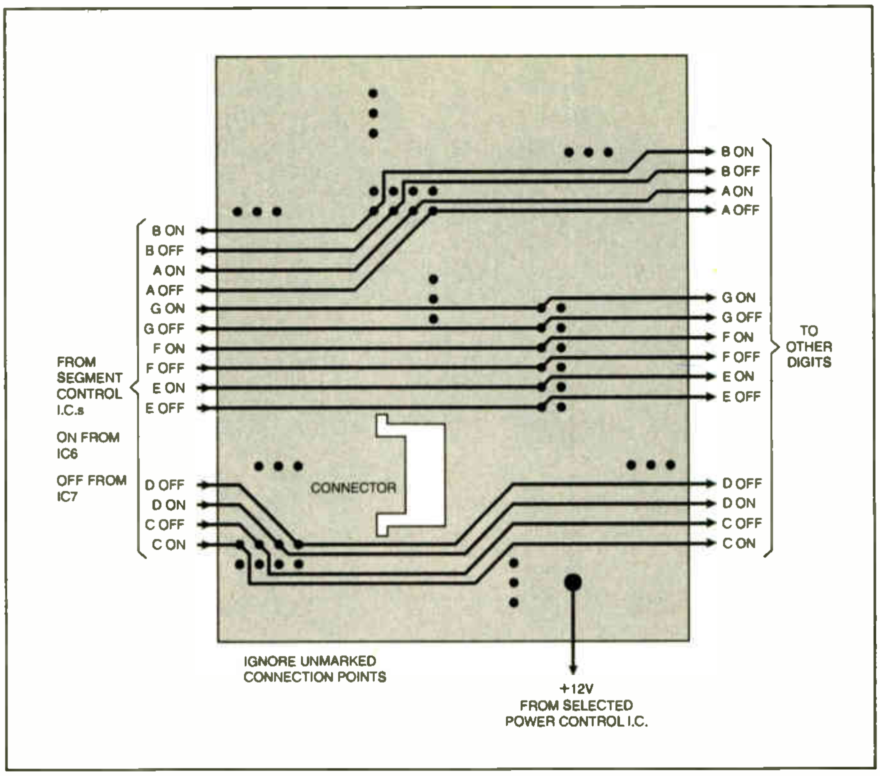
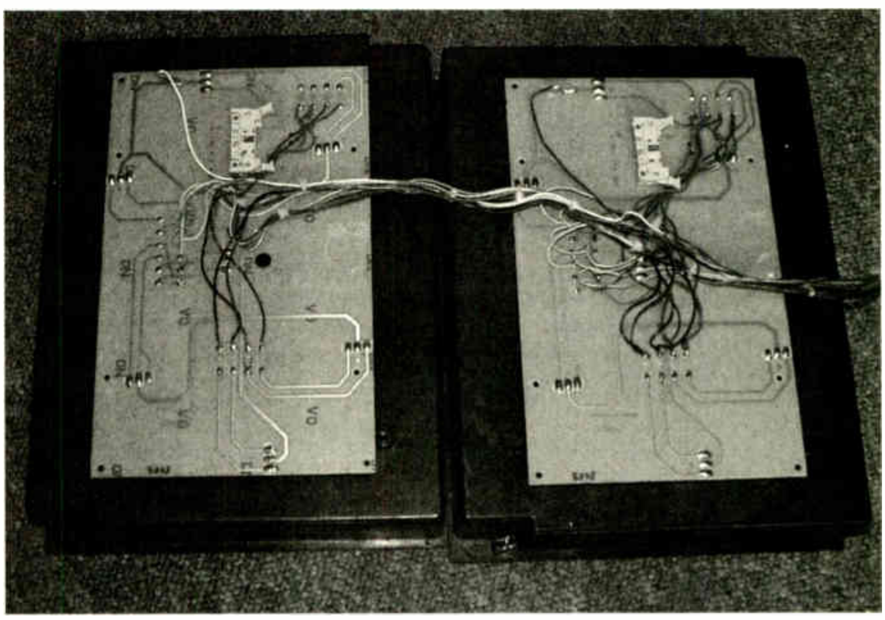



*Fig.13. Wiring details for a single digit.*



*Interwiring between the two digits used during development.*

### LISTING 1

```
TABLE:
    addwf PCL,F
    retlw %00111111     ; 0
    retlw %00000110     ; 1
    retlw %01011011     ; 2
    retlw %01001111     ; 3
    retlw %01100110     ; 4
    retlw %01101101     ; 5
    retlw %01111101     ; 6
    retlw %00000111     ; 7
    retlw %01111111     ; 8
    retlw %01100111     ; 9
    retlw %01110111     ; 10 A
    retlw %01111100     ; 11 b
    retlw %00111001     ; 12 C
    retlw %01011110     ; 13 d
    retlw %10000000     ; 14 blank
    retlw %01000000     ; 15 -
            GFEDCBA
```

Note that bit 7 in the 14th jump is set at 1. This prevents the PIC from returning a zero value from this location, which would otherwise be recognised as "no data entered from keypad".

Whilst it is suggested that decimal display values from 0 to 9 are retained, other segment arrangements could be provided for the other six positions by readers having their own PIC assembly-programming facilities, such as the author's *Toolkit Mk3/TK3* (Oct/Nov '01).

It is also worth recognising that 7-segment displays cannot in many instances be used to represent alphabet characters. For example, capital letter *A* can be represented, but lower case *a* cannot. Conversely, *b* can be, but *B* cannot (it would just look like an *8*).

Also note that any letters having diagonals cannot be represented, such as *K, M, N, Z*, nor can *T*. It is worth experimenting to see what characters can be represented, and what compromises you might have to make. You may recall that the author's *Teach-In 2000* series demonstration software illustrated the principle of 7-segment control.

Having established the segment code required, the PIC then has to send the corresponding data to the segments individually. From within a loop, the PIC reads each data bit position to see whether a segment should be On or Off. At each position it uses another look-up table (TABLE2 – see Listing 2) for the code needed to send to multiplexers IC4 and IC5 in order to control that bit.

The code also takes into account that the p.c.b. tracks are connected to the three control pins in the opposite order than might normally be expected (this was done for p.c.b. design simplicity). Only bits 6 to 4 are of importance in this table.

### LISTING 2

```
TABLE2:
        addwf PCL,F
        retlw %01000000   ; a
        retlw %00100000   ; b
        retlw %01100000   ; c
        retlw %00010000   ; d
        retlw %01010000   ; e
        retlw %00110000   ; f
        retlw %01110000   ; g
        retlw %00000000   ; -
```

The code is output on the 3-line common bus feeding to IC4 and IC5. Which of these i.c.s is activated depends on whether the segment needs to be turned on or turned off. To turn on IC4 (segment On), bit 7 in the code is set high. If IC5 is required (segment Off) bit 3 is set high.

It is also necessary to specify which of the digits is the target for the segment information. This data is set into the code's bits 0 to 2, representing the number (1 to 8) of the digit in the allocated bank, and destined for IC1 (see Fig.6).

## DIGIT SELECTION VIA KEYPAD

Because the digits might be located away from the controlling keypad, and not be visible to the user, it was decided to allocate two keypad keys as digit stepping controls. At switch-on digit 1 is the default target, and any numeric data keyed in continues to be routed to it.

To choose Digit 2 instead, press keypad "D" (*D*igit step). This changes the control code fed to IC1, incrementing it from binary 000 to binary 001, so selecting digit 2. Display data is now repeatedly fed to this digit. Pressing "D" repeatedly steps through each digit position in turn, irrespective of whether the digit physically exists in the system.

To return to Digit 1 at any time press "C" (*C*lear back to start). It is not possible to step back individually from digit to digit. This, though, is a facility for which PIC-wise users could write a software routine. In this case it is suggested that key "B" is intercepted (*B*ackwards) in a similar way to which letters "C" and "D" are intercepted.

Each time the digit number is stepped forward, the software increments a 24-value counter (rolling over to 1 again following 24). This not only provides information on which digit is selected (from 1 to 8), but also on which Bank it is in (Bank 0 to 2), using yet another look-up table. This results in Port A pins RA0, RA1 or RA2 being selected as appropriate (in Bank order).

Referring back to Fig.6 again, it will be seen that IC2 and IC3 are shown to be under selection control by pin RA0. If additional IC2 and IC3 devices are used they would be allocated to one of the other Port A pins, RA1 or RA2, in that order of Bank.

In this way, 24 digits can be stepped through by pressing key "D" the required number of times. Yes, it tests the user's counting ability, but seemed the best solution considering the limited number of keys available.

The provision of monitoring via an alphanumeric liquid crystal display was considered, but was rejected on the grounds of adding complexity to a moderately simple design.

PIC-knowledgeable readers could probably add l.c.d. facilities if needed. There are numerous examples of l.c.d. control in many of the published *EPE* PIC projects (especially in the author's designs). Such a routine could be integrated almost as a "library" file.

It is suggested that l.c.d. control is basically via Port B with the exception of the l.c.d. E line, which is better suited to control by the otherwise unused pin RA3 (it is only used when under PC control).

Line E cannot be satisfactorily controlled by Port B as all pins are in use for other purposes, which would cause undesirable l.c.d. response. It is only Line E that is critical in this context.

## COMPUTER CONTROL

When under computer control, data is fed to the PIC via the same connections as the keypad (but preferably in the keypad's absence). It is in a different coding format to that used with the keypad, however.

Because of the full range of keys on a PC keyboard, is it is possible to send a much greater variety of data to the digits. On recognition by the PIC that a PC is connected to it (see earlier), it goes into a different monitoring routine (COMPROG).

Synchronisation between the PIC and PC is maintained by using two handshake lines at the PIC end of the system, pins RA3 and RA7 as mentioned earlier. Port B pull-up resistors are turned off in this mode.

The first significant handshake action the PIC takes following switch on for PC mode, is to set pin RA3 high. This indicates to the PC that the PIC is ready to receive data. The PIC then sits in a holding loop until acknowledgement from the PC is received.

The PC software in its turn holds its printer port output DA7 low and waits for the RA3 = high signal to arrive via its printer port "Error" line. Having received this signal, however, it takes no immediate action, but waits for a keyboard key to be pressed.

Having received a keypress, the PC relates it to a lengthy look-up table that holds segment data in respect of keypresses. If segment data has been allocated to that key, it is output as seven bits (same relationship as with keypad data) plus bit 7 set high. It then remains in another holding loop until the "Error" line goes low.

The PIC, recognising that its RB7 pin has gone high, accepts the incoming 7-bits of RB0-RB6 data as valid. It immediately acknowledges this to the PC by setting line RA3 low.

The PC, having accepted this acknowledgement, is now free to wait for another keypress, but will not send it until the PIC signals that it is ready.

Between accepting bytes of data, the PIC sends the segment data serially to the selected digit in a similar fashion to that described earlier. On completion of each digit's output, the PIC again sets handshake line RA3 high, asking for more PC data.

## DIGIT COUNT SELECTION

The PC program has been written so that it can be set to the exact number of digits in use, unlike the keypad software which always expects 24 digits. It also provides the facility to select which printer port register address is used.

On running the program, the screen shown in Fig.14a will be displayed. The three possible printer port registers addresses are displayed at the top. It is necessary to select the one appropriate to your PC's configuration. Most likely it will be address 378 hex, but could be hex 278 or 3BC. Select the address by pressing 0, 1 or 2 (pressing any other key, including <ENTER>, always selects 0, i.e. address 378).

If you do not know which address your PC uses, try all three. The system will show you have the correct one when it proves that it can send data to the displays. (The PIC board must be free of assembly errors of course!)

Having selected the register, the screen changes to that in Fig.14b. Underneath the main title you are asked to enter the number of digits that you wish to be controlled, with a range of 1 to 24. Values outside this range are not accepted.

At the bottom of the screen are displayed the characters which can be sent for display via the 7-segment digits. With the exception of the control keys mentioned next, this represents the full range of keys that are functional. Any others will be ignored by the program (although you can add to the range as discussed later).

To either side of the screen are quoted the commands available when the program is in full control mode. The <ESC> (escape) key causes the program to restart from its beginning and may be used at any time. Pressing the <CTRL> and <BRK> keys simultaneously causes the program to end. This is the only way in which it can be halted and exited.

Otherwise, all keyboard characters shown in the bottom line are available for output to the digits. Acceptable keypresses are responded to immediately, and data is output to the digits in sequence, the PIC's digit count being incremented following receipt of each character. When the final digit in the sequence has been triggered, the count automatically recommences from Digit 1.

When entering data for output to the digits, pressing <ENTER> causes the PIC to reset the digit count back to Digit 1. Pressing the space bar causes the next digit to be cleared (no segments showing).

## PC FIRST, PIC SECOND

In the mid-screen area you are told that you should switch on the PIC unit "now". As said earlier, when the PIC program is first switched on, the PIC examines Port B to see whether its pins are high or low. If high, keypad control is assumed. On running the PC program, however, its first activity is to set its printer port lines low. On reading Port B being low, the PIC knows that PC control is required.


*Fig.14. Sections of Big Digit PC program setup screens, (a) printer port selection, (b) digit quantity selections.*


*Fig.15. Example of PC screen during digit control.*

Consequently, do not switch on the PIC unit until you see the screen now being discussed. When you have switched on the PIC, then enter the number of digits to be controlled and press <ENTER>.

The program then enters its full operational mode, first drawing on screen the same number of boxes as the number of digits specified. These boxes represent the 7-segment digits and display the same characters.

Next the program sends data for numeral 8 to all digits required. It then sends a reset command to the PIC, resetting it for Digit 1, after which it sends data to clear all required digits, again followed by a reset command.

This action has three functions, to synchronise the PIC with the computer's order of digits, to prime the PIC so that it knows which segments are in which state, and thirdly to clear any existing display data.

In the latter context it is worth recognising that the segments can be set by hand without damaging them. They are only balanced on light-duty pivots, freely responding to the electromagnetic fields generated by their coils. It is quite possible that someone could have set them by hand to random positions. (In a "field" situation, it is advisable to enclose the digits to prevent this happening – and of course to protect them from the "elements".)

From this point onwards, pressing any recognised key causes the data to be displayed sequentially, with the count returning to zero (Digit 1) after the final digit (or on pressing <ENTER> as described earlier). An example PC screen display is shown in Fig.15.

## PC CONTROL DATA OPTIONS

Because of the greater variety of segment codes that can be generated via the PC than with the keypad, there is the option to program the PC software with any segment combination required.

The data is held in a look-up table which can be added to by readers who have QBasic or QuickBASIC resident on their PC. The data is held as in the format extract example shown in Listing 3, in the bit order of segments ABCDEFG (the opposite order used by the PIC software's table).

### LISTING 3

```
DATA 01111110
DATA 10110000
DATA 21101101
DATA C1001110
DATA c0001101
DATA D0000000
DATA d0111101
DATA K0000000
DATA k0000000
DATA " 0000000"
DATA "^1100011"
```

When the program is started, all data statements are "Read" and analysed. The first character in each data string holds the keyboard character that represents the following 7-bit segment data. Its ASCII value is taken and the remaining seven bits in the data are stored in a string array, seg$(x), at the address corresponding to the ASCII value.

For example, in the first case, "01111110", the leading "0" is the first character. Its ASCII value is 48 and so the rest of the data string ("1111110") is stored at string array position seg$(48). In the fourth case, "C" is the character, having the ASCII value 67, so its 7-bit string data is stored at seg$(67).

Note that some data statements have had to be enclosed in quotes so that the program recognises the associated character correctly (the last character in the above list cause the "degrees" symbol to be displayed when the "^" is pressed (as in 20°C). The one before it is for the space bar (turns off all segments in a digit).

You will see instances where the character may be in upper or lower case, and in some cases both. If the value following the character contains one or more "1"s, the equivalent character *can* be generated on a 7-segment display. In the other cases, all zeros, the character *cannot* be formed using a 7-segment display.

If a character is not included in the table, a value of zero is returned if its key is pressed. All unacceptable keypresses are ignored.

## ALLOCATING SEGMENTS

For such "unacceptable" keys, however, a segment or PIC control code can be allocated separately. For instance, the program allocates the code "00000001" when the <ENTER> key (ASCII 13) is pressed. The PIC has been programed to recognise this bit combination as the command to reset the digit number count to Digit 1, in a similar way to that in which it responds when the "D" key on the 4 × 4 data keypad is pressed.

You could, for example, allocate specific codes for the PC's forwards/backwards cursor keys. The PIC could then be told to step the digit count value backwards or forwards without causing the display data to change. Then, on pressing another key, its character would be displayed at the new digit address.

Such a facility would be of help in a display having many digits and where only one or two might need to be changed at any time. This would remove the need to key in data for all digits in the full display when only a few might need changing.

Another option open to those who are familiar with QB programming is to write a code routine that allows a string of characters to be entered via the keyboard as a sentence (using INPUT instead of INKEY$). This would not be transmitted to the PIC until the <ENTER> key had been pressed. Each character would then be sent automatically in sequence to successive digits as required.

## SETTING PULSE LENGTH

So far the discussion has assumed that the length of the control pulse that activates the segment coils is correct. Setting preset VR1 earlier to a fully clockwise position sets the length to the maximum design limit. It is likely that the pulse can be shortened, so speeding segment changes.

The simple data sheet received indicated that a pulse length of about 0·25 seconds was required. Experiments with the digits showed that it could be much shorter. Although there was a slight variation in minimum operational pulse length for the various segments, the requirements were typically found to be about 70 milliseconds, but cannot be guaranteed in other assemblies (hence the need for user-adjustment rather than specifying the length as an accurate timing within the software).

A 70ms pulse length is generated with preset VR1 at a roughly midway setting. The maximum pulse length that can be set is about twice that. These figures are based on the PIC being run at 4MHz.

Once you have ascertained the correct response of the segments using a long pulse set via VR1, it is worth experimenting to find the lowest VR1 setting at which the segments will respond. This will speed the rate at which the displays can be changed.

The digits will not respond if the resistance is set too low. An intermediate stage may also be found in which some digits respond but not others. Avoid setting VR1 to a nil resistance position which will overload RA4 when it is in output-low mode (the PIC is internally protected against brief overloads – but do not sustain this condition).

It is worth noting that the software has also been written to speed segment changing. The status of each segment is recorded in the PIC's memory. When a new character is to be displayed on a particular digit, the digit's current segment status is checked against the segment requirement for the new character. If any segments match, they are ignored by the output routine, so saving one pulse duration – which can be a significant saving when many digits are in use.

## SCHMITT PULSING

This now brings us to a software/hardware aspect that has not been used before in an *EPE* project – analogue control of frequency via a digital input.

You are no doubt familiar with the type of circuit in which a single Schmitt trigger inverter is used with a resistor and capacitor in order to generate a frequency (an RC oscillator). The technique used in Big Digit is similar.

The PIC16F84 has a Schmitt trigger input, pin RA4. Referring to Fig.7, the resistance is provided by preset VR1, and the capacitance by C5. Initially software sets RA4 as an output set for logic 0. This discharges C5. RA4 is then set as an input, allowing current to charge up C5 via VR1.

When the Schmitt threshold is reached, the software responds to this as an input change from logic 0 to logic 1. It immediately sets RA4 as an output at logic 0 again, discharging C5, and then resets RA4 as an input once more, and so the cycle can continue for as long as the software requires it.

In this design, 16 waveform cycles are used, which allows a lower value capacitor to be used than with a single cycle. It also increases the capacitor's discharge rate and reduces current flow when RA4 is briefly set low. Listing 1 shows the full pulse delay generation routine.

The frequency of oscillation can be changed by varying VR1 or by using a different value for C5.

## EXPANSION

As said earlier, additional banks of eight digits can be controlled. In this case IC2 and IC3 need to be duplicated on a stripboard layout. Their pins should be connected identically to those in Bank 1, referring to Fig.6. The connection points on the p.c.b. are those alongside IC1, previously left unused.

The difference is that their enable pins (1 and 9) need to be controlled by a different Port A pin, RA1 for Bank 2, and RA2 for Bank 3. It is permissible to omit IC3 in the final bank if the digit count does not require it.

If more than three Banks are needed (more than 24 digits), pins RA0 to RA3 should be wired into another 74HC237, mounted on stripboard, at its pins A0 to A2. The outputs would then be used as the Bank Select lines for up to eight pairs of IC2 and IC3.

If using the extra 74HC237, remove the p.c.b. link wire marked Bank 1 Link. Connect point Y to pin Y0 of the new multiplexer. Point X then becomes the point to be regarded as the RA0 connection.

The software for the PIC and the PC will need to be modified to cope with more than three banks of digits. For this reason, only readers highly familiar with programming in both PIC and QB languages should undertake this option.

To such experienced programmers, the changes required should be obvious, but the author cannot offer advice on it. Nor can advice be offered on a breadboard layout for any additional chips added.

Note that it will be necessary to change regulator IC9 to a standard 7805 +5V 1A type if additional copies of IC2/IC3 are added (each extra chip adds about 20mA to the power drawn from the +5V line – see earlier).

QB programmers will recognise that the multiplexing circuit could be controlled directly from the PC's printer port data lines, omitting the PIC entirely. The port's other control lines could then be used in place of the RA0 to RA2 connections. The QB software would largely need to be rewritten, of course.

### LISTING 4 Send pulse to segment control

```
PULSEIT:
        movlw %00010000       ; number of cycles required
        movwf PULSECNT
PULSE2:
        btfss PORTA,4         ; has bit 4 gone high (cap charged
                              ;   up enough)?
        goto PULSE2           ; no, repeat check
        bcf PORTA,4           ; yes, set bit 4 low to discharge cap
                              ;   again

        PAGE1
        bcf TRISA,4           ; set bit 4 as output
        PAGE0
        nop                   ; brief wait discharge capacitor
        PAGE1
        bsf TRISA,4           ; set bit 4 as input
        PAGE0
        decfsz PULSECNT,F     ; repeat for set delay loop time
        goto PULSE2
        return
```

## VALEDICTUM DIGITALIS!

Two digits were sent to the author for experimentation. As described in this article, the resulting design is intended to drive up to at least 24 digits, and up to 64 with modification. Obviously this ability has not been fully proved in practice. However, extensive bench-tests and simulations have been made using the two digits and it is believed that the claims are valid. If you find any aspect that does not justify this belief, let the author know via *EPE* HQ (*NOT* via the *Chat Zone* as messages posted there may be overlooked).

The author hopes that readers will find ways in which the PIC and QB programs can be enhanced and write additional routines to suit their own needs. His intention has been to show with this design how the Big Digits can be controlled, and to provide an elementary framework within which readers can work to suit their own needs and the number of digits actually used.

Readers who do not wish to tailor the programs, though, will find that the software is perfectly usable as it stands, and that it provides a reasonable method of controlling the digits, whether just one is used, or many more. We would be interested to know how many you use and in what applications.

## RESOURCES

The software for this design is available on 3·5in disk (for which a nominal handling charge applies) from *EPE* Editorial office, or free via the *EPE* ftp site (path PUB/PICS/bigdigit). The easiest route to the ftp site is via the link at the top of the main *EPE* web page at **www.epemag.wimborne.co.uk**.

The PIC software is supplied as a source code (ASM – TASM grammar), HEX code (MPASM) and OBJ code (TASM). It was developed using *EPE Toolkit Mk3/TK3*. The PC program is supplied as a stand-alone program (EXE) and as QBasic/Quick-BASIC source code (BAS).

The PIC configuration required is XTAL XS, POR on, WDT off. This is embedded in the ASM and HEX codes, but readers using the TASM OBJ code must configure the PIC in the usual separate manner.

Ensure that you read this month's *Shoptalk* page for details of component buying for this project.


## ACKNOWLEDGEMENT

The author thanks Display Electronics (**www.distel.co.uk**) for providing the Big Digits for experimental use in the development of this project.

# PRACTICALLY SPEAKING

## *Robert Penfold looks at the Techniques of Actually Doing It!*

ELECTRONIC project construction is certainly a technical hobby, but it is not only a matter of test equipment, PIC programming, and electronic theory. It is not just soldering irons, electronic components, and circuit boards either. There is also a "nuts and bolts" side to the hobby. Having completed a circuit board successfully you are by no means "home and dry". There is usually a fair amount of work to do before you are ready to show off your new masterpiece. You should not find things too difficult if you have a reasonable selection of tools and often undertake DIY jobs around the house. On the other hand, project construction and general DIY jobs are certainly different.

Electronic project construction requires a more gentle approach. The "hammer and tongs" approach usually ends in disaster, with a lot of time and materials being wasted. Most projects are housed in plastic or aluminium cases that are easily damaged. Some cases are actually quite tough, but many of the plastic cases are prone to cracking, and it is easy to dent or distort most aluminium cases. Bear in mind that most cases have finishes that are easily spoiled. With the "nuts and bolts" side of construction it is definitely advisable to proceed carefully and always use the minimum amount of force.

### Look Before You . . .

If you look through a selection of project articles you will find detailed instructions for building the circuit boards and completing the hard wiring. Articles are usually more sketchy about the mechanical side of construction. This is simply because most constructors prefer to "do their own thing" with this aspect of project building. You can try to produce an exact copy of the original each time you build a project, but it is more interesting and satisfying if you do things your own way. You have greater freedom when "doing your own thing", but the chances of ending up with a complete mess are greatly increased.

It is fair to say that careful planning is important when building anything, and electronic projects are certainly no exception. Simply making it up as you go along is likely to produce an end result that looks muddled and badly thought out. It might even produce a 90 per cent complete project that can be taken no further.

Without planning it is easy to produce projects that are fine, apart from the fact there is insufficient space for the battery, or the lid of the case can not be fitted into place. Another popular mistake is to miss out a control or socket which then has to be fitted in as best you can. At best this produces some odd-looking panel layouts. At worst you find that one or two controls cannot be adjusted when the headphones are plugged in, or something of this nature.

### Project Cases

Although there are many different types of project cases in use at present, they break down into two main categories. The cheapest are the simple boxes that are normally of plastic construction, but can be made of metal or a mixture of plastic and metal. Instrument cases are generally larger and more expensive.

The simple boxes consist of a five-sided main section plus a removable lid, although the latter is often used as the front panel. The more expensive metal types are of diecast aluminium construction and are very tough. They also have good screening properties that prevent radio signals from entering or exiting. The cheaper metal boxes use folded aluminium construction. While nothing like as tough as the diecast variety, they are more than adequate for most projects.

Simple boxes are fine for projects that require a small to medium size enclosure, but they are often a bit awkward when applied to larger projects. Instrument cases are usually the better option for larger projects. Apart from the fact that they "look the part", they generally provide better access to the interior of the case which makes it easier to work on larger and more complex projects.

Instrument cases vary considerably in design, but many have a base section combined with front and rear panels. The lid and sides are combined in another section. Ideally, the case should have removable front and rear panels, as this makes working on the panels very much easier.

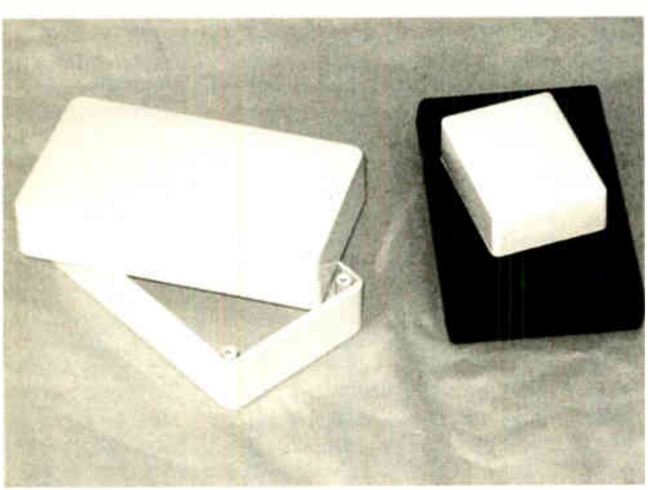
While it is normally acceptable to use any case that is large enough, it is as well to read the construction notes in the article. There may be other considerations, and in some applications plastic cases are not suitable while in others a metal case must not be used.

Some projects rely on the metal casing to act as a heatsink or to provide screening, or earthing. Other projects, such as radios, require plastic cases that do not provide screening. It is important to heed the advice when an article stipulates a certain type of case.

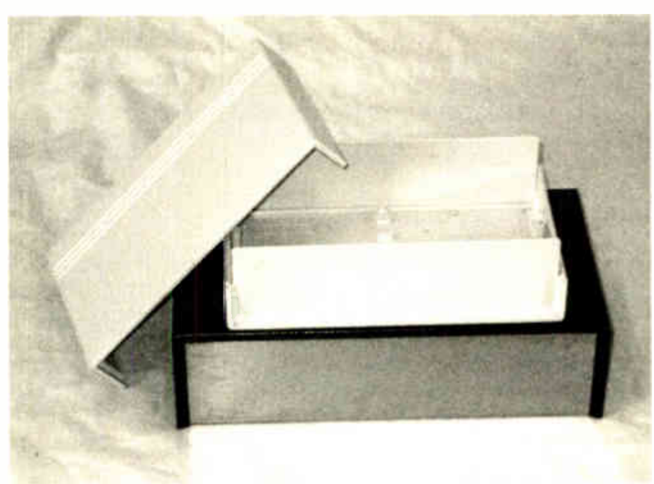
In most instances the exact type of case used is unimportant, and it is then a matter of choosing one that is big enough and within your price range. In general, simple boxes are substantially cheaper than instrument cases, and they are perfectly adequate for most small projects. For larger projects it is probably worthwhile paying the extra for an instrument case. The finished unit will probably look much better in an instrument case, and it will be easier to build as well.

### Size Is Important

How do you work out whether or not a likely looking case will actually



*A wide range of inexpensive plastic boxes are available, they are well suited to most small projects.*



*Instrument cases are a better choice for larger projects.*

accommodate your latest project? Measurements taken from the circuit board and other large components might give some guidance, but even this early in the proceedings it is really advisable to give some thought to the general layout of the project. There is otherwise a risk of buying a case that is big enough to take the components, but not with the components positioned sensibly.

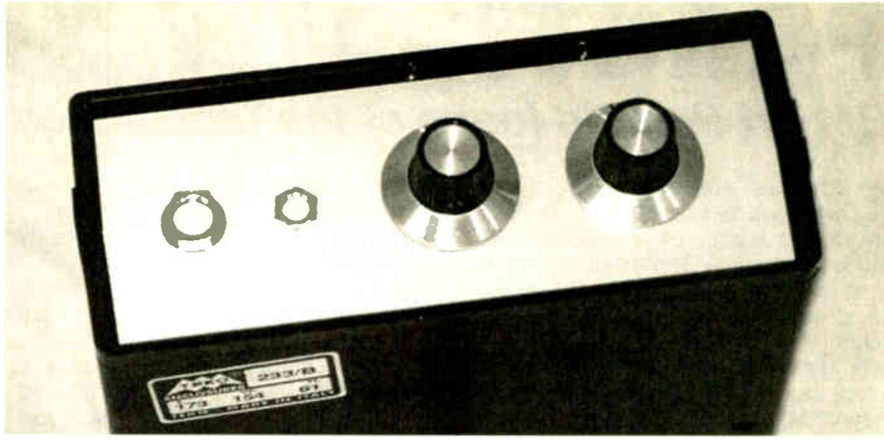
Most component catalogues give both the internal and external dimensions for cases. It is the internal dimensions that are of most importance. Where no internal size is given, deducting about 8 millimetres from the external dimensions usually provides figures that are quite close to the internal ones. There is a slight problem in that most cases have internal obstructions that effectively reduce their internal dimensions. For example, most cases have mounting pillars and (or) guide-rails for printed circuit boards, and threaded pillars for the lid mounting screws.

Many cases have mouldings that seem to serve no purpose at all, and make it difficult to fit in even the simplest of projects. Be especially careful with cases having fixing screws that penetrate several millimetres into the open area inside the case. Many metal instrument cases fall into this category.

It is easy to produce a plausible looking layout that actually results in a fixing screw going straight into the battery or a circuit board when the lid of the case is fitted in place. Where a case is supplied with fixing screws that are clearly longer than necessary, it is probably worthwhile replacing them with shorter ones.

It is not a good idea to make every project as small as possible. If a project really needs to be of diminutive proportions, then try to work out a layout that will give a really compact finished article. It is otherwise better to err on the side of caution and choose a case that seems to be slightly too large. This avoids making construction unnecessarily awkward, and will probably result in a finished unit that looks neater and is easier to use.

It is certainly a good idea to place the circuit board, battery, and any other large components inside the case before you start the cutting and drilling. Alternatively, make some careful measurements and some drawings. This should enable you to establish that everything fits, and that the controls, circuit board, etc., are not vying for the same space.



*Position control knobs, etc., on the front panel and move them around to find the best layout.*

## Long and Short of it

When designing layouts you are often faced with conflicting requirements. You would like to place controls and sockets to give a neat and usable layout, but such a layout might not be very practical. It is best to avoid layouts that have long wires running all over the place. This is not simply because layouts of this type tend to look rather scrappy. With many projects it is best to keep the wiring short in order minimise problems with stray pick up of "hum" and other signals, and to keep stray feedback to a minimum. The article should point out any restrictions on the layout, such as leads that have to be kept very short, or components that should be mounted well apart. It is advisable to keep inputs and outputs well separated.

Layouts normally look neater if the spacing between control knobs of the same size is constant. On the other hand, a purely mathematical approach to front panel layouts will not necessarily produce the best looking results. The neatest layout is the one that looks best "in the flesh", and not the one that looks best "on paper".

The best way to try out layouts is to place the control knobs onto the front panel, together with fixing nuts to represent things like toggle switches or sockets. This way you get a very accurate impression of what the finished project will look like. When everything looks just right, make careful measurements so that a plan of the layout can be drawn up.

## Perfect Marks

Always check the final layout to make sure you have not overlooked something. When you are sure everything is correct, transfer the layout to the front panel, but take due care when doing this. Most project cases are made from soft plastics or aluminium that is easily worked, but they are also easily chipped and scratched.

Mark the drilling points using something like a fibre-tip pen that will not scar the case for life. It is advisable not to use spirit-based inks on plastic panels. The spirit in the ink might dissolve and seriously damage the case. If in doubt, try the pen on the inner surface of the panel, where any damage will be of no consequence. Very soft pencils (about 5B or 6B) work well on aluminium panels and should not cause any damage. The lines can be removed using an ordinary eraser.

Some plastic panels are resistant to virtually all inks. One option is to scratch the design onto the panel, making sure you only place marks in areas that will be cut or drilled away. The more popular option is to fix paper onto the panel with double-sided tape or a Pritt-Stick. This method is quite a good one using any case, since it is easy to mark the layout very accurately, and the paper gives some protection to the panel. The paper is peeled off once work on the panel has been completed, and any adhesive or paper that remains is easily washed off.

Use a centre punch to mark the centres of all holes in metal cases prior to drilling them. The small indentations guide the drill bit and make accurate drilling much easier. An automatic punch works well with aluminium. Go carefully when using an ordinary punch with aluminium panels. These buckle and distort quite easily, as you will soon discover if due care is not taken. Centre punches are unsuitable for many plastic cases, which could easily be cracked or more seriously damaged. An indentation is still needed to stop the drill bit from wandering, and this can be made using a pointed tool such as a bradawl, together with a minimum of pressure.

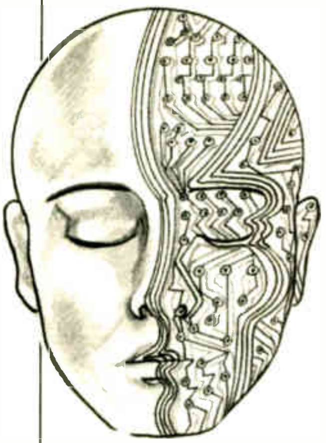
## Drilling Holes

It is then a matter of using standard do-it-yourself tools to drill the holes, file cutouts, or whatever. Due to the softness of the materials used for most cases it is best to drill slowly and very carefully. If you use an electric drill that has some sort of speed control, a low speed is best. A hand drill is perfectly adequate for most project construction.

With an awkward case it might be necessary to enlist the services of a helper to keep it in place while the holes are drilled. Normal clamping techniques can be used with most cases, but use some cloth to protect the panels from damage. Do not rely on any paper or plastic coverings to protect panels from clamps.

Always have a piece of scrap timber, MDF, etc. under the work piece. This supports the panel so that there is less risk of it buckling and it gives "cleaner" holes that require less deburring. With metal panels you will still need to do a certain amount of deburring using a miniature file, or there are special tools for this task.

Be careful when dealing with steel panels. Any raised edges around holes are likely to be quite sharp, so do not feel for them using a fingertip! Look carefully for any projections and immediately remove any that are found.



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## Battery Discharger – Out in a Flash

THE circuit diagram of Fig.1 discharges any rechargeable 1·5V cell and the light-emitting diode D3 starts to flash when the battery connected across the "test" terminal is sufficiently discharged. The design uses a two-transistor astable multivibrator operating at a frequency of about 25kHz. When transistor TR2 conducts, a current flows through the 4·7mH inductor L1, whereupon energy is stored in the resulting electromagnetic field.

When TR2 is cut off, the surrounding electromagnetic field collapses which produces a back-e.m.f. at a level that exceeds the forward voltage (about 1·6V) of the l.e.d. D3. A current then flows through the l.e.d. which appears to be continually alight in normal operation. Diode D2 prevents the current flowing through resistor R6 and capacitor C2. This process is halted only when the battery voltage no longer provides a sufficient base potential for the transistors, and the battery can now be removed.

However, the addition of the forward bias of D1 (about 0·3V) means that the final "discharge voltage" of the battery is raised to 0·9V to 1·0V. Additional resistors R3 and R5 ensure that sufficient current flows through D1.

It should be noted that the battery is discharged sufficiently when the l.e.d. begins to flash. When the discharge is complete (i.e. to 0·9V), the l.e.d. goes out altogether. *(Total discharge may damage Nickel Cadmium or Nickel Metal Hydride cells and is not recommended – ARW.)*

The flashing of l.e.d. D3 when the battery is nearing the recommended discharge level is caused by the increasing internal resistance of the battery lowering the terminal voltage to below the threshold level. Then when no current flows, the internal resistance is of no consequence since the terminal voltage rises to the threshold voltage by taking some energy from the battery.

***Liao Jian Mei, Singapore.***

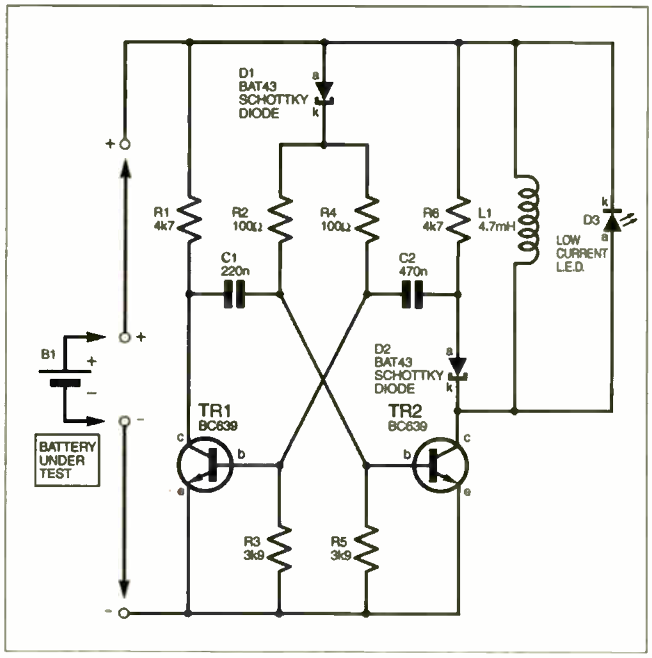


*Fig.1. Circuit diagram for the Battery Discharger.*

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## Emergency Light – A Wind-up

THE circuit diagram shown in Fig.2 offers a stepper-motor powered Emergency Light.

When spun rapidly between the fingers, a small four-phase stepper motor will produce an a.c. voltage of around 5V at 25mA per phase. If all four windings are paralleled, up to 100mA can therefore be produced.

If this is stepped up with a small 230V to 6V-0V-6V centre tapped mains transformer, a small stepper motor is capable of powering a 6 inch 4W fluorescent tube. The transformer must be a small one (around 250mA) or so, otherwise efficiency is compromised.

Once the stepper motor's common lead or leads have been identified, the others can be identified through trial and error. First take the common lead(s) to one terminal of the transformer's primary windings, and try combinations of two wires on the other terminal until the tube lights up. Then connect the remaining wires.

To obtain a good level of light for shorter term use, consider using gears on the motor to avoid the need for any undue exertion.

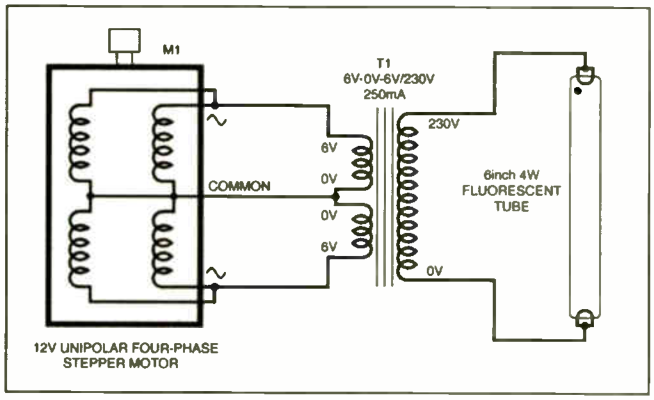


*Fig.2. Emergency Light circuit diagram.*

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# SIMPLE AUDIO CIRCUITS

## Part 1 – Introduction and Power Amplifiers

RAYMOND HAIGH

*A selection of "pic-n-mix" low-cost audio circuits – from preamplifier to speaker!*

WHATEVER their particular area of interest, most electronics enthusiasts encounter the need to amplify and reproduce audio signals. The final stages of radio receivers, intercom units, security and surveillance installations, or just a hankering for a big sound from a Walkman or portable CD player, all involve audio amplification and a speaker system. And the amplification usually goes hand-in-hand with some form of signal processing.

Music reproduction calls for a wide frequency response and tone-control circuitry. Speech communication, especially under difficult conditions, is greatly clarified if the frequency response is curtailed.

This short series of articles describes simple, but effective, ways of meeting these different requirements. Although the circuits are capable of a good standard of reproduction, they will particularly interest the constructor who looks for plenty of performance per pound or dollar.

We begin with the power amplifier. Six alternatives are given and, with the requirement of maximum performance for minimum cost and effort, they are all based on widely available integrated circuits (i.c.s):

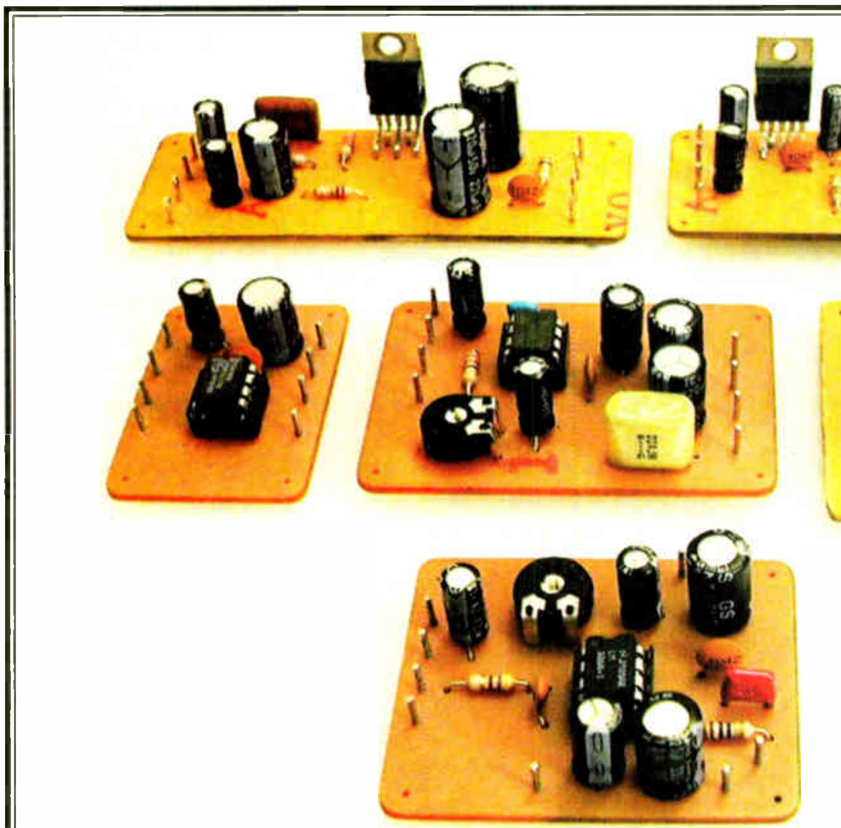
- LM386N-1
- TDA7052
- TBA820M
- LM380N
- TDA2003.

### HOW MUCH POWER?

Before considering the various circuits, it is worthwhile to reflect on the amount of power actually needed.

Clear reproduction in Walkman type earphones of reasonable sensitivity can be achieved with a miserly milliwatt (0·001W). When listening to talk programmes in a quiet domestic setting, the power fed to the speaker will hover around 50mW (0·05W), and this is ample for the operator of a communications receiver whose ears are closer to the sound source.

During the valve era, ten watts was considered adequate for the realistic reproduction of orchestral music, and some experts suggested a figure as low as five. One watt of power delivered to a



*Collection of simple i.c. power amplifier modules (left-to-right, top-to-bottom).*

- *Single TDA2003 Amp*
- *Twin TDA2003 Amp*
- *TDA7052 Amp*
- *TBA820M Amp*
- *LM380N Amp*
- *LM386N-1 Amp*

reasonably efficient speaker will produce a loud sound, a *continuous* five watts is becoming deafening, and ten will rattle windows. This assumes single channel, or mono, reproduction in a normal living room. The impact is, of course, greater with a stereo system.

This is at odds with the high power ratings of many of the quality amplifiers currently advertised. The desire for a big reserve of power, the low efficiency of some modern speakers, and different ways of measuring output, may account for the difference.

Output is variously rated as music power, sustained music, speech and music, and sinewave power. To add to the confusion, the figures are quoted at different distortion levels. The standard most often used when valves were commonplace, and the one adopted in this article, is the r.m.s. (root mean square) value of a continuous sinewave. This gives the lowest rating and is the most realistic expression of the amplifier's ability to deliver power into a load (speaker).

An increase in output power is reflected as much, if not more, in the cost of the power supply as it is in the actual amplifier. Because the theme of this article is good performance at modest cost, the most powerful amplifier described is rated at 12·5W r.m.s.

## DISTORTION

Manufacturers of power-amplifier integrated circuits and modestly priced hi-fi systems (which invariably incorporate devices of this kind) usually rate the maximum power output at 10 per cent distortion. At this level there is a very noticeable roughness to the sound and clipping of the waveform on loud passages.

The power output levels quoted here have been measured just before the onset of clipping or any noticeable distortion of the output waveform. They are somewhat lower than the figures quoted by the i.c. manufacturers, but they do represent the highest output, free from audible distortion, that the device can deliver for a particular supply voltage and load.

## NOISE

Modern power amplifier i.c.s have a very low noise level. Manufacturers usually define this internally generated electrical noise as an equivalent signal voltage at the input, but this doesn't give the average experimenter an immediate impression of its audible effect.

Accordingly, the devices described here were tested by disconnecting the signal source, turning the input or volume control to maximum, and then listening to the output on a pair of sensitive, Walkman type earphones.

In all cases the noise was no more than barely audible. The two devices which can be configured for high gain (LM386N and TBA820M) did produce a faint, but audible, hiss when the gain was set at maximum. The hiss was also noticeable with a loudspeaker connected.

However, when the gain preset was turned back a little, these i.c.s became as silent as the rest. Some constructors may need the highest possible gain, and details will be given later of measures which can be taken to eliminate the noise.

## STABILITY

Provided a few basic precautions are observed, the amplifiers are all unconditionally stable. Most i.c.s of this kind have a ground connection for the input circuitry and a *separate* ground pin for the output stage.

The printed circuit board (p.c.b.) layouts have been designed to maintain this isolation, and care should be taken to ground the signal inputs and connect the negative power supply lead to the designated points on the board. Failure to do this could result in "motor boating" (low frequency instability).

Input leads should be *screened* to avoid mains hum and radio frequency (r.f.) signal pick up. Speaker leads should be twisted together to minimise external fields. Input and output leads should be spaced as far apart as possible: this is particularly important when the LM386N and TBA820M are set for high gain.

All of the circuits include high and low frequency bypass capacitors across the supply rails. The former minimise the possibility of r.f. oscillation: the latter avoid low frequency instability when long power supply leads are used, or when batteries are ageing.

## HIGH FREQUENCY RESPONSE

The bandwidth of the amplifiers extends into the r.f. spectrum, and this makes the devices vulnerable to r.f. interference. Some of the i.c.s provide for the connection of an external capacitor in a negative feedback loop to "roll-off" the high frequency response. Selecting an appropriate value for this component will help to make the device immune.

The problem of r.f. pick up invariably manifests itself when a high value (more than 10 kilohms) input potentiometer (VR1) is used to match the amplifier to the impedance of a signal source. If the potentiometer or volume control must have a high resistance, connecting a 1nF or, at most, 10nF capacitor across its track will shunt unwanted r.f. to ground.

## LOW FREQUENCY RESPONSE

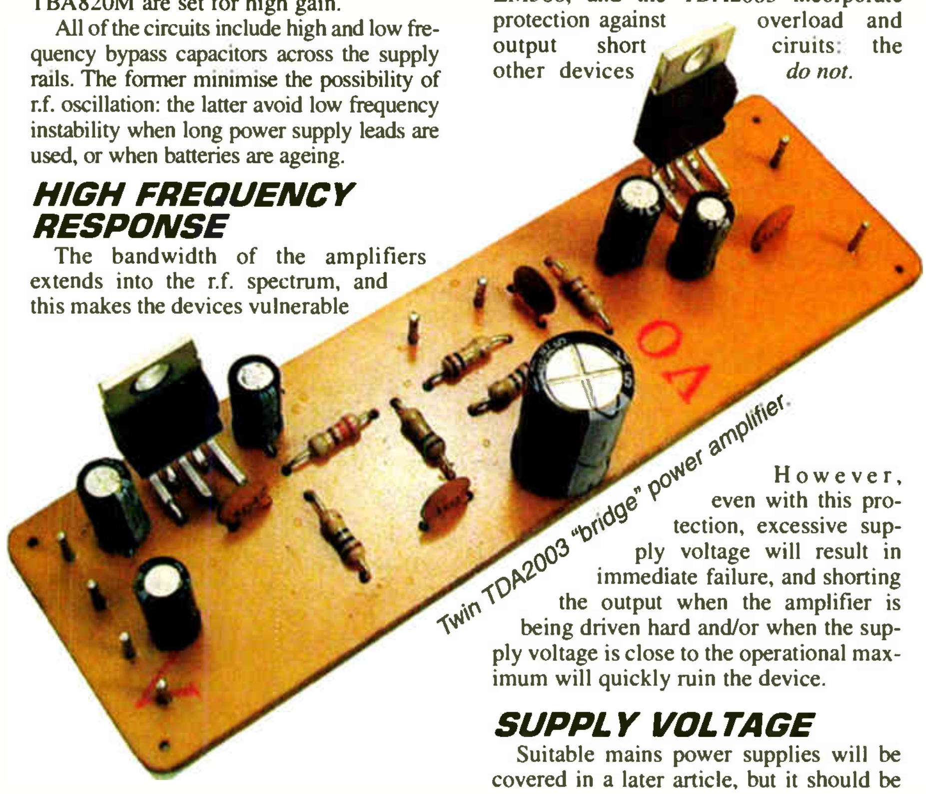
The low frequency response of three of the lower powered amplifiers has been curtailed a little by fitting a 220$\mu$F speaker coupling capacitor. Amplifiers of this kind are invariably used with small, inexpensive speakers which are incapable of producing an audible output at frequencies below 150Hz or so. Feeding low frequencies to speakers of this kind only overloads them, causing distortion and loss of clarity.

Indeed, if the amplifier is being used primarily for speech, clarity can be much improved by rolling-off the frequency response below 300Hz, and an even lower value of coupling capacitor, say 100$\mu$F or even 47$\mu$F, would be of benefit. Readers seeking quality music reproduction at low power, via a speaker of reasonable size, should increase the coupling capacitor to say 1000$\mu$F.

This relationship between coupling capacitors and frequency response will be considered more fully in the next article.

## DEVICE PROTECTION

The integrated circuits covered here are electrically robust but they are by no means indestructible. The TDA7052, LM380, and the TDA2003 incorporate protection against overload and output short ciruits: the other devices *do not.*



Twin TDA2003 "bridge" power amplifier.

However, even with this protection, excessive supply voltage will result in immediate failure, and shorting the output when the amplifier is being driven hard and/or when the supply voltage is close to the operational maximum will quickly ruin the device.

## SUPPLY VOLTAGE

Suitable mains power supplies will be covered in a later article, but it should be mentioned now that, off-load, d.c. output voltages rise to 1·4 times the a.c. voltage delivered by transformer secondaries. When using unregulated mains power supplies care should, therefore, be taken to ensure that the off-load voltage is always less than the maximum safe working voltage of the amplifier. *Never connect a working power supply to an amplifier without first checking its output voltage.*

## ELECTRICAL CHARACTERISTICS

The electrical characteristics of the various devices are tabulated alongside the circuit diagrams (except one) for easy reference. Power output figures are based on measurements taken on a single, randomly purchased sample. For reasons already given, they are somewhat lower than the figures quoted by the manufacturers.

Recommendations are made regarding the speaker impedances to use with various supply voltages in order to keep the dissipation of the devices within reasonable limits.

The input resistance, maximum voltage ratings, and frequency response details are those supplied by the manufacturers.

## AMPLIFIER PROJECTS

In use, there is little to distinguish between the four, low powered amplifiers, all perform well. There are, however, differences which make one device more suitable than another for a particular application.

Low current consumption is important when equipment is powered from dry batteries. Quiescent current drawn by the small amplifiers is in the region of 6mA (13mA for the LM380).

In the case of the LM386N, TBA820M and LM380, current rises to around 120mA when 500mW is being delivered into an 8 ohm load. Current consumed by the TDA7052 is approximately 220mA, or almost double, under these conditions.

In all cases, the signal input pin has been connected to the slider (moving contact) of the Volume control potentiometer (via a blocking capacitor in the case of the TDA2003). This minimises hum and noise and ensures that a more or less constant impedance is presented to the signal source. Potentiometers of 4700 ohms or 10 kilohms (10k) are usual, but the value can be increased to 100k to raise input impedance.

This will, however, make the circuits more vulnerable to mains hum, r.f. interference and instability, and the value should be kept as low as the signal source impedance permits. This applies particularly to the TDA7052, where the value of the Volume control should, if possible, be no more than 10k. Earlier comments regarding stability are of relevance here.

# LM386N-1 AMPLIFIER

A circuit diagram for a simple amplifier using the low-voltage LM386N-1 power amplifier i.c. is shown in Fig.1. Also shown are the general performance and electrical characteristics of the circuit.

Blocking capacitor C1 prevents any disturbance of the d.c. conditions in the signal source and potentiometer VR1 (the Volume control) sets the input level. The manufacturers of the chip, National Semiconductor, suggest an input network to roll-off high frequencies and resistor R1 and capacitor C2 perform this function.

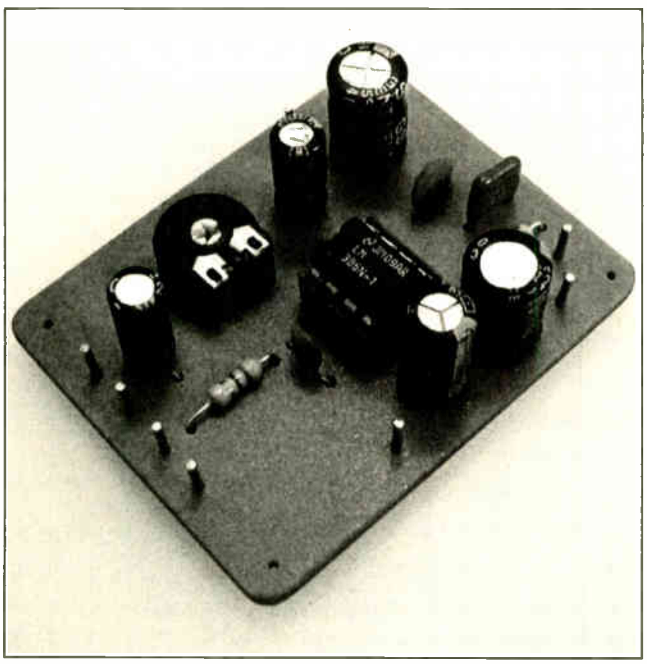
The unused non-inverting input (pin 3) is grounded to avoid instability when gain is set high. Capacitors C3 and C4, connected across the supply rails, prevent low and high frequency instability.

## FEEDBACK

An internal negative feedback path can be accessed via pin 1 and pin 8. Bypass capacitor C5 reduces the feedback and increases the gain of the chip from 23 to 170 times (as measured: samples will vary). Preset potentiometer VR2 (wired as a variable resistor) controls the bypassing effect of C5 and enables the gain to be set within these limits.

Bypass capacitor C6 makes the device more immune to supply line ripple, and C8 couples the output to the speaker LS1. The Zobel network, formed by resistor R2 and capacitor C7, ensures that the speaker always presents a resistive load to the amplifier. Without these components there is a risk of high level transients causing damage to the output transistors.

Tabulated power output levels for various supply voltages and speaker impedances are included below the circuit diagram. Sustained operation at more than 300mW is not recommended.



Completed LM386N-1 circuit board.

## CIRCUIT BOARD

The printed circuit board component layout, wiring details and full-size copper foil master pattern are shown in Fig.2. This board is available from the *EPE PCB Service,* code 343 (LM386N-1).

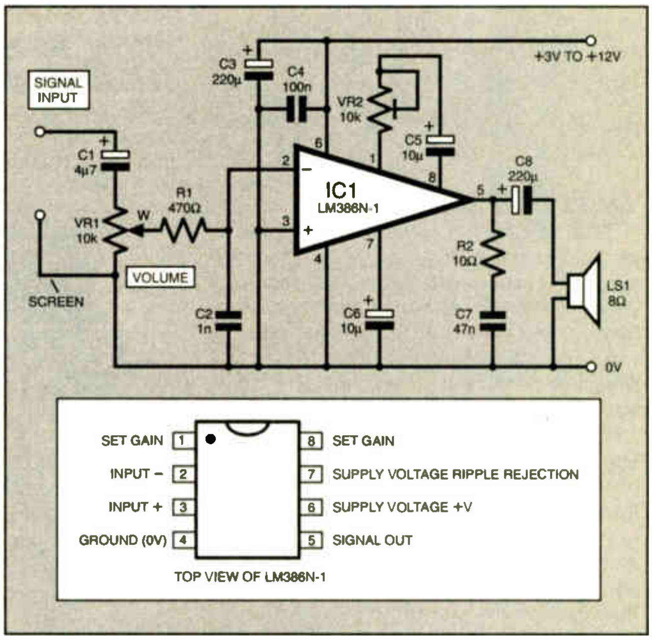



*Fig.1. Circuit diagram and pinout details for the LM386N-1 Power Amplifier.*

### LM386N-1 POWER AMPLIFIER

**R.M.S. power output just before the onset of waveform clipping**

| Speaker Impedance ohms | 3V | 4·5V | 6V | 9V | 12V |
|---|---|---|---|---|---|
| 4 | 60mW | 150mW | 320mW | 500mW | – |
| 8 | 26mW | 105mW | 200mW | 560mW | 900mW |
| 16 | 15mW | 60mW | 110mW | 320mW | 605mW |
| 32 | - | 35mW | 62mW | 170mW | 330mW |

| | |
|---|---|
| Quiescent current: | 6mA |
| Input resistance: | 50k ohms |
| Input sensitivity for 560mW output (8 ohm load, 9V supply), | |
| (a) VR2 set for maximum resistance: | 90mV r.m.s. (gain 23) |
| (b) VR2 set for minimum resistance: | 12mV r.m.s. (gain 170) |
| Absolute maximum supply voltage, beyond which damage will occur: | 15V |
| Suggested maximum supply voltage with a 4 ohm speaker | 6V |
| Frequency response | up to 300kHz |

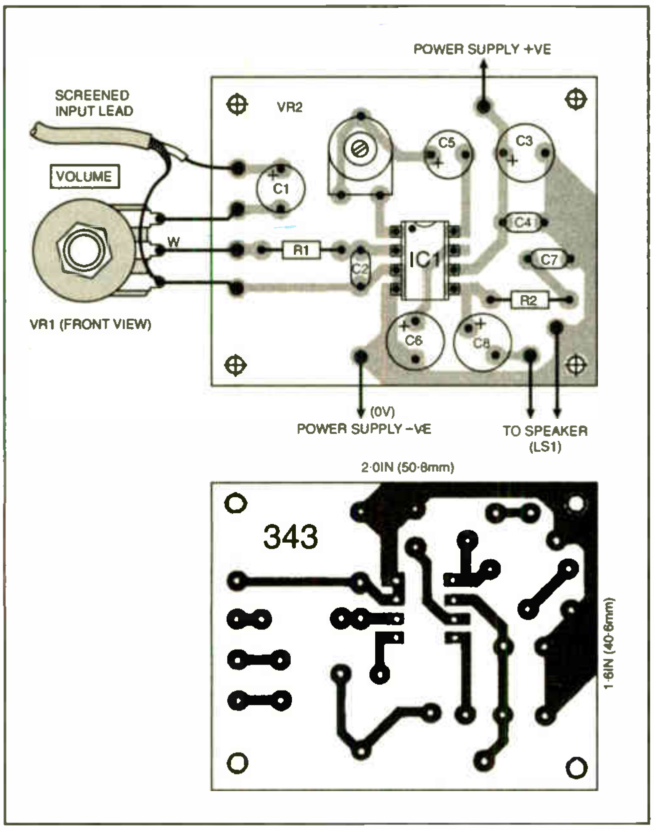



*Fig.2. Printed circuit board, component layout, full-size copper foil master and interwiring for the LM386N-1 Amp.*

## COMPONENTS

### LM386N-1 AMPLIFIER

**Resistors**

| | | | |
|---|---|---|---|
| R1 | 470Ω | R2 | 10Ω |

All 0·25W 5% carbon film

See SHOP TALK page

**Potentiometers**

| | |
|---|---|
| VR1 | 10k min. rotary carbon, log. |
| VR2 | 10k enclosed carbon preset |

**Capacitors**

| | |
|---|---|
| C1 | 4µ7 radial elect. 25V |
| C2 | 1n disc ceramic |
| C3, C8 | 220µ radial elect. 25V (2 off) |
| C4 | 100n disc ceramic |
| C5, C6 | 10µ radial elect. 25V (2 off) |
| C7 | 47n polyester |

**Semiconductor**

| | |
|---|---|
| IC1 | LM386N-1 audio power amp i.c. |

**Miscellaneous**

| | |
|---|---|
| LS1 | 4 to 32 ohm loudspeaker (see text) |

Printed circuit board available from the *EPE PCB Service*, code 343 (LM386N-1); case (optional), size and type to choice; 8-pin d.i.l. socket; multistrand connecting wire; audio screened cable; solder pins; solder etc.

*Approx. Cost Guidance Only* **£10.50** *excluding case & speaker*

# TDA7052 AMPLIFIER

Philips have adopted a bridge arrangement for the TDA7052's output stage. This enables the chip to maintain a good output at low supply voltages and eliminates the need for a speaker coupling capacitor.

Gain is fixed internally, no provision is made for ripple rejection, and there is no Zobel network. This reduces the external component count to the d.c. blocking capacitor C1, Volume control VR1 and the supply line bypass capacitors, C2 and C3. The full circuit diagram, together with a specification guide, for the TDA7052 amplifier is shown in Fig.3.

Protection against output short circuits is built in and the device shuts down when the dissipation becomes excessive. This explains the small rise in sustainable output when the speaker impedance is increased to 16 ohms with a 9V supply.

Although usually costing a little more than the other low-power chips, this is the device of choice when the supply voltage has to be low, a good output is required, and high gain is not important. Current consumption for a given output power is, however, almost twice that of the LM386N and the TBA820M.

## CIRCUIT BOARD

The printed circuit board component layout, wiring details and full-size copper foil master pattern are shown in Fig.4. This board is available from the *EPE PCB Service*, code 344 (TDA7052).

### TDA7052 POWER AMPLIFIER
**R.M.S. Power output just before the onset of waveform clipping**

| *Speaker Impedance Ohms* | *Supply Voltage* 3V | 4·5V | 6V | 9V | 12V |
|---|---|---|---|---|---|
| 4 | 70mW | 500mW | 780mW | – | – |
| 8 | 60mW | 455mW | 640mW | 1W | – |
| 16 | 40mW | 235mW | 450mW | 1·12W | – |
| 32 | 24mW | 145mW | 250mW | 600mW | 1·26W |

| | |
|---|---|
| Quiescent current | 5mA |
| Input resistance | 100k ohms |
| Input sensitivity for 1W output (8 ohm load, 9V supply) | 40mV r.m.s. (gain 70) |
| Absolute maximum supply voltage beyond which damage will occur | 18V |
| Suggested maximum supply voltage: | |
| with a 4 ohm speaker | 6V |
| with 8 or 16 ohm speakers | 9V |
| Frequency response at the –3dB points | 25Hz – 20kHz |

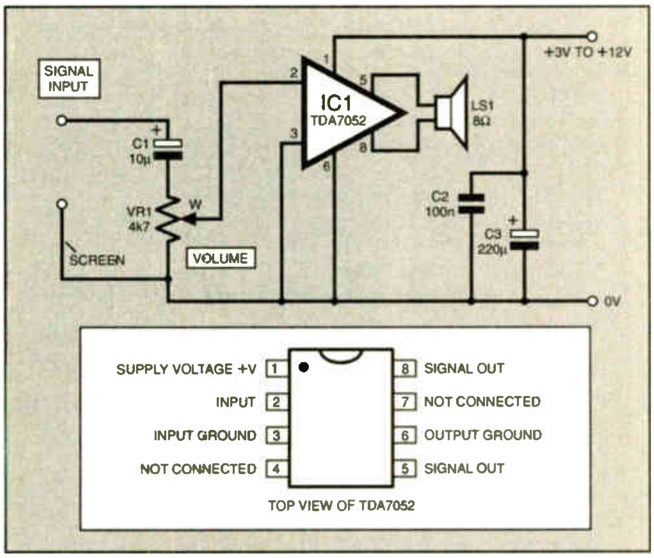



*Fig.3. Circuit diagram and pinout details for the TDA7052 Amp. See left for performance guide.*

# COMPONENTS

### TDA7052 AMPLIFIER

See SHOP TALK page

**Capacitors**
C1 10µ radial elect. 25V
C2 100n disc ceramic
C3 220µ radial elect. 25V

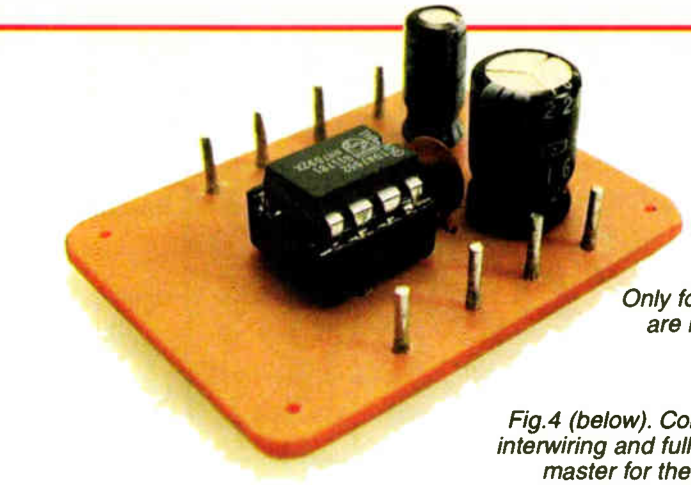
**Potentiometers**
VR1 4k7 min. rotary carbon, log.

**Semiconductor**
IC1 TDA7052 power amp i.c.

**Miscellaneous**
LS1 4 to 32 ohm loudspeaker (see text)

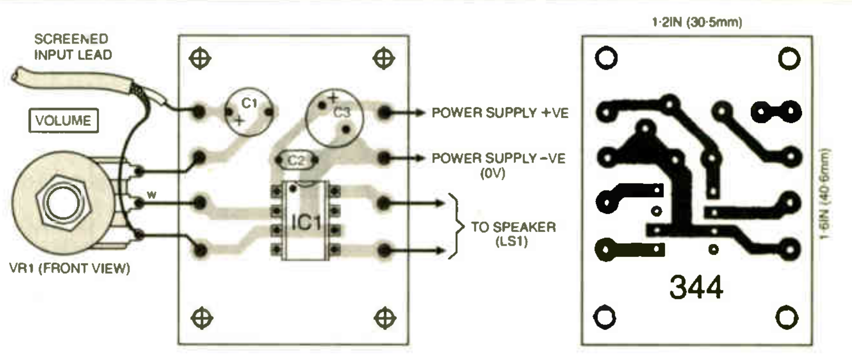
Printed circuit board available from the *EPE PCB Service,* code 344 (TDA7052); case (optional), size and type to choice; 8-pin d.i.l. socket; multistrand connecting wire; audio screened cable; solder pins; solder etc.

*Approx. Cost Guidance Only* **£9.50** *excluding case & speaker*



*Only four components are mounted on the TDA7052 p.c.b.*

*Fig.4 (below). Component layout, interwiring and full-size copper foil master for the TDA7052 Amp.*




# TBA820M AMPLIFIER

A circuit diagram incorporating the TBA820M audio amp i.c., which is manufactured by SGS-Thomson, together with a general performance guide, is given in Fig.5. The input arrangements, supply line bypassing, speaker coupling and Zobel network are conventional, and the relevant components can be identified from previous circuit descriptions.

Gain can be controlled by shunting an internal negative feedback loop, which is accessed at pin 2. Preset potentiometer VR2, placed in

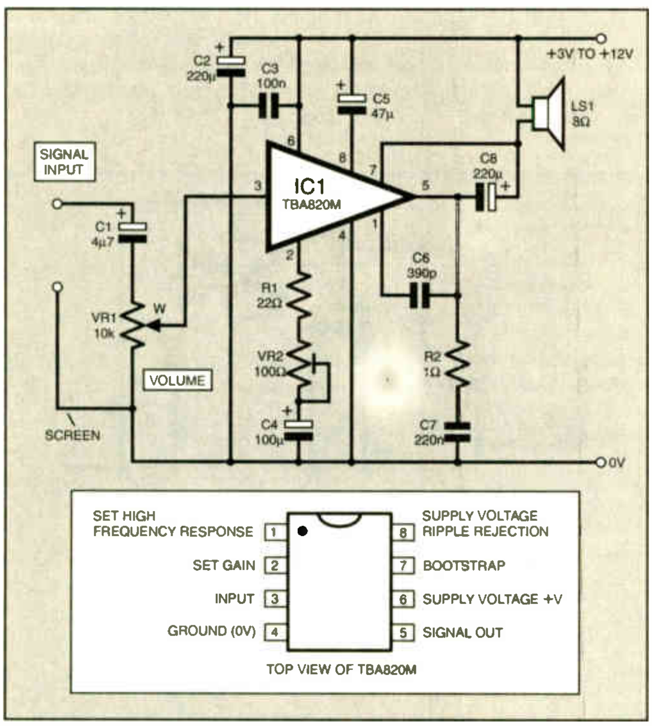
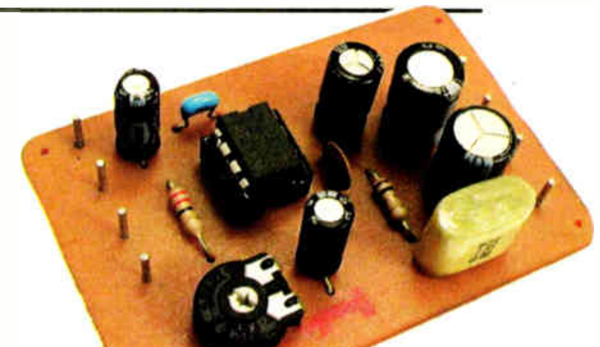



*Fig.5. Circuit diagram and pinout details for the TBA820M power amplifier. See right for general performance details.*



*Completed TBA820M amplifier module.*

### TBA820M POWER AMPLIFIER

**R.M.S. power output just before the onset of waveform clipping**

| *Speaker Impedance Ohms* | *Supply Voltage* 3V | 4·5V | 6V | 9V | 12V |
|---|---|---|---|---|---|
| 4 | 10mW | 320mW | 405mW | 980mW | – |
| 8 | 20mW | 200mW | 300mW | 680mW | 1·1W |
| 16 | 30mW | 115mW | 180mW | 405mW | 720mW |
| 32 | 20mW | 60mW | 90mW | 225mW | 390mW |

| | |
|---|---|
| Quiescent current | 6mA |
| Input resistance | 5M ohms |
| Input sensitivity for 680mW output (8 ohm load, 9V supply): | |
| (a) VR2 set for maximum resistance | 56mV r.m.s. (gain 40) |
| (b) VR2 set for minimum resistance | 10mV r.m.s. (gain 230) |
| Absolute maximum supply voltage beyond which damage will occur | 16V |
| Suggested maximum supply voltage: | |
| with a 4 ohm speaker | 9V |
| with an 8 ohm speaker | 12V |
| High frequency response at –3dB point: | |
| with C6 220pF | 20kHz |
| with C6 680pF | 7kHz |

# COMPONENTS

**TBA820M AMPLIFIER**

See SHOP TALK page

**Resistors**

| | |
|---|---|
| R1 | 22Ω |
| R2 | 1Ω |

All 0·25W 5% carbon film

**Potentiometers**

| | |
|---|---|
| VR1 | 10k min. rotary carbon, log. |
| VR2 | 100Ω enclosed carbon preset |

**Capacitors**

| | |
|---|---|
| C1 | 4µ7 radial elect. 25V |
| C2, C8 | 220µ radial elect. 25V (2 off) |
| C3, | 100n disc ceramic |
| C4 | 100µ radial elect. 25V |
| C5 | 47µ radial elect. 25V |
| C6 | 390p ceramic |
| C7 | 220n polyester |

**Semiconductor**

| | |
|---|---|
| IC1 | TBA820M audio power amp i.c. |

**Miscellaneous**

| | |
|---|---|
| LS1 | 4 to 32 ohm loudspeaker (see text) |

Printed circuit board available from the *EPE PCB Service*, code 345 (TBA820M); case (optional), size and type to choice; 8-pin d.i.l. socket; multistrand connecting wire; audio screened cable; solder pins; solder etc.

*Approx. Cost Guidance Only* **£10** *excluding case & speaker*

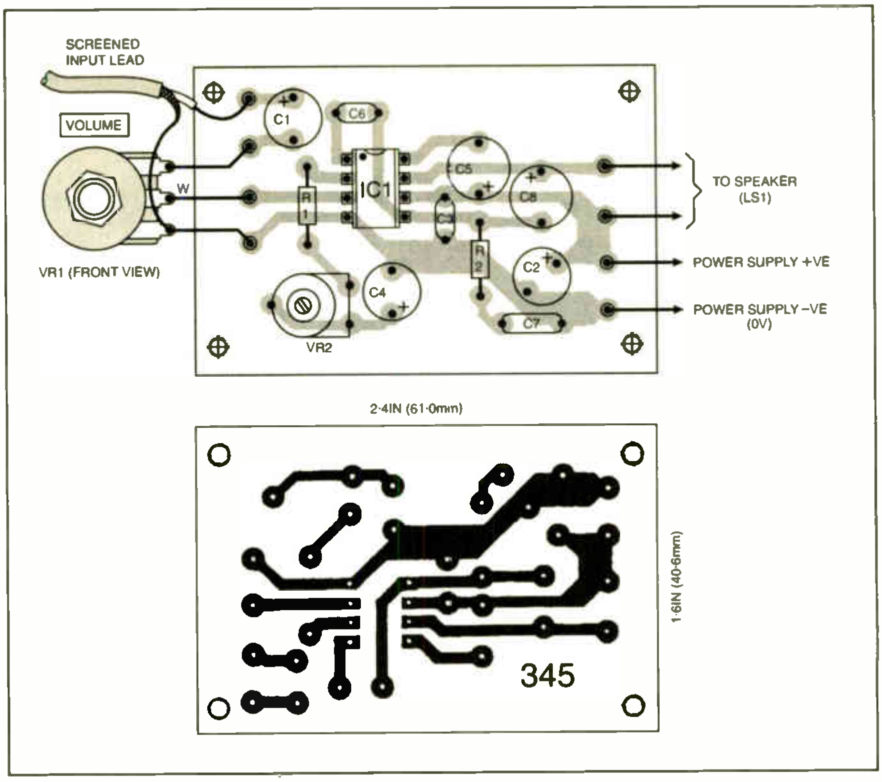



*Fig.6. Topside component layout, off-board wiring details and full-size copper foil master for the TBA820M Amplifier.*

series with capacitor C4, controls the shunting effect and, with the sample tested, gain could be set between 40 and 230.

High frequency response is determined by capacitor C6. The response at the –3dB points for different capacitor values is also listed in the table. If desired, the value of C6 can be increased to reduce the upper frequency response even more.

In this application, the speaker LS1 is connected to the positive supply rail as this reduces the component count (a capacitor and resistor are saved).

## CIRCUIT BOARD

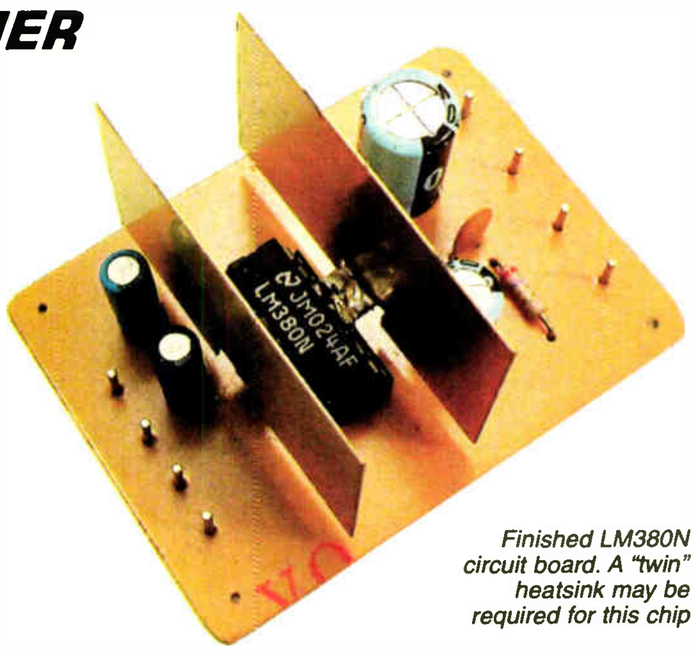
The printed circuit board component layout, wiring details and full-size copper foil master pattern are shown in Fig.6. This board is available from the *EPE PCB Service*, code 345 (TBA820M).

# LM380N AMPLIFIER

An amplifier circuit diagram incorporating the LM380N audio i.c. is shown in Fig.7. A general specification guide is shown below.

The manufacturers, National Semiconductor, have made provision for optional heatsinking via some of the pins, and this makes the package larger (14-pin). The output is short-circuit proofed and there is dissipation limiting. Gain is fixed.

Again, the purpose of the various components will be evident from earlier descriptions. In this version of the circuit, the signal




*Finished LM380N circuit board. A "twin" heatsink may be required for this chip*

### LM380N POWER AMPLIFIER

**R.M.S. power output just before the onset of waveform clipping**

| *Speaker Impedance Ohms* | *Supply Voltage* 9V | 12V | 15V | 18V |
|---|---|---|---|---|
| 4 | 400mW | 1·12W | 1·62W | – |
| 8 | 275mW | 720mW | 1·32W | 2·25W |
| 16 | 137mW | 405mW | 720mW | 1·32W |
| 32 | 68mW | 202mW | 360mW | 765mW |

| | |
|---|---|
| Quiescent current | 13mA |
| Input resistance | 150k ohms |
| Input sensitivity for 720mW output (8 ohm load, 12V supply) | 50mV r.m.s. (gain 50) |
| Absolute maximum supply voltage beyond which damage will occur | 22V |

A heatsink should be fitted if the device is to be operated, other than intermittently, at output levels in excess of 1W.

| | |
|---|---|
| Without a heatsink, the suggested maximum supply voltages are: | |
| with a 4 ohm speaker | 12V |
| with an 8 ohm speaker | 15V |
| Frequency response | up to 100kHz |

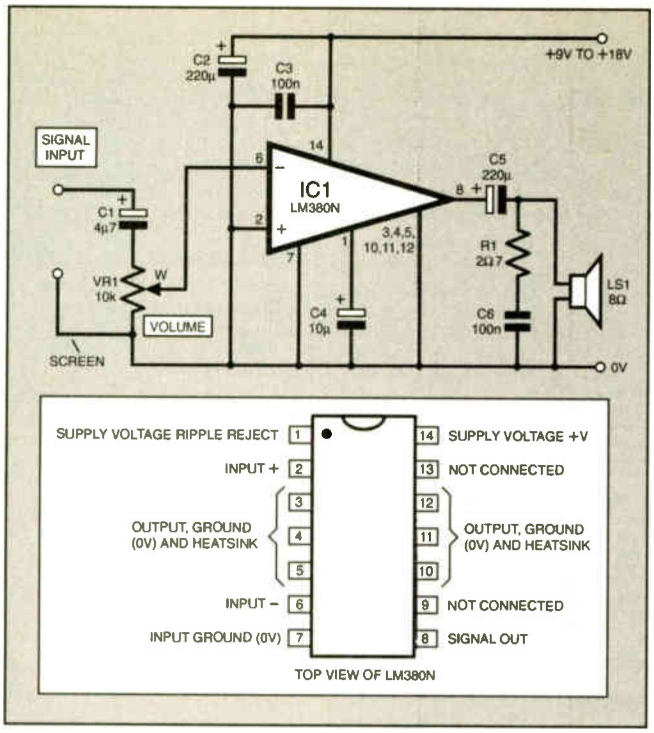



*Fig.7. Circuit diagram for the LM380N Amplifier.*

## COMPONENTS

### LM380N AMPLIFIER

**See SHOP TALK page**

**Resistors**

| | |
|---|---|
| R1 | 2Ω7 0·25W 5% carbon film |

**Potentiometers**

| | |
|---|---|
| VR1 | 10k rotary carbon, log. |

**Capacitors**

| | |
|---|---|
| C1 | 4µ7 radial elect. 50V |
| C2, C5 | 220µ radial elect. 50V (2 off) |
| C3, C6 | 100n disc ceramic (2 off) |
| C4 | 10µ radial elect. 50V |

**Semiconductor**

| | |
|---|---|
| IC1 | LM380N audio power amp i.c. |

**Miscellaneous**

| | |
|---|---|
| LS1 | 4 to 32 ohm loudspeaker (see text) |

Printed circuit board available from the *EPE PCB Service*, code 346 (LM380N); case (optional), size and type to choice; 14-pin d.i.l. socket; heatsink (see text); multistrand connecting wire; audio screened cable; solder pins; solder etc.

*Approx. Cost Guidance Only* **£11** *excluding case & speaker*

is applied to the inverting input (pin 6) and, to avoid instability, the non-inverting input (pin 2) is grounded (0V).

The manufacturers quote a minimum supply voltage of 10V. The sample tested worked with a 9V supply, but performance became erratic at lower voltages. Quiescent current, although modest, is double that of the other low-power devices, and this, together with the higher operating voltage, makes the i.c. more suitable for mains-powered equipment.

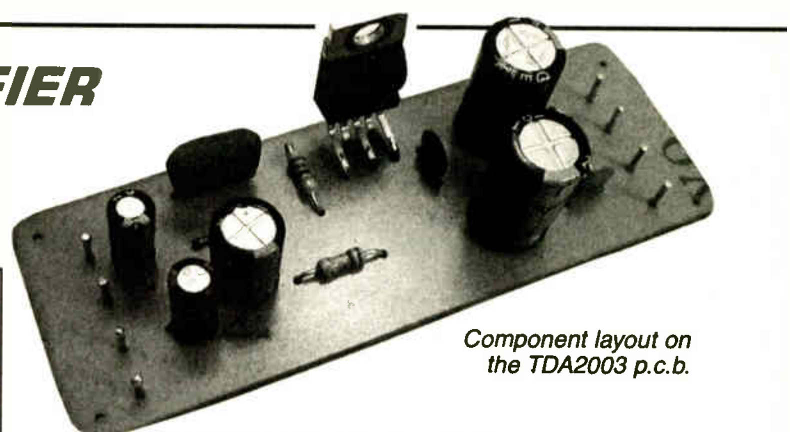
### CIRCUIT BOARD

Details of the printed circuit board component layout, wiring and copper foil master are given in Fig.8. This board is also available from the *EPE PCB Service*, code 346 (LM380N).

Although the board has been kept small, as much copper as possible has been retained to afford some heatsinking.

## TDA2003 AMPLIFIER

Produced by SGS-Thomson, the TDA2003 low-cost i.c. is mainly for use in car radios. Although chips designed specifically for "hi-fi" amplifiers are available, they usually require higher voltage and/or split rail power supplies. This makes them less easy and more expensive to use.



*Component layout on the TDA2003 p.c.b.*

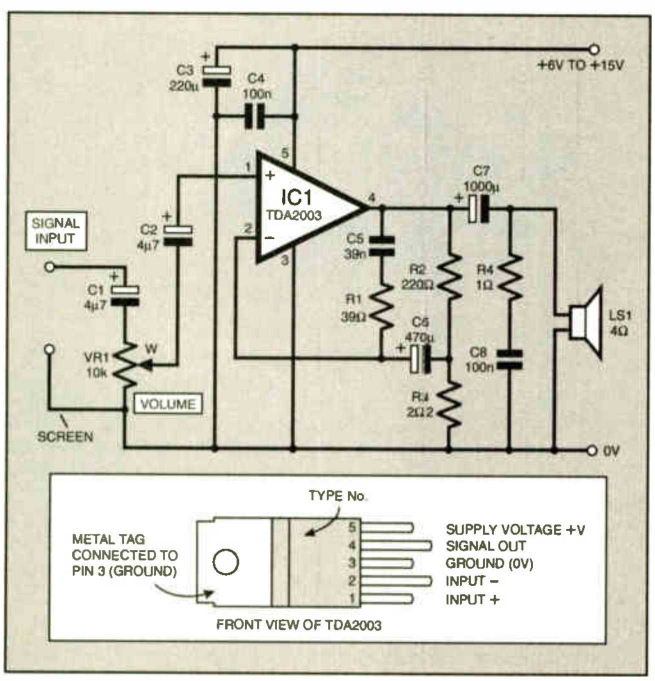



*Fig.9. Circuit diagram for a single TDA2003 Amp.*

### TDA2003 POWER AMPLIFIER

**R.M.S. power output just before the onset of waveform clipping**

| Speaker Impedance Ohms | Supply Voltage 9V | 12V | 15V |
|---|---|---|---|
| 2 | 2·25W | 4W | 5·75W |
| 4 | 1·28W | 2·6W | 3·9W |
| 8 | 720mW | 1·44W | 2·1W |

| | |
|---|---|
| Quiescent current | 45mA |
| Input sensitivity for 2.6W output (4 ohm load, 12V supply) | 42mV r.m.s. (gain 80) |
| Absolute maximum supply voltage beyond which damage will occur | 28V |
| Absolute maximum operating voltage | 18V |

Frequency response: 40Hz to 15kHz at the –3dB points.

The upper frequency limit can be extended by reducing the value of C5.

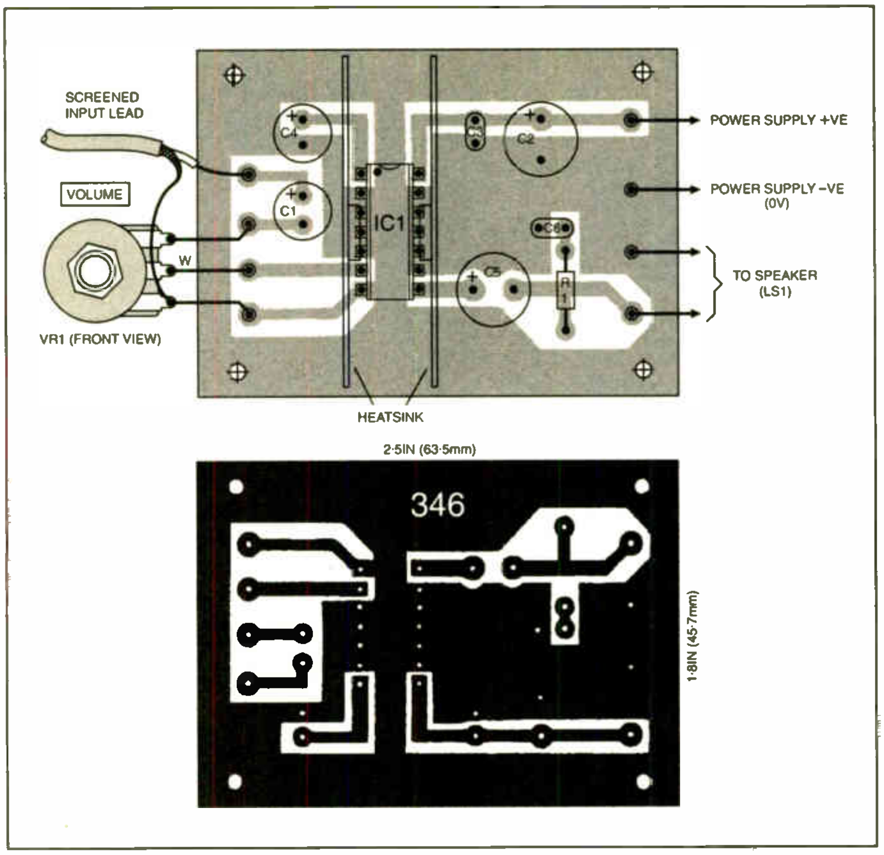



*Fig.8. The LM380N printed circuit board component layout, off-board interwiring and full-size copper foil master pattern. Note the heatsinks.*

## HEATSINKS

For those readers who wish to get the most out of the chip, a suitable heatsink for the LM380 (Fig.7 and Fig.8) can be formed from two, 40mm (1⅝in.) lengths of 25mm × 0·4mm (1in. × 1/64in.) brass strip. Make two shallow cuts, 5mm (3/16in.) apart, close to the centre, and bend out a tag which can be soldered to the relevant pins of the i.c. Thin brass strip can be purchased from almost all model shops.

## COMPONENTS

### TDA2003 AUDIO AMPLIFIER

See SHOP TALK page

**Resistors**

| | |
|---|---|
| R1 | 39Ω |
| R2 | 220Ω |
| R3 | 2Ω2 |
| R4 | 1Ω |

All 0·25W 5% carbon film

**Potentiometers**

| | |
|---|---|
| VR1 | 10k rotary carbon, log. |

**Capacitors**

| | |
|---|---|
| C1, C2 | 4µ7 radial elect. 50V (2 off) |
| C3 | 220µ radial elect. 50V |
| C4 | 100n disc ceramic |
| C5 | 39n polyester |
| C6 | 470µ radial elect. 50V |
| C7 | 1000µ radial elect. 50V |
| C8 | 100n polyester |

**Semiconductor**

| | |
|---|---|
| IC1 | TDA2003 audio power amp i.c. |

**Miscellaneous**

| | |
|---|---|
| LS1 | 4 to 32 ohm loudspeaker (see text) |

Printed circuit board available from the *EPE PCB Service*, code 347 (TDA2003); case (optional), size and type to choice; heatsink (see text); audio screened cable; multistrand connecting wire; solder pins; solder etc.

*Approx. Cost Guidance Only* **£11** *excluding case & speaker*

The TDA2003 incorporates short circuit and overload protection, and is extremely rugged. It will deliver a worthwhile output at modest supply voltages, and the suitability of car batteries as a power source may make it of particular interest to some readers. The circuit diagram of a single chip TDA2003 audio amplifier is given in Fig.9.

Grounding the input (pin 1) of this device would upset the internal biasing arrangements, so a second blocking capacitor C2 must be provided. The high frequency response is set by capacitor C5 in conjunction with resistor R1. The response can be extended by reducing the value of C5. Supply line ripple rejection is afforded by capacitor C6.

The outputs which can be delivered at various supply voltages are tabulated in the accompanying table. The current drawn from a 15V supply when 4W are dissipated into a 4 ohm load is around 500mA. The 2 ohm load is obtained by connecting two 4 ohm speakers in parallel.

At these power levels, the device must, of course, be connected to an adequate heatsink, and this is discussed later.

The printed circuit board component layout, wiring and full-size copper foil master pattern for the single chip TDA2003 amplifier are shown in Fig.10. This board is available from the *EPE PCB Service*, code 347 (TDA2003).

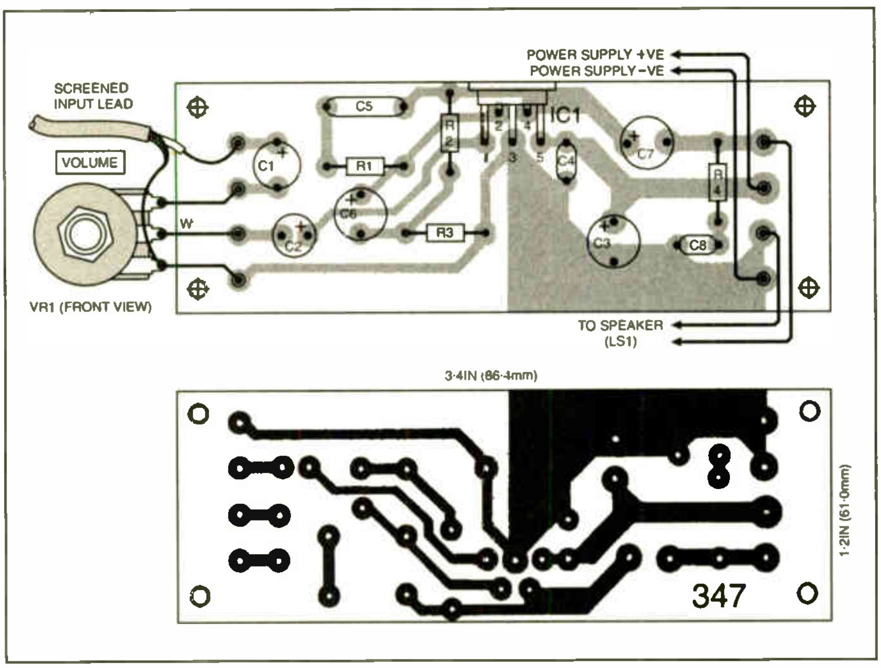



*Fig.10. Printed circuit board component layout, full-size foil master and off-board wiring for the single TDA2003 Amplifier.*

## TWIN TDA2003 AMPLIFIER

A circuit diagram using two TDA2003 chips in a bridge configuration is shown in Fig.11, together with a general performance guide.

Drawing around 1·7A from a 15V supply, this combination will deliver a clean 12·5W into a 4 ohm load. The case for this being adequate for domestic listening has already been argued, but individual constructors will, of course, decide whether or not it will meet their needs.

# TWIN TDA2003 AMPLIFIER

## COMPONENTS

### TWIN TDA2003 POWER AMP

See SHOP TALK page

**Resistors**

| | |
|---|---|
| R1, R4 | 1Ω (2 off) |
| R2 | 220Ω |
| R3, R5 | 10Ω (2 off) |
| R6 | 470Ω |

All 0·25W 5% carbon film

**Potentiometers**

| | |
|---|---|
| VR1 | 10k rotary carbon |

**Capacitors**

| | |
|---|---|
| C1, C2 C9 | 4μ7 radial elect. 50V (3 off) |
| C3, C8 | 100n disc ceramic (2 off) |
| C4 | 22μ radial elect. 50V |
| C5, C6 | 100n polyester (2 off) |
| C7 | 10μ radial elect. 50V |
| C10 | 220μ radial elect. 50V |

**Semiconductor**

| | |
|---|---|
| IC1, IC2 | TDA2003 audio power amp i.c. (2 off) |

**Miscellaneous**

| | |
|---|---|
| LS1 | 2 to 8 ohm loudspeaker (see text) |

Printed circuit board available from the *EPE PCB Service*, code 348 (TDA2003); case (optional), size and type to choice; heatsink (see text); audio screened cable; multistrand connecting wire; solder pins;

*Approx. Cost Guidance Only* **£14** *excluding case & speaker*

*Twin TDA2003 Amplifier circuit board component layout.*

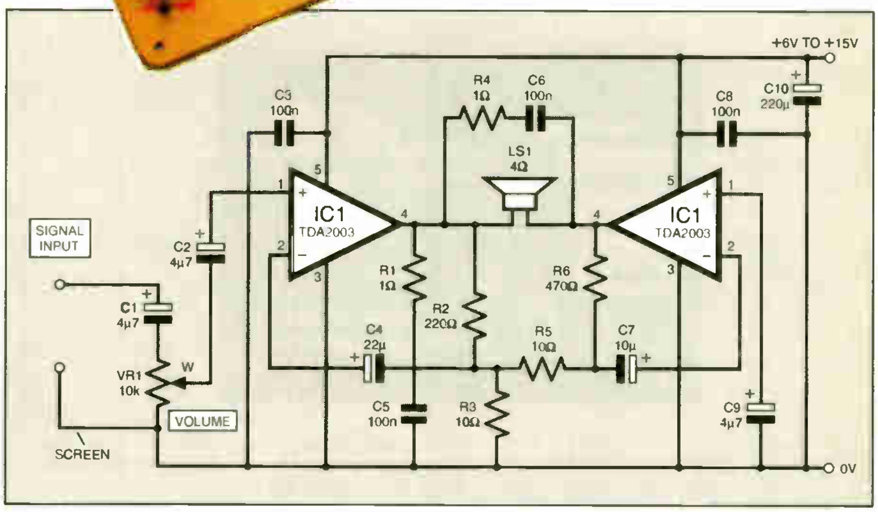



*Fig.11 (above). Circuit diagram for the Twin TDA2003 Power Amplifier.*

### TWO TDA2003 BRIDGE CONFIGURATION POWER AMP

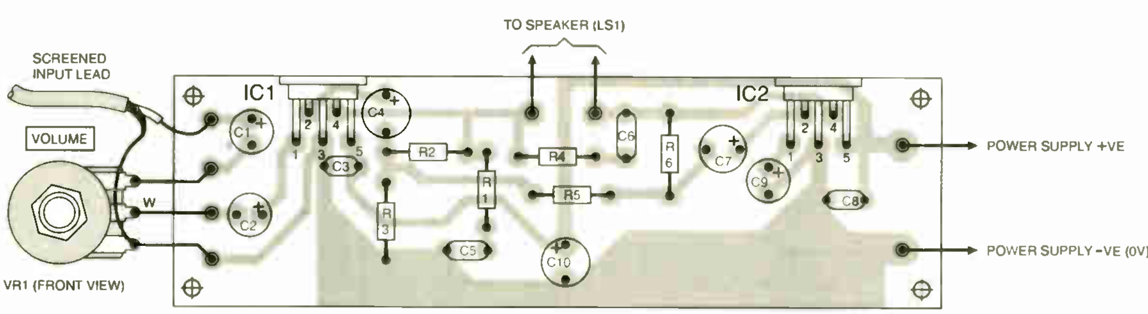
**R.M.S. power output just before the onset of waveform clipping**

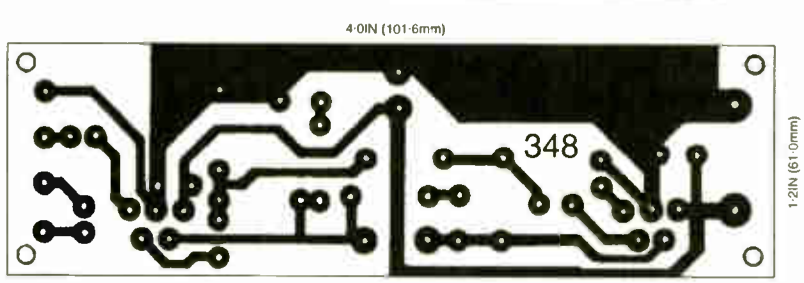
| *Speaker Impedance Ohms* | *Supply Voltage* *9V* | *12V* | *15V* |
|---|---|---|---|
| 2 | 6·25W | 10·5W | – |
| 4 | 3·78W | 8W | 12·5W |
| 8 | 2W | 5W | 8·2W |

| | |
|---|---|
| Quiescent current | 80mA |
| Input sensitivity for 8W output (4 ohm load, 12V supply) | 70mV r.m.s. (gain 40) |

See single TDA2003 for details of absolute maximum ratings.

*Fig.12 (below). Component layout, off-board interwiring and full-size copper foil master for the Twin TDA2003 Amp. You will need a heatsink for these devices.*



The printed circuit board component layout, wiring and copper foil master are detailed in Fig.12. Again, combined or separate heatsinks must be fitted to the integrated circuit's metal tabs. The p.c.b. is obtainable from the *EPE PCB Service*, code 348 (Twin TDA2003).

## HEATSINKS

A large area metal heatsink is required for the TDA2003 (Fig.9 and Fig.11). Because the device incorporates overload protection, the actual size is not too critical (the i.c. will shut down when it begins to overheat), but sustained high output will only be developed if the heatsink is adequate. At the very least use 40sq. cm (6·5sq. in.) of 16s.w.g. aluminium per chip, or fit a proprietary heatsink with a thermal resistance not greater than 7°C per watt.

The i.c.s are arranged on the p.c.b. (see Fig.10 and Fig.12) so that they can be bolted to the back of a metal case by their metal tabs. A 50mm × 150mm × 200mm (2in. × 6in. × 8in.) aluminium box would be more than adequate as a heatsink. Insulating washers are not required, but a smear of heat transfer compound should be applied.

## COMPONENTS

Slight differences in the i.c. type numbers can cause confusion. The LM386N-1 has the lowest power rating of this group of devices. The suffixes "N-3" and "N-4" indicate devices rated at 700mW and 1W respectively. The suffix "M' indicates surface mounting. Suppliers offering the LM386 are usually referring to the N-1 version.

The TDA7052 is sometimes given the suffix "A". This indicates that the chip contains a d.c. volume control and is *not* suitable for the circuit described here.

Some suppliers give the LM380 the suffix "14" to indicate the 2·5W 14-pin version, and the suffix "8" for the 8-pin 600mW alternative. When ordering, make it clear that the 14-pin chip is required.

The suffix "P" or "V" is sometimes added by suppliers to the TDA2003 to indicate that it is for vertical, and "H" for horizontal, mounting. There is no electrical difference, but the p.c.b.s illustrated here have been designed for vertical chips.

## CONSTRUCTION

All the amplifiers covered in this part are assembled on printed circuit boards and construction is reasonably straightforward. The use of an i.c. holder will permit the substitution and checking of the low power amplifiers. However, if reliance is to be placed on the p.c.b. foil for minimal heatsinking of the LM380, the device should be soldered directly in place. Solder pins, inserted at the lead-out points, will simplify off-board wiring.

It may help to start construction of the chosen circuit board by first placing and soldering the i.c. holder on the p.c.b. to act as an "orientation" guide. This should be followed by the lead-off solder pins, and then the smallest components (resistors) working up to the largest, electrolytic capacitors and presets. Finally, the lead-off wires (including the screened input cable), off-board Volume control and loudspeaker should be attached to the p.c.b.

On completion, check the board for poor soldered joints or bridged tracks. Check the orientation of the electrolytic capacitors and the i.c.(s).

If using a mains power supply, make sure the voltage delivered does not exceed the safe working voltage of the amplifier for the load impedance being used.

If all is in order, connect the power supply and check the quiescent current consumption. Inject a signal and re-check the current drain and supply voltage.

**Next Month: Transistor preamplifiers**

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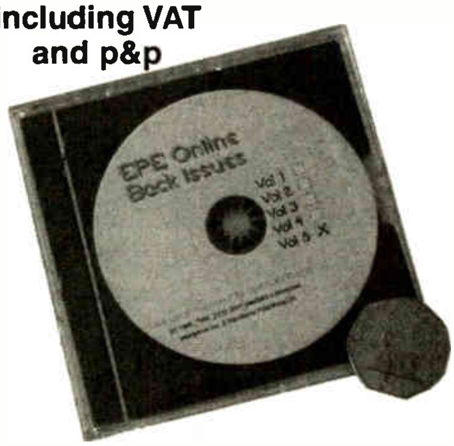


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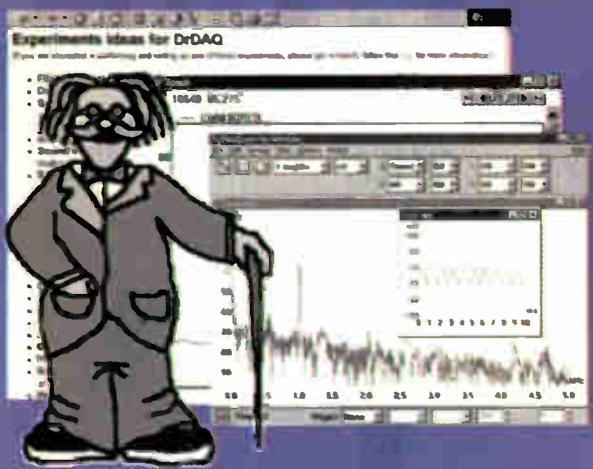


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## ★ LETTER OF THE MONTH ★

### ANALYSING NYQUIST

Dear EPE,

I read with interest the email from Mr Nick de Smith in *EPE* March '02, concerning the *PIC Spectrum Analyser*.

What he says about the lack of anti-aliasing filters and the problems with signals greater in frequency than half the sampling rate (Nyquist frequency) causing aliasing of the signals is absolutely correct.

It has been accepted as a fact that in signal analysis it is not possible to retrieve signals which are greater than half of the sampling frequency. This premise is clearly stated in all textbooks on this subject as the "Nyquist Criteria" or as "Shannon's Sampling Theory".

For example, with a sampling frequency of 2kHz it is not possible to retrieve signals in excess of 1kHz. Any frequencies greater than this 1kHz value will appear as a false or aliased signal and a considerable amount of research and commercial activity has emerged to eliminate such signals by filtering them out from the signal presentation.

However, it has now been proved through a research program (undertaken by myself and Dr R. F. McLean) that the above premise is false and that the limitation of the Nyquist Criteria can easily be overcome. A theoretical study along with a simple capturing device has been developed which can retrieve signals in excess of 2000 times this hitherto limitation in frequency. The system also dispenses with the need for any form of filtering of the incoming signal. For example, by sampling at no greater than 2kHz, frequencies of up to 2·4GHz are unambiguously retrievable.

The technique has been used in vibration condition monitoring and it removes the need for the analyst to predict the maximum frequency of interest in a signal, and thus removes the need to predict the maximum sampling frequency, nor does the analyst need to consider filtering, which could inadvertently filter out the signals of interest. It therefore ensures greater accuracy in diagnosing machinery defects. Also, with its high frequency potential, it will be suitable for use in the field of communication, data encryption and associated disciplines.

The above technique and equipment has already been successfully used within industry. There is a patent pending on this technique and more information can be seen on our web site at **www.HolisticSignals.co.uk**.

**Stephen H Alsop,**
**Sands Systems Ltd, Sheffield,**
**via email**

*Thanks, Stephen. Historically, I understand that Nyquist was a radio engineer investigating the most economically reliable method for transmitting speech data. It was in this context that his ratios were established, with 2:1 being the absolute minimum but 3:1 being considered better for adequate intelligibility.*

*Although I know that stable waveforms can be accurately sampled at frequencies well below their fundamental, I assume your techniques are far superior. In which case you have an amazing breakthrough – a bit like breaking the light barrier, or turning the arrow of time backwards!*

### PIC MINI-ENIGMA

Dear EPE,

The *Mini-Enigma* (Mar '02) is an intriguing idea from Nick Dossis, but please bear in mind that your encryption is not as secure as the original Enigma. It is (worst case figures) eight times more complex than a simple substitution cipher. Like the original Enigma, no letter codes to itself, so for each of the first eight characters there are 25 possible resulting encryptions (these eight being the maximum codeword length). This gives rise to $25^8$ possibilities. Daunting perhaps, but not outside the scope of modern computing equipment.

The example BYEBYE only appears to have no repetition as the codeword in your article is four characters, ABCD. If, instead, a 3-character codeword was applied, then repetition would be immediately apparent – bad news for attempted secrecy!

I found a software emulation of the original machine, on the Internet, at:
**www.ugrad.cs.jhu.edu/~russell/classes/enigma/**.

**Godfrey Manning,**
**Edgware, Middlesex, via email**

*Hello again Godfrey. You are reading more into Nick's design than you should. Don't you recall passing coded messages on paper between you and your classmates at school, probably even written using "invisible" lemon juice ink? That's how we felt* Mini-Enigma *would find appeal – as a modern equivalent!*

*Nick himself replies:*

It is nice to hear from someone who also takes an interest in encryption techniques.

I appreciate your comments pointing out that the encryption technique used in the project does not match that of the original Enigma machine. As mentioned in the article, my design was never meant to be a simulation of the original, however to the untrained eye the coded message would still be difficult to crack. I am sure that if you wanted to make the encryption technique more secure it would be quite straightforward to alter the software. I would certainly be interested to know if anybody tries it.

Don't forget that the message could be made more secure if the user transfers the encrypted message into the match-box memory unit. By using this method, the would-be cracker would first need to know how to retrieve the data out of the PIC's EEPROM memory (which, of course, is in encrypted binary format) and then attempt to decipher the message. How this affects the possibility of cracking the code is practically immeasurable.

**Nick Dossis**

### WEATHER MONITORING

Dear EPE,

I came across your magazine quite by chance with the February issue. For some time now I have been wanting to put together a weather station, just for my own records. I am more mechanical/hydraulic orientated but have sort of taught myself a bit about the electrical side. Am currently doing a course with Colu to make me Mech/Elect. Have looked at some of the off the shelf jobs, just plug in as it were but my goodness what a price! Wonder if NASA can afford them?

Do you perhaps know where I can purchase stand-alone units/senders or where to get kits or plans to build my own units. The parameters I am interested in are: barometric pressure; min/max temperature, including windchill (wet bulb thermometer); wind speed/direction; rainfall; humidity. I plan to download this info say every six hours into a datalogger (if feasible) or direct to PC and would also want the results output as graphs.

I am also busy setting up to capture images from satellite to show what the sky is doing. Maybe there are future articles planned? I really enjoy reading the mag.

**Albin Draper, via email**

*Well Albin, my* Met Office *weather station was published in* EPE *issues Dec '95, Jan '96. However, I am working on a sophisticated update for publication later this year, PIC controlled complete with logger and PC interface. It will do all you mention, except windchill (which I'd not thought about, but might look into). Wind sensing will be solid-state. I regret that I don't know of commercial sources, although a general search via the web may help you. No, we've nothing astronomical in the pipeline.*

### PICtutor AND TK3

Dear EPE,

I recently bought a *PICmicro* development board and the *PIC Toolkit TK3 V1.1*. I was under the impression that with these two I would be able to program the PICMicro on the board and run my own programs. I also have Windows 2000.

When I got the CD it told me that the *Toolkit* will not run on Windows 2000 and it also seems that I need to order more software in order to use the *PICmicro* development board. I also now notice that the *PICTutor* software does not appear to work on Windows 2000 either.

**Chris Ringrow,**
**Linden, Alhampton, Somerset,**
**via email**

*Chris, you have misunderstood –* PICtutor *and* Toolkit *are not related to each other.* PICtutor *is to teach about PICs, with reference to the PIC16F84 (which the* Tutor *board will handle).* Toolkit 3 *is for those who are experienced PIC programmers for use in developing their own programs. As said in the article,* Toolkit *does not run under Win2000 (although we have an article in the pipeline which gives details of using it with 2000 and XP).* PICtutor *runs under any Windows format, but if you have problems you should contact the manufacturers, Matrix Multimedia.*

## MSF, WWVB AND BBC

Dear EPE,

Andy Flind's answer to Steve Davenport's email (Mar '02) prompted me to look up the original article (which was July '01 not July '98 as quoted!). Since WWVB broadcasts on the same frequency as MSF (60kHz), there seems every chance that the MSF repeater will work with WWVB without modification.

I wonder if Steve is aware of **www.boulder.nist.gov/timefreq/stations/wwvb.htm** It wasn't until I did a Google search on WWVB and spent 30 minutes trawling through this splendid site, which although not totally relevant unless you live in the US, has some excellent info about time and related topics.

**Barry Taylor, Rickmansworth, via email**

*Thanks Barry, nice to hear from you again. And, yes, July '01!*

*Incidentally, folks, Barry also drew our attention to a web site devoted to the history of BBC equipment and those who helped run it, of whom Barry was one. The site is well worth a visit and is at:*

**www.roger.beckwith.btinternet.co.uk/bh/menu.htm**.

## INTERRUPTING THE Z BIT

Dear EPE

The article by Malcolm Wiles on *Programming PIC Interrupts* (Mar-Apr '02) was of interest and I was surprised to see the query raised over the use of the instruction MOVF Status,W i.e. what will be the bit in W corresponding to the Z bit of the Status register. Will it be the value in the Status register at the start of the instruction or the value at the end of the instruction? A simple consideration of the hardware of registers will indicate what happens.

The flip-flops of W will have the Status register routed to it and it will be clocked into the flip-flops at the same time that the output of the Zero detection logic is being clocked into the Status register. Hence the old value of the Status register is clocked into W and the zero condition of the old value of the Status register is reflected in the new Z bit which is clocked into the Status register.

**Ken Naylor, via email**

*Malcolm replies:*

As a software engineer I would never presume to guess or assume how Microchip have implemented their hardware.

Just because there is a simple, or obvious, maybe even textbook, way of doing something, does it necessarily follow that every implementation does it that way? If the spec or data sheet doesn't explicitly state something, I think it is safest, from a software point of view, not to make any assumptions.

The situation is almost identical with instructions in which W is both the source of data and its destination e.g. SUBWF f,W . The hardware functions as required because the old value of W at the start is processed with the contents of 'f' and the result clocked back into W to give a new value. Hence the new value does not circulate round giving another 'new' value in the same clock cycle.

**Malcolm Wiles**

## INTERRUPTS CONTEXT

Dear EPE,

I wonder if I have misunderstood the concept of changing memory bank as part of the "context" in Malcolm Wiles' *Using PIC Interrupts*.

Referring to Listing 2 (page 171) it is necessary to select BANK1 prior to initiating the reading of EEPROM by instruction BSF EECON1,RD. Now, what if the interrupt is activated between these two instructions? One of the actions inside the interrupt service routine at ISR is to set its own context and select BANK0. I can't see how the bank selected by the main program is reinstated prior to return at the RETFIE instruction. It looks as though the return continues to thread main program code but with BANK0 still selected. Is there some implicit reselection of the main program's required BANK, for example, through the STATUS word?

As an aside, and as I've said before, it's been a revelation starting to read *EPE* again – keep up the good work and don't change any of it! Let me also put in a good word for BBC Basic for Windows (not just because it's developed by a fellow licensed radio amateur!). Limitations it has, just as with any language, but its use must not be underestimated and its new lease of life under Windows is a boon. At its quoted price, it's also excellent value.

**Godfrey Manning, G4GLM**

*Thanks Godfrey for your continued appreciative interest in us. Malcolm Wiles replies to your question:*

Reference to the PIC data sheets will show that the Bank select bits (RP0 and RP1) are physically part of the STATUS register (bits 5 and 6 respectively). So their setting on entry to the ISR is preserved (along with Z, C, DC, TO, PD, and IRP) when the STATUS register is saved by the SWAPF STATUS,W . . . MOVWF SAVES sequence at the beginning of the ISR.

After that has been done, the ISR can safely change any of these flags, because they will all be reinstated to the values they had on entry to the ISR by the POP: SWAPF SAVES,W . . . MOVWF STATUS instructions at the end of the ISR. This reinstatement includes the values of RP0 and RP1, so at this point Bank 1 will again be selected if it was the setting on entry to the ISR.

Clearly the ISR must not subsequently contain any code which depends on Bank or other STATUS register flag settings made in the ISR itself. (Recall the discussion in the article which noted that once STATUS has been so restored, only non-STATUS affecting instructions (e.g. SWAPF) can be used in any further ISR code.)

**Malcolm Wiles**

## NOTABLY SENIOR

Dear EPE,

This year I will become an official Senior Citizen, and although a long-time reader of *EPE* and *PE* before that, I have never written to the magazine before, so would you indulge me for a moment and allow me to say:

Thank you and all contributors for a splendid magazine, I have had many hours of pleasure, education and also some frustration – due to my shortcomings, not *EPE*'s! In particular, the (relatively) recent interest in PIC's has certainly given my grey matter a bashing – that's not a bad thing! – and your *Toolkit Mk3* is a joy. Following the *PIC Tutorials* has enabled me to modify Bart Trepak's excellent *Xmas Lights Dimmer* (a wonderfully informative article, Dec '98) to suit my taste – you are definitely never too old to learn!

My circumstances are such that I am not able to buy *EPE* every month, and this sometimes leaves me with a problem regarding the *Please Take Note* messages. Of course gremlins creep in occasionally, that is understood, but if I can't afford to buy the mag for a month or two after I've built a project, I miss any error corrections that appear.

Would it be possible for *all* error correction notes to be put onto the Web site? Of course it would be best if I could buy the mag every month – I wish! – but I expect some other readers may have the same problem, and using the already excellent site would really help.

I now intend to construct the *EPE Virtual 'Scope* (Jan/Feb '98). Without asking you to give too much away, should I go ahead, or do you have any news of an updated version in the pipeline (perhaps using your mastery of VB? – is flattery ok?)!

**Derek Waite, via email**

*I wholeheartedly agree, Derek, that keeping the grey cells active is vital (and enjoyable!). I'm pleased to know we've helped to inspire you, and flattery is always welcome! We shall actively consider putting* Please Take Note *on our FTP site, thanks for the suggestion.*

*My* Virtual Scope *is the most advanced of all those I've done. There have been some simpler versions based around PICs since then but they are more limited than the* VS. *I've no plans to do another scope unless technology takes a quantum leap forward again in some way regarding the hardware – VB would only offer a cosmetic advantage, not a physical one.*

## WHEELS A-TURNING?

Dear EPE,

We need to measure distances on archeological sites. Did I see a project for a measuring wheel in *EPE* some time ago?

**Philip Vallis, via the net**

*I replied to Philip that I had designed a PIC unit for use on my pushbike for distance etc, and that it was published as* PICagoras *in two parts Apr/May '97. Philip came back saying:*

I am not allowed to ride a bike after a heart attack. We need a machine that we can carry around and measure distances accurately. We use 30-metre tapes at present. I built the *Earth Resistivity Meter* (Jan/Feb '97), but the archeologist that wanted it has not yet built the frame. I built a magnetometer last year that worked first time! We have used it but found nothing so far. If you can design a measuring wheel I would appreciate it.

That reminds me of a tale when I was in local government. White lines were paid for by the yard. One day an engineer had to measure a road about one mile long, using the measuring wheel. On that day he had been in the pub for lunch. He was somewhat incapable so he called on a van driver to let him lay down in the back and he put the wheel down at the start of each line and lifted it off at the end. Unfortunately the driver decided that he was going too slow and the wheel started going faster and faster. When they got to the end of the road they had measured enough white lines to stretch from London to Brighton.

*Philip, I'm sorry to hear you can't enjoy the pleasures(?) of pushbikes, although I'm on the verge of feeling that age is gradually putting a spoke in my wheels!*

*My* PICagoras, *though, can be used with any wheel and its diameter can be easily programmed into the unit using a signal generator. I still think it might do for you, but regret I can't offer to do it for you.*

*What a delightful tale! It reminds of when my wife and I were in Zante, one of the Greek islands. Cycling along a main road that had recently been white lined, the painting gang had not bothered to avoid a snake in their path, which was now also painted, but dead of course!*

*Incidentally, I'm soon to start testing an Earth Resistivity Logger that (I think!) I have designed for archeology.*

## TK3 AND PIC16F74

Dear EPE,

Is it possible to modify the TK3 software to incorporate the PIC16F74? I have several for my private use, but no means to program them as yet. It would seem they are not as popular as their 8K cousins.

**Peter Barratt, Australia, via email**

*It appears to be pin-compatible with the F874/7 series and should program OK in TK3 – just treat it as being from that family, although its configuration bits may not be the same. Reading its data sheet via www.microchip.com should give you the '74's full details.*

# WASHING READY INDICATOR

TERRY DE VAUX-BALBIRNIE

*Has the washing machine finished? – Avoid those washday blues!*

OUR OLD washing machine gave long and faithful service. Unfortunately, when it did eventually fail, it was not possible to repair it economically.

## DREAM MACHINE

The replacement washing machine is a famous brand, renowned for its high quality and long life. However, after using it for the first time, it became apparent that something that "old faithful" had was lacking in its successor. This was a lamp that came on when it had completed the washing.

The only way of knowing whether it has finished or not is to look closely at the program switch or listen until the machine has not made a sound for some time. Taking the washing out promptly is important if you wish to re-load the machine or if you want to dry the laundry as quickly as possible.

A further point is that if the washing machine is situated in a garage or other place remote from the house, even a warning light will be of little help. You would have to visit it periodically to check whether it had finished its work.

## LAUNDRY DONE

The washing machine alarm circuit described here will give an audible signal (in the form of high-pitched bleeping) when the washing cycle has finished. If the machine has been left on a "rinse hold" setting, it will give a signal when the program has reached this point.

This will prevent the user from forgetting about it and leaving the washing overnight in a machine filled with water. Readers may find the circuit useful for other similar appliances and it has been tested successfully with tumble driers.

However, if the washing machine is situated in some place remote from the house, the buzzer could be placed somewhere else – in the kitchen, for example. For this to be done, you would need to route a length of light-duty twin wire between the main unit and buzzer position.

While operating under standby conditions, the prototype required just 500μA, which may be regarded as negligible. While actually sounding, the current rises to a few milliamps depending on the buzzer used. The internal 6V battery pack will provide several hundred operating hours and will probably give more than one year of service.

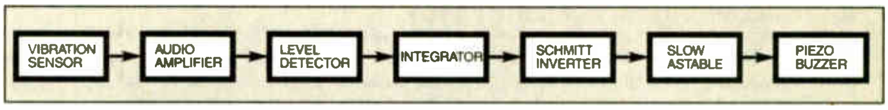



*Fig.1. Block schematic diagram for the Washing Ready Indicator.*

Being battery-operated, the circuit is safe to construct and in operation. Also, because no modifications are made to the appliance itself, using the device will not invalidate any manufacturer's warranty.

The circuit consists of a main unit (see photographs) which is placed near the washing machine. This contains the circuit panel and a 6V battery pack. There is an on-off switch on the front of the case and a socket on the side which is used to connect a sensor. This is placed so as to make mechanical contact with some part of the washing machine.

The warning device (a small piezo buzzer) will normally be mounted on the circuit board with a hole drilled in the box to allow the sound to pass through.


## OVERVIEW

The Washing Ready Indicator works by responding to the sound and/or vibration that occurs while the washing machine motor is operating. When correctly adjusted, other sources of sound have only a minimal effect unless they are particularly loud. Even if they do have some temporary effect, this should not prevent the circuit from giving a proper warning.

The sensor consists of an electret microphone insert (that is, the working part without the external case). While the motor is turning, this provides an electrical signal which is passed to the main unit.

While the machine vibrations continue, the warning does not sound. When it stops, the warning continues to be held off for a further preset time and after that the buzzer sounds.

## HOLD-OFF TIME

This hold-off time is necessary because the motor in a washing machine is not operating all the time during the washing cycle. The drum turns in alternate directions to prevent the clothes tangling and there will be several seconds of silence between each movement.

There may also be longer "quiet" times when the machine is filling with water. The hold-off time must be sufficient to take account of all these factors and will be set by the user for best effect at the testing stage.

## LONG SILENCE

To prevent the warning being given while the washing machine is not in use (obviously a long period of silence!), the unit must be switched on and off manually. The user is unlikely to forget to switch it off because the buzzer will continue to sound until this has been done. However, he or she will need to remember to switch it on at the beginning of the washing cycle whenever a warning is required.

## HOW IT WORKS

Basic operation of the Washing Ready Indicator is best illustrated by the block diagram shown in Fig.1. It will be seen that this comprises seven main parts: vibration sensor; audio amplifier; level detector; integrator; Schmitt trigger inverter; slow astable (low-frequency oscillator) and piezo buzzer.

The complete circuit diagram is shown in Fig.2. MIC1 is the electret microphone insert of the type specified in the parts list. This has an inbuilt f.e.t. preamplifier which requires its own power supply. This is derived from the 6V battery pack, B1, through resistor R1.

Operational amplifier (op.amp), IC1 is a quad device – it contains four identical units IC1a, IC1b, IC1c and IC1d (although only three of these are actually used). IC1a is used for the audio amplifier, IC2b for the level detector and IC1c for the Schmitt trigger inverter.

Taking IC1a first, this is used in a.c. inverting mode. For this, the signal arriving from the sensor MIC1 is applied, via coupling capacitor C1 and input resistor R2, to the inverting input (pin 2).

Capacitor C1 allows the alternating current (a.c.) component (that is, the signal) to pass while blocking the passage of direct current (d.c.) This prevents it interfering with the d.c. conditions of the op.amp.

## STANDING CONDITIONS

As far as d.c. is concerned, the op.amp non-inverting input (pin 3) is held at one-half of supply voltage (3V nominally) by the potential divider action of equal-value resistors R3 and R4. Regarding the a.c. signal, it is at 0V since the impedance of capacitor C2 is very small at the audio frequencies involved. The standing d.c. voltage at the output (pin 1) is equal to that at the non-inverting input – that is, nominally 3V.

The gain of the amplifier is determined by the ratio of feedback resistance (R5) to input resistance (R2). In fact, the gain is *negative* but this has no practical consequence here.

With the values specified, the gain is therefore fixed at (–)220. The result is that a voltage of some 1V peak-to-peak will exist at the output, pin 1, and this will be superimposed on the standing d.c. voltage.

Capacitor C3, connected in parallel with the feedback resistor R5, provides a low impedance path at higher frequencies but a much higher one at the typical frequencies of vibration. It thus has little effect at the "intended" frequencies but the gain is much reduced at higher ones. The circuit is therefore less sensitive to much of the "normal" sound in the vicinity of the washing machine.

## ON THE LEVEL

The level detector based on IC1b "looks at" the voltages applied to its inverting (–) and non-inverting (+) inputs (pin 6 and pin 5 respectively). If the voltage at pin 5 exceeds that at pin 6 the op.amp will be on with the output (pin 7) high. Otherwise it remains low.

The signal provided by the output of the audio amplifier (IC1a pin 1) is applied direct to IC1b inverting input (pin 6). A certain preset voltage is applied to the non-inverting input, pin 5, by the potential divider network made up of R6/VR1/R7.

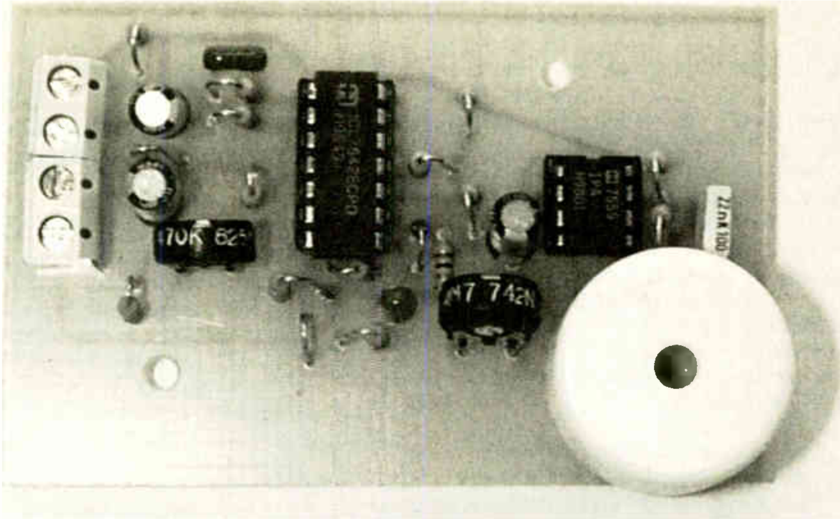
Preset potentiometer VR1 will be adjusted at the end so that the voltage at pin 5 is slightly lower than that at pin 6 (that is, less than 3V) when no vibration is detected. The state of the level detector output (pin 7) will therefore be low when no vibration exists.

Fixed resistors R6 and R7 narrow the range of adjustment of VR1 to the middle one-third of the voltage range (nominally 2V to 4V) and this simplifies setting-up at the end.

## RAPID SWITCHING

When vibration is detected, the voltage at IC1b pin 6 rises on the positive half-cycles and falls on the negative ones. The former have no effect.

However, on the negative excursions, the voltage at pin 6 will fall below that at



Component layout on the finished circuit board.

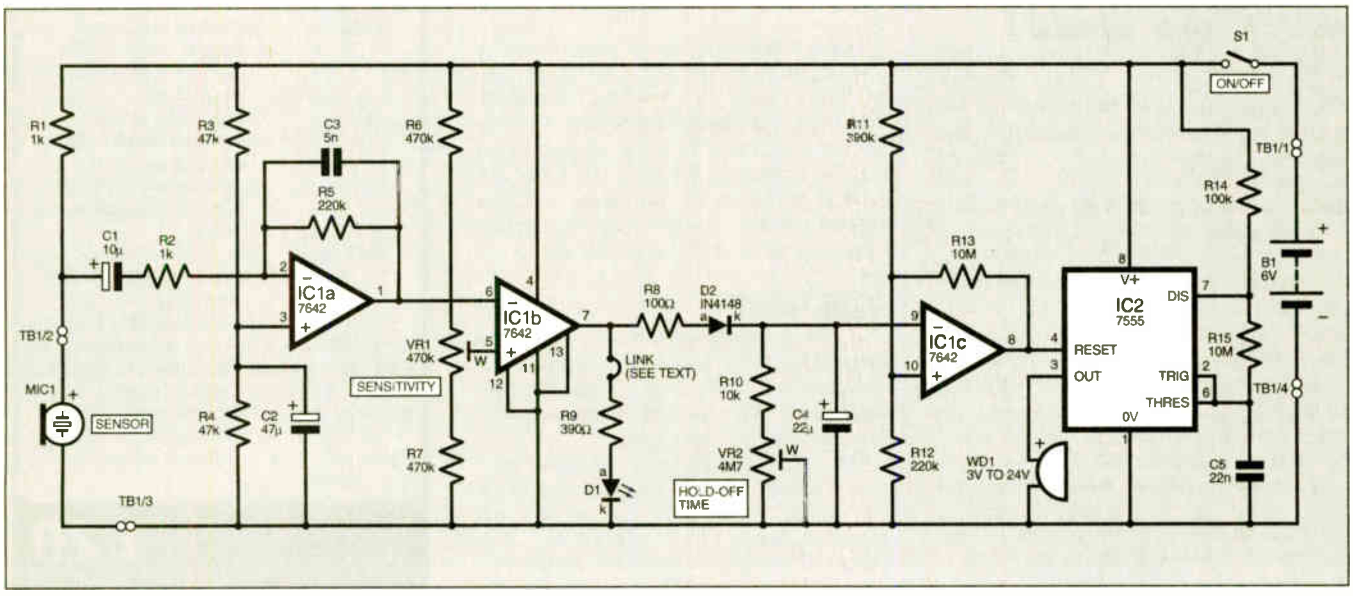



Fig.2. Complete circuit diagram for the Washing Ready Indicator. The battery pack B1 is made up of 4 x AA alkaline cells.

pin 5 and this will result in the output (pin 7) switching between high and low states at the frequency of vibration. The length of the *on* times will depend on how much the a.c. wave falls below the voltage at pin 5 as set by preset VR1. This preset therefore provides the Sensitivity control.

Note that, as the supply voltage falls in the process of battery ageing, this makes no difference to the operating point. This is because the voltages applied to both IC1b inputs vary in the same proportion.

Ignoring the connection from the output of IC1b at pin 7 to resistor R8 for the moment, the signal from the output of the level detector can be directed to the light-emitting diode (l.e.d.) D1 using a "jumper wire" on the circuit board. The operating current is limited to some 10mA by series resistor R9.

The l.e.d. is used to check operation of the circuit up to this point because it will flash when vibration is picked up. It is also used to make a reasonably correct adjustment to preset VR1. At the end of testing, the jumper wire will be cut to prevent the l.e.d. from working and so reduce the current requirement of the circuit.

## INTEGRATION

Returning now to the output from the level detector IC1b at pin 7, consider the current flowing through fixed resistor R8 and diode D2. This allows capacitor C4 to charge up and provides the "integrator" aspect of the circuit.

While pulses are given by IC1b output (pin 7), the relatively small value of resistor R8 allows the capacitor to charge to almost supply voltage in a very short time. In fact, it will not quite reach this value because it is being constantly drained by the network comprising fixed resistor R10 and preset VR2.

When the pulses stop, the capacitor gradually discharges in a time dependent on the adjustment of VR2. It cannot drain back into IC1b pin 7 because diode D2 is reverse biased.

Note that without R10 and VR2, capacitor C4 could only discharge by leakage and this would take a very long time. This is because the input resistance of op.amp IC1c (whose purpose will be explained presently) is extremely high.

## INVERTING EFFECT

Op.amp section, IC1c gives a Schmitt trigger inverting effect. It works like this. The voltage existing across capacitor C4 is applied to the inverting input (pin 9). The non-inverting input (pin 10) is maintained at approximately 2V by the potential divider action of resistors R11 and R12.

While pulses are detected, the inverting input voltage (which is close to supply positive voltage) will exceed the non-inverting one and IC1c output (pin 8) will be low. When the pulses stop and sufficient time has elapsed to discharge C4 below the 2V level, the conditions reverse and pin 8 will go high. Resistor R13 provides some positive feedback and sharpens the switching between the output on and off states.

When the "machine" vibration stops for a short time, the voltage across capacitor C4 does not fall sufficiently for IC1c output pin 8 to go high. When vibration is detected again, the capacitor rapidly charges to its former value.

## TIME ADJUSTMENT

The hold-off time can be adjusted using preset VR2 between limits of almost zero and two minutes approximately. The shortest timing is provided simply for testing purposes. The maximum timing could be extended if required by raising the value of capcitor C4.

A CMOS version of the 555 timer i.c., IC2, is configured as a low frequency astable. While vibration is detected, the low state of IC1c output (pin 8) applies a similar state to IC2 reset input (pin 4). This disables the device and it does nothing.

When the hold-off time expires, IC1c pin 8 goes high and, with IC2 reset input also high, a stream of pulses are passed to IC2 output at pin 3 and hence to buzzer WD1. The frequency of oscillation is determined by the value of fixed resistors R14 and R15 in conjunction with capacitor C5 and with the values used, this should be some 3kHz.

In fact, it appears to vary with operating conditions and was much slower in the prototype. This may be seen as a benefit because it reduces the current requirement. The buzzer connected to IC2 output, pin 3, therefore bleeps in sympathy.

## CONSTRUCTION

Construction of the Washing Ready Indicator is based on a single-sided printed circuit board (p.c.b.). This board is available from the *EPE PCB Service*, code 342. The topside component layout, interwiring to off-board switch and jack socket, and full-size underside copper foil master pattern are shown in Fig.3.

Begin construction by drilling the two mounting holes and soldering the i.c. sockets and p.c.b. mounting terminal block (TB1) in position. Solder the jumper wire to link points *A* and *B*. Follow with the resistors and capacitors (including preset potentiometers VR1 and VR2).

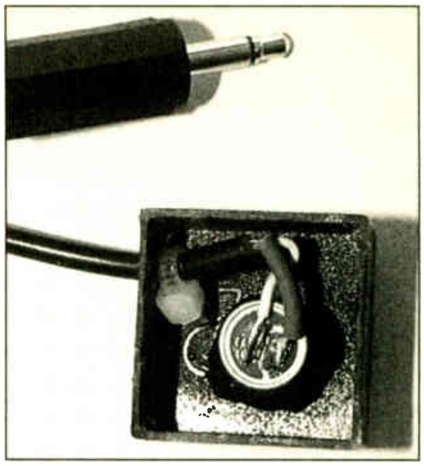
Now, add the polarity-sensitive components which are the electrolytic capacitors, l.e.d. D1, diode D2 and buzzer WD1 (if this is to be mounted on-board) taking care over the orientation of these components. Adjust preset VR1 to approximately mid-track position and VR2 fully anti-clockwise (as viewed from the bottom edge of the p.c.b.). This gives a near-zero hold-off time.

Finish construction of the circuit board by inserting IC1 (but not IC2 at this stage) into its socket taking care with the orientation. Since this is a CMOS component, it is vulnerable to damage by static charge which may be present on the body. To avoid any such problems, touch something which is earthed (such as a metal water tap) before removing the i.c. from its packaging.

## TESTING

It will be found convenient to make a basic test on the unit before the p.c.b. is mounted in its box. In this way, errors are more easily corrected and the preset potentiometers are more accessible.

Cut off a short piece of light-duty twin wire to connect the microphone insert sensor (MIC1) temporarily to the terminal block at points TB1/2 and TB1/3. Look carefully at the microphone connecting pads. The one which is connected to the metal case of the device must be taken to



*Using screened audio cable to connect the electret microphone to the main unit.*

## COMPONENTS

**Resistors**

| | | |
|---|---|---|
| R1, R2 | 1k (2 off) | |
| R3, R4 | 47k (2 off) | |
| R5, R12 | 220k (2 off) | |
| R6, R7 | 470k (2 off) | |
| R8 | 100Ω | |
| R9 | 390Ω | |
| R10 | 10k | |
| R11 | 390k | |
| R13, R15 | 10M (2 off) | |
| R14 | 100k | |

All 0·25W 5% carbon film.

See SHOP TALK page

**Potentiometers**

| | |
|---|---|
| VR1 | 470k sub-min. enclosed carbon preset, vert. |
| VR2 | 4M7 sub-min. enclosed carbon preset, vert. |

**Capacitors**

| | |
|---|---|
| C1 | 10µ radial elect. 16V |
| C2 | 47µ radial elect. 16V |
| C3 | 5n ceramic |
| C4 | 22µ radial elect. 16V |
| C5 | 22n ceramic |

**Semiconductors**

| | |
|---|---|
| D1 | 3mm red l.e.d. |
| D2 | 1N4148 signal diode |
| IC1 | ICL7642 quad op.amp |
| IC2 | ICM7555IPA CMOS timer |

**Miscellaneous**

| | |
|---|---|
| WD1 | miniature solid-state buzzer – 3V to 24V operation at 10mA maximum |
| TB1 | 4-way p.c.b. screw terminal block – 5mm pin spacing |
| MIC1 | miniature two-terminal electret microphone insert |
| SK1/PL1 | 3·5mm mono panel mounting jack socket, with plug |

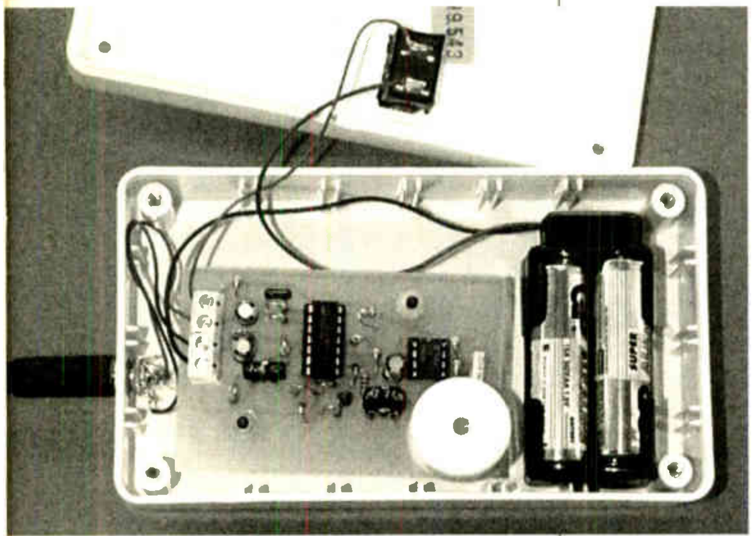
Printed circuit board available from the *EPE PCB Service*, code 342; plastic box, size 143mm x 82mm x 44mm; 8-pin i.c. socket; 14-pin i.c. socket; battery holder and four AA size alkaline cells; PP3 type battery snap (or as required); light-duty screened wire; multistrand connecting wire; solder, etc.

*Approx. Cost Guidance Only* **£20** *excluding batt* the negative (0V) of the supply – that is to TB1/3. The other one is connected to TB1/2.

Connect the PP3 battery snap (or as appropriate) to TB1/1 and TB1/4 taking care over the polarity. Insert the cells in their holder, apply the battery snap and switch on.

Adjust Sensitivity preset VR1 to the point where the "test" l.e.d. D1 is just off. If the microphone is touched, or the table top is tapped, the l.e.d. should flash momentarily. Adjust VR1 so that this happens reliably.

The battery should now be disconnected and IC2 inserted into its socket observing the anti-static precautions mentioned earlier for IC1. It is best to leave the l.e.d. in circuit for the moment.



*Positioning of components inside the plastic case.*

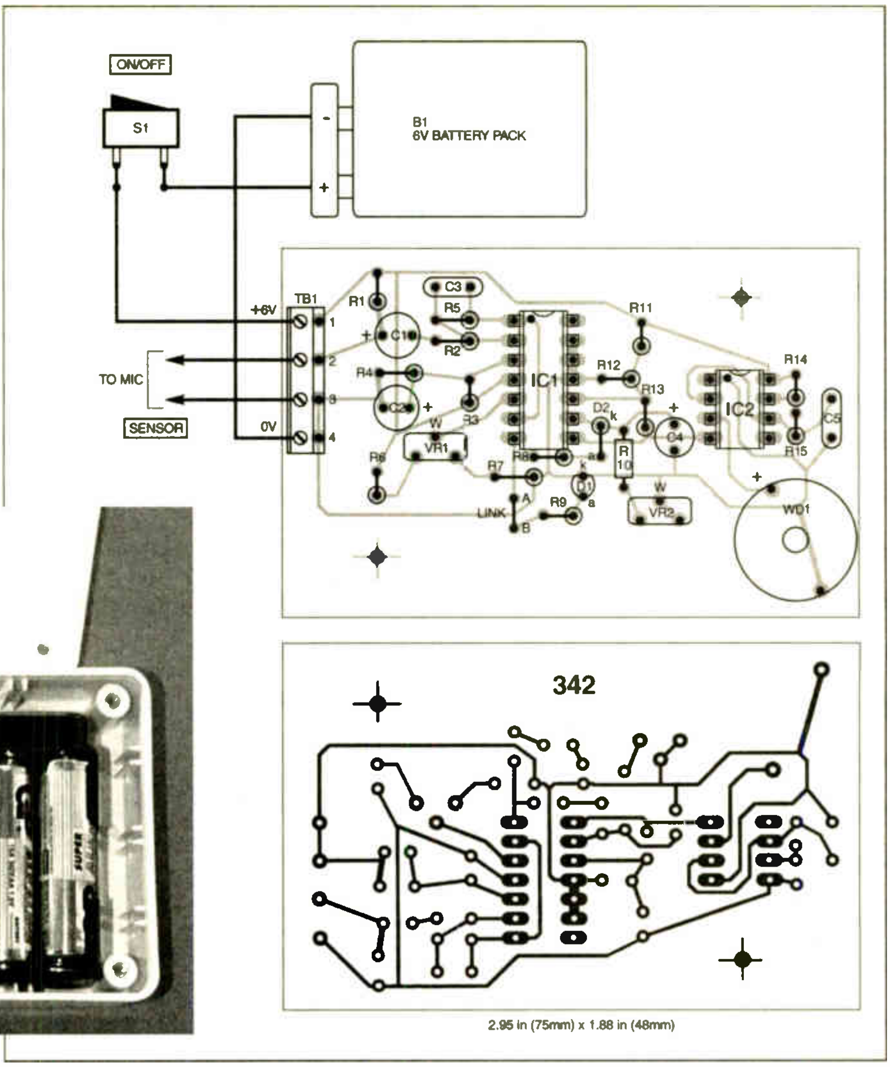



*Fig.3. Printed circuit board component layout, full-size copper foil master and wiring to off-board components.*

With no sound detected, buzzer WD1 should operate. Sound should make the buzzer stop but begin again as soon as it stops. This might not work properly unless preset VR2 is adjusted slightly clockwise to give a small hold-off time. If that works, adjust VR2 to provide a longer hold-off time of, say, 30 seconds.

Check that if sounds are made periodically within this time, the sound is held off. This will provide an approximate setting but final adjustments to the presets can only be made with the unit under actual operating conditions.

## BOXING UP

Remove the temporary sensor wires from terminal block TB1. Place the p.c.b. and battery holder on the bottom of the box to find their best positions. If the unit is to be wall-mounted, remember to allow space for the holes which will be used to attach it.

Mark through the holes for the various parts, also mark positions for on-off switch (S1) and the 3·5mm mono jack socket which is used for sensor MIC1 connection. Measure the buzzer position and drill a hole in the lid directly above this. If the buzzer is to be mounted remotely, mark the position for a further socket (say, a small "power-in" or a 2·5mm mono jack type) for this to be connected.

Remove all these parts, drill the holes and attach them. Use plastic stand-off insulators for p.c.b. mounting to bring the buzzer up to level of the hole in the lid.

Refer to Fig.3 and complete the wiring using light-duty stranded connecting wire. If buzzer WD1 is mounted remotely, connect the buzzer pads on the p.c.b. to the buzzer output socket taking account of the polarity.

## SITING THE UNIT

Decide on a suitable position for the main unit. This should be placed fairly close to the washing machine (say, within 4 metres). Make the sensor connection using light-duty single *screened* wire (microphone cable). This is because ordinary wire could pick-up stray mains "hum" and could result in the injection of unwanted signals into the circuit. It is possible that this could hold off the warning in the absence of any vibration. When connecting the jack plug to the sensor wire, solder the outer (sleeve) terminal to the *screening*.

Mount the microphone insert inside a small plastic box (a potting box was used in the prototype). To do this, drill a hole to make a push fit for the microphone insert. Secure it using a little quick-setting adhesive.

Drill a further hole in the side of the box for the connecting wire to pass through. Pass the wire through the hole and, allowing a little slack apply a tight cable tie to provide strain relief.

Twist and sleeve some of the screening braid and solder the wires to the microphone pads. The pad which is connected to the metal case of the microphone should be the one which is connected to the screening.

If the buzzer is to be mounted remotely, the connecting wire may be of any convenient length and be of any light-duty stranded twin type.

## FINAL TESTS

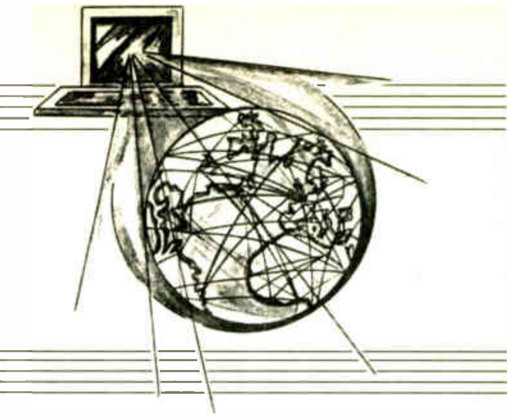
With the main unit in position, route the screened sensor wire between it and the washing machine and plug it in. Make some tests with the sensor in various positions observing the l.e.d. A suitable place should be found where the drumming noises of the washing machine case cause the l.e.d. to flash brightly. When satisfied about this, make further adjustments to preset VR1 as required.

In some cases it will not be found necessary for the sensor to touch the washing machine at all – just placed close enough for it to pick up the noise. However, if doing this, you may need to set the sensitivity somewhat higher and this may make the unit more susceptible to the pick-up of stray random noise.

Make some tests under real operating conditions. Adjust preset VR2 for a suitable hold-off time so that the buzzer is prevented from operating under all "silent" conditions on all washing programs. When satisfied about all aspects of operation, cut the jumper wire on the p.c.b. to prevent the l.e.d. operating.

Happy washday! □

# SURFING THE INTERNET



# NET WORK


## ALAN WINSTANLEY


WELCOME to *Net Work*, our monthly column written for Internet users. Have you visited our web site at **www.epemag.wimborne.co.uk** recently? You can view a summary of all issues of *EPE* dating back several years, with colour photographs and indexes of projects also available together with any *Please Take Note* corrections for that year. You can buy back issues, books, CD-ROMs, videos and p.c.b.s online via our online shop (**shopdoor.htm**). You can also download copies of the magazine from **www.epemag.com** (our Online issue priced in US dollars).

Our "Chat Zone" message board is proving to be increasingly popular, and is an easy way of posting plain text messages into a forum where you can communicate with other readers; if you are looking for advice or help from fellow electronics enthusiasts, why not ask them by posting your message into the *EPE* Chat Zone? We are very grateful to the regular readers who support us and help out with queries in the Chat Zone.

### Strip Teaser

In the March '02 issue of *EPE Net Work* I pointed the way to a simple Stripboard Designer graphics program that is available as shareware from **www.geocities.com/stripboarddesigner**. The principle of shareware is very simple – you download the demo for free and if you like the product, you buy it! If you don't like it, you haven't lost anything! Some of the world's best programs such as JASC Paint Shop Pro started out as modest shareware, so by supporting shareware honestly you encourage software authors to develop their ideas further.

One of the tasks I still enjoy is the creation of stripboard layouts, which I always found to be a stimulating mental exercise (followed by all the troubleshooting afterwards!). For decades I used quadrille (squared) paper and after some frenetic scribbling and erasing I would finally develop a layout that I could take to the workbench. Nowadays, computers can help a lot by allowing layouts to be created and edited on-screen, also the design can be saved and printed for future reference.

Probably the first commercial program to help with this task was Ambyr's *Stripboard Magic*, which my fellow contributor Andy Flind (who creates many of *EPE*'s drawings) reviewed in *EPE* March 1998 issue. The program could create automatically from a circuit diagram a layout either for stripboard or a plug-in solderless breadboard.

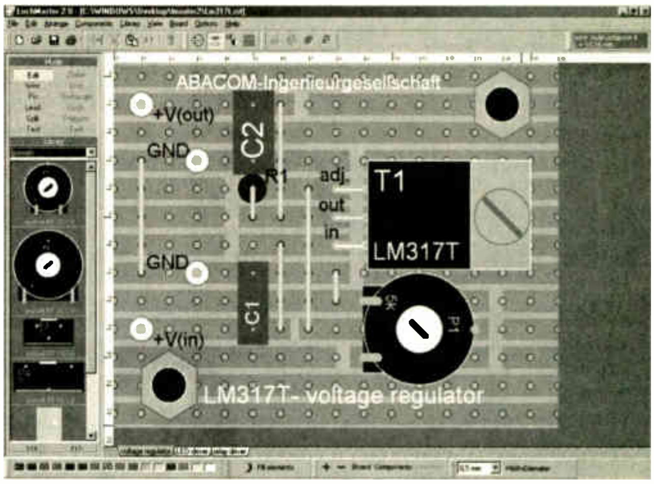
I occasionally get emails asking me what happened to Stripboard Magic. Well, just as the program was starting to gain acceptance, it is believed that Ambyr sold the exclusive distributorship to a mail order company. The program and its web site sank without trace and Ambyr Ltd. was dissolved in December 1999 (according to Companies House Online at **www.companieshouse.gov.uk**).

### Lochmaster 2.0

However, I am very grateful to reader ***Branko Zupan*** in Slovenija who has brought to my attention a German stripboard design package called *Lochmaster*. This is produced by Abacom and an English version is downloadable from **www.abacom-online.de**. The demo allows ten elements to be positioned, and print and save functions have been disabled. It appears to be a very good tool for helping to design layouts by hand, although it does not automate the total design process as Stripboard Magic did.

The component library is comprehensive and incorporates all the usual discrete and integrated devices, semiconductors, plus a good range of hardware, including fasteners, pin headers and d.i.l. sockets. New components can also be added to the library.

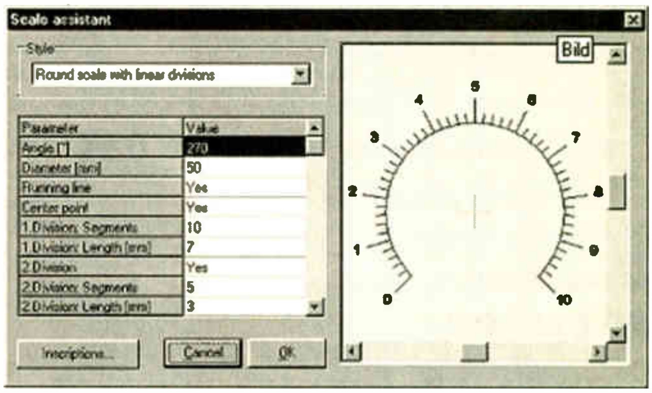
Stripboards are designed by placing components on the board, rotating and linking as necessary and making breaks in the copper track using the Split command. Different views are available – the component side of course, plus an X-ray mode and a solder-side (flipped) view. The views are zoomable and, usefully, a Components List can be created and printed from the board design.




*Top view of a small sample board created in Lochmaster 2.0.*

New pages can be added to a project design, each page having its own "tab". A very handy feature is the Test command, which literally highlights a route taken by a conductor throughout the board, including wire jumper links (but not through components). You can, therefore, reveal a path of interconnections to prevent unwanted short circuits to other components or strips.

You still need rather an agile mind to create stripboard layouts, but this technique will suit many electronics enthusiasts absolutely fine. Lochmaster 2.0 is available direct from Abacom for 35.28 (about £22 or US$30).




*Scale Assistant, part of the Front Designer package, creates complex scales for rotary controls.*

### Front Line

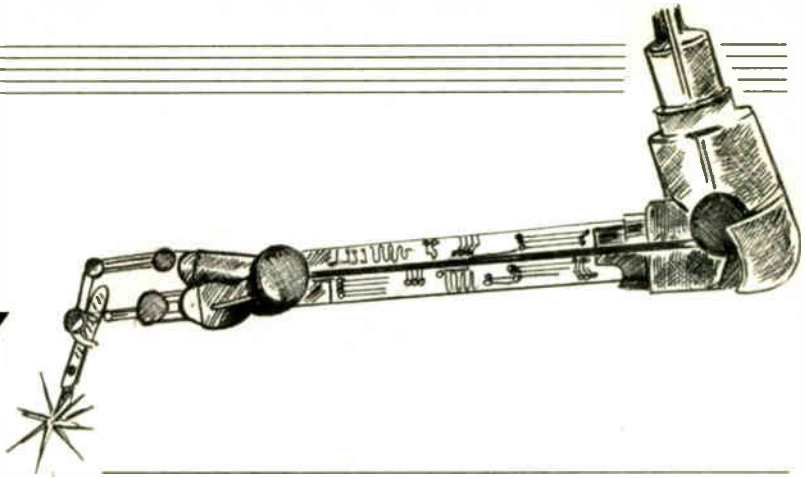
Also worth checking out is Abacom's Front Designer package for drafting front panel layouts for your projects. Amongst other things, its "Scale Assistant" helps with the divisional markings for those pesky rotary switches and volume controls. You can then print out the final design onto transparent film or photopaper (or consider large Avery "invisible" clear inkjet labels?) and affix it to your project. The whole point of such software packages, of course, is that you can play around on-screen to your heart's content without doing any damage to that precious anodised aluminium panel.

See you next month – you can email Alan at **alan@epemag.co.uk** or visit his web site at:

**http://homepages.tcp.co.uk/~alanwin**.

Regular Clinic

# CIRCUIT SURGERY



**ALAN WINSTANLEY and IAN BELL**

***Our monthly feature of readers' queries looks at analogue opto-couplers and a timely problem***

## Linear Opto-coupler

My thanks to *Dave Larner* who writes by email;

*I found the March instalment of* Teach-In 2002 *with the practicalities of the instrumentation amplifier very informative and helpful. I wondered if you could give me a pointer of where to look for a linear opto-coupler. I have been experimenting with some of the biofeedback circuits dating back to* Practical Electronics *May 1987!*

*I would like to connect these to my oscilloscope or maybe some kind of recorder. This would leave the biofeedback circuit battery powered for reasons of safety and electrical noise. I have tracked down a number of data sheets but the applications all seem to be for coupling digital circuits. Are there specialist types available?*

We're pleased you're enjoying *Teach-In 2002 Making Sense of the Real World*, our multi-part series created to help constructors adapt and use many types of environmental sensors within their own projects. We hope that there is something in this *Teach-In 2002* series to suit everyone: as we said right at the beginning, "one often gets the impression that the world has gone completely *digital* in nature, with telephones, television, music, photography and radio all following this trend.

None of this allows us to escape the fact that the real world is actually *analogue* – a world in which many electronics applications must obtain information from their environment and condition it correctly, before it can be handed over for digital processing." Our series outlines many fundamental principles of operational amplifiers, instrumentation amplifiers, low noise techniques, including a lot of material not covered before in *EPE.*

## In Isolation

How to optically isolate an analogue signal is something I put to Dr David Chesmore, one of the *Teach-In 2002* co-writers and closely involved with the Biomedical Engineering Research Group at the University of York. Dave has produced most of the environmental monitoring material of our series, and he suggested that most opto-isolators can be operated linearly since they contain l.e.d.s and (usually) phototransistors.

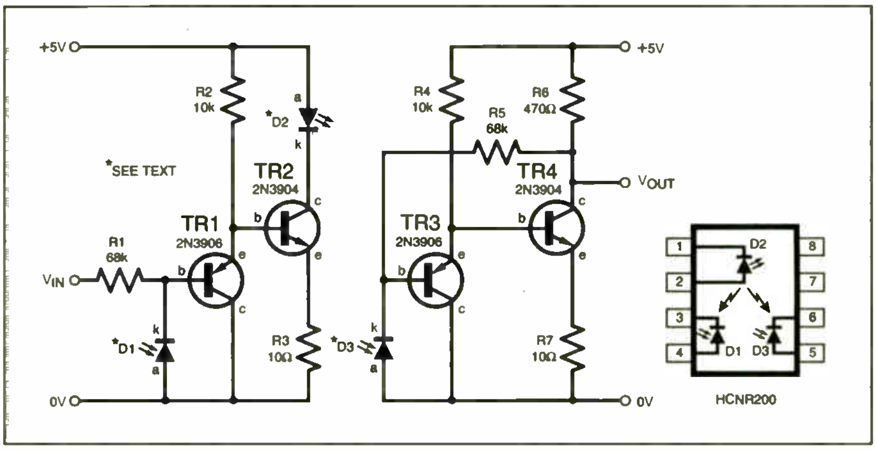




*Fig. 1. Circuit for a high speed, low-cost analogue opto-isolator using the HCNR200.* (Courtesy Agilent.)

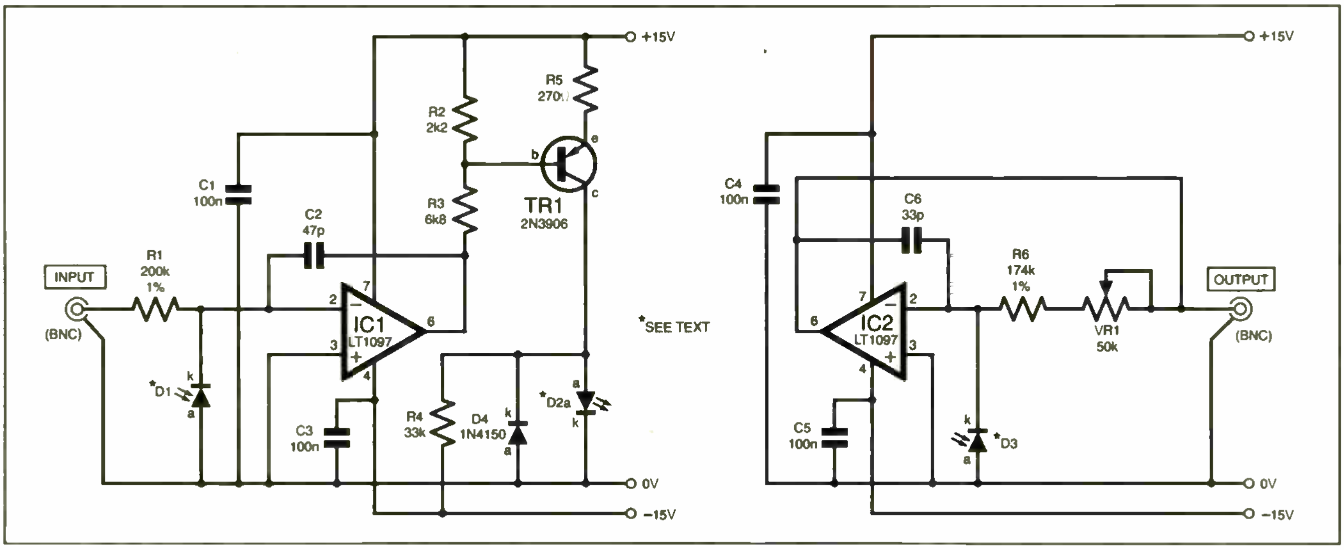




*Fig.2. Circuit for a precision analogue isolation amplifier based on the HCNR200.* (Courtesy Agilent.)

It would be worth putting a variable voltage onto such an l.e.d. and observing the output. The Toshiba 4N29, for example, has an l.e.d. and a photo-Darlington transistor which means the transistor output (with load resistor from emitter to ground and collector to positive supply) will produce an output proportional to the l.e.d.'s drive current.

Subsequently, Mr. Larner reverted with more details of an interesting device he had found after consulting Agilent (the opto-electronics offshoot of Hewlett Packard). The Agilent HCNR200 is a high linearity *analogue* opto-coupler containing a high efficiency l.e.d. that illuminates *two* closely matched photodiodes (see Fig.1). The "input side" photodiode (D1) can be used to stabilise the light output of the l.e.d. (D2), so that the non-linearity and drift of the l.e.d. can be eliminated.

The Agilent HCNR200 claims 0·25% non-linearity and the higher spec. HCNR201 0·05% maximum non-linearity. You can download the data sheet from **www.agilent.com**. They are available from RS Components (**rswww.com**) e.g. the HCNR200 Part No. 801-465 is listed at £2.47, excluding VAT and P&P. Other linear opto-couplers are also available from RS including the IL300 which may be worth investigating.

A practical example of a low cost analogue isolator is shown in Fig.1, while Fig.2 shows a suggested precision analogue isolation amplifier. Low noise and shielding techniques using BNC and triaxial connectors are also covered in *Teach-In 2002* and may be helpful in applications like these. The Agilent data sheet contains more practical circuits and detailed theory.

Thanks for letting us know! *ARW.*

## Dog and Cat Scarer

An interesting circuit recently appeared in our readers' circuits feature – *Ingenuity Unlimited*, March 2002 (p163). *The Dog and Cat Scarer* prompted a letter from reader **Martin Stubbs** who emails:

*A device such as the* Dog and Cat Scarer *would be extremely useful to us as we enjoy walking, particularly on holiday as last year we were harassed by dogs in Greece. I am intrigued to know how the two 555 timers used in the circuit work. I cannot determine how IC1 is set up as an oscillator or IC2 as a buffer amplifier. Perhaps* Circuit Surgery *could dedicate a few lines of explanation as to how it works.*

Referring back to the March *I/U*, first of all an unfortunate error crept into the circuit diagram: note that the connections to pin 2 and pin 3 of IC2 should be reversed. The circuit's operation then makes a whole lot more sense! We also stated that it should *NOT* be relied upon as a defence against aggressive dogs.

First, IC1 is configured as an oscillator using a method that is often overlooked by constructors. It utilises one feedback timing resistor between the output (pin 3) and the threshold (pin 6) and a capacitor to control the frequency.

If the CMOS 7555 version is used, then the fact that it switches from rail-to-rail means that you can obtain a 50 per cent duty cycle (the main advantage of this type of circuit). The result is a square wave appearing at pin 3.

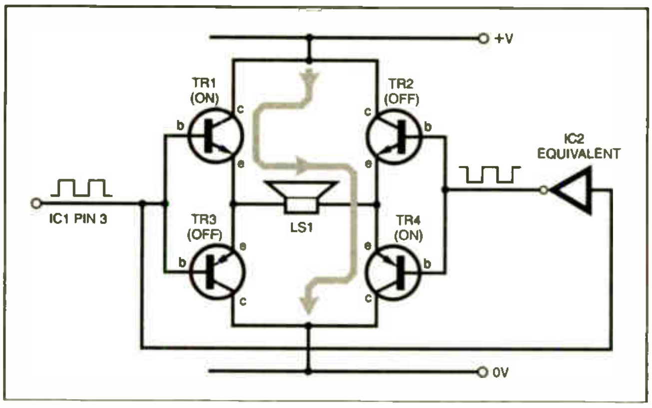



*Fig.3. In an H-bridge driver, opposing pairs of complementary transistors drive the load as shown by the path (tint) taken by the current. (One phase of full circuit is shown.)*

Turning to the H-bridge arrangement, this uses four power transistors wired in complementary opposing pairs. When IC1 output goes ***high***, this turns on the ***npn*** transistor TR1, but the *pnp* transistor TR3 does not conduct. The output of IC1 also triggers the monostable IC2 – the trigger pin (2) needs to be taken low for the timer to trigger.

So, with IC1 output high, IC2 trigger input is pulled high, so IC2 output remains ***low***. This allows the *pnp* transistor TR4 to conduct because its base is pulled low – so with the pair TR1 and TR4 conducting hard, current flows through the ultrasonic sound transducer LS1 as shown in Fig.3.

The designer mentioned a current flow of 4 amps when using a bench power supply which I can well believe; the *Power Siren* shown in *Circuit Surgery* June 1997 uses a ZSD100 siren chip and an H-bridge driver to produce an ear-splitting and highly efficient loudspeaker siren.

When IC1 output goes ***low*** then TR3 conducts instead of TR1, and IC2 is now triggered at pin 2. The monostable timer output goes high which supplies base current to TR2. Current therefore passes through TR2, LS1 and TR3 to 0V.

Thus, two opposing transistors are switched alternately in order to supply high currents through LS1. Exactly the same principle is often used to control the direction and speed of powerful d.c. motors, and special driver chips are available for this.

## Buffered Solution

You asked how IC2 works as a buffer amplifier. It is wired as a monostable (single shot timer) with a short period. Once triggered by IC1, the monostable will start timing and it will ignore any more trigger signals until it times out. However, if a trigger signal is *present when the monostable tries to time out*, then a 555 will *carry on timing* until the trigger is removed, when the output will go low at the same time.

A quick 555 breadboard experiment will demonstrate this – build the monostable of Fig.4, briefly trigger it and watch the l.e.d. time out automatically after a second or two. Then keep it triggered for several seconds – the output will go low as soon as the trigger is removed.

Taking a brief look at the timing of the circuit, in theory the on-time of IC2 is calculated approximately by 1·1 R2.C4 which is 11$\mu$s. If IC1 is said to run at 40kHz then by using frequency = 1/t the period (t) of its output is 25$\mu$s. These figures do not allow for component or formula tolerances and are only for illustration.

Let's think about this a bit more. If we assume the astable has a 50% duty cycle then it is high for (say) 12·5$\mu$s and low for 12·5$\mu$s, see Fig.5. Each negative-going edge triggers the monostable for 11$\mu$s, after which the monostable wants to time out but the trigger voltage is still there (with 1·5$\mu$s still to go): so the monostable

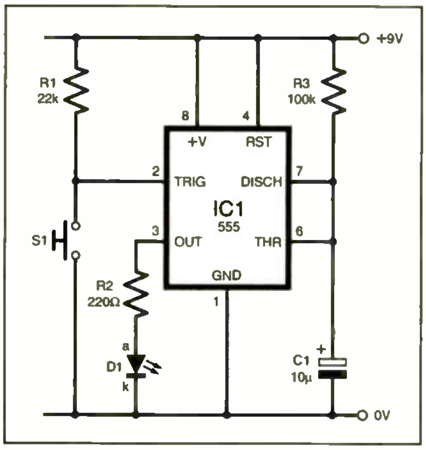



*Fig.4. Circuit for testing the re-triggerability of a 555 monostable. Keep switch S1 closed for several seconds and observe the l.e.d. D1.*

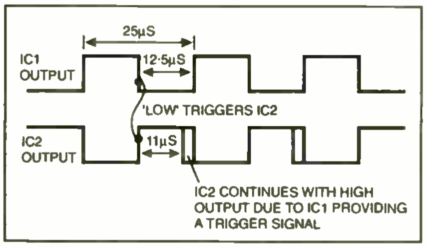



*Fig.5. The monostable IC2 will continue to give a High output for as long as its trigger pin is held low by IC1. IC2 can therefore be used as an inverter.*

carries on timing until the trigger is removed, when the monostable output will go low at the same time. After a further 12·5$\mu$s the monostable is triggered once again. These timing values may not be quite the same in practice, but you get the general idea.

The overall result is that the monostable simply inverts the astable's square wave. It provides base current to both transistors TR2 and TR4, because the *bipolar* 555 is able to sink up to 200mA current into its input and source current out when it's high.

You could perhaps "force" the inverter operation more by ensuring the monostable period is even shorter still. Overall, it's quite a cunning design and I look forward to constructing one myself. My thanks to ***Dave Stringwell*** in Scunthorpe for submitting the design. *ARW.*

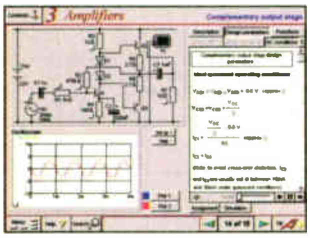
# ELECTRONICS CD-ROMS

## ELECTRONICS PROJECTS

Logic Probe testing

*Electronic Projects* is split into two main sections: **Building Electronic Projects** contains comprehensive information about the components, tools and techniques used in developing projects from initial concept through to final circuit board production. Extensive use is made of video presentations showing soldering and construction techniques. The second section contains a set of ten projects for students to build, ranging from simple sensor circuits through to power amplifiers. A shareware version of Matrix's CADPACK **schematic capture, circuit simulation** and **p.c.b. design** software is included.
The projects on the CD-ROM are: Logic Probe; Light, Heat and Moisture Sensor; NE555 Timer; Egg Timer; Dice Machine; Bike Alarm; Stereo Mixer; Power Amplifier; Sound Activated Switch; Reaction Tester. Full parts lists, schematics and p.c.b. layouts are included on the CD-ROM.

## ANALOGUE ELECTRONICS

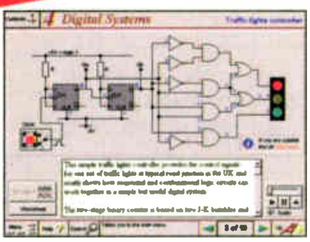


Complimentary output stage

*Analogue Electronics* is a complete learning resource for this most difficult branch of electronics. The CD-ROM includes a host of virtual laboratories, animations, diagrams, photographs and text as well as a SPICE electronic circuit simulator with over 50 pre-designed circuits.
Sections on the CD-ROM include: **Fundamentals** – Analogue Signals (5 sections),Transistors (4 sections), Waveshaping Circuits (6 sections). **Op.Amps** – 17 sections covering everything from Symbols and Signal Connections to Differentiators. **Amplifiers** – Single Stage Amplifiers (8 sections), Multi-stage Amplifiers (3 sections). **Filters** – Passive Filters (10 sections), Phase Shifting Networks (4 sections), Active Filters (6 sections). **Oscillators** – 6 sections from Positive Feedback to Crystal Oscillators. **Systems** – 12 sections from Audio Pre-Amplifiers to 8-Bit ADC plus a gallery showing representative p.c.b. photos.

## DIGITAL ELECTRONICS V2.0

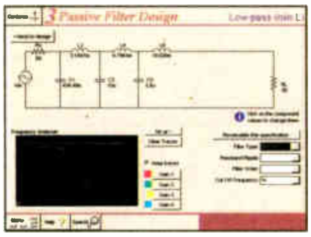
NEW VERSION 2



Virtual laboratory – Traffic Lights

*Digital Electronics* builds on the knowledge of logic gates covered in *Electronic Circuits & Components* (opposite), and takes users through the subject of digital electronics up to the operation and architecture of microprocessors. The virtual laboratories allow users to operate many circuits on screen.
Covers binary and hexadecimal numbering systems, ASCII, basic logic gates, monostable action and circuits, and bistables – including JK and D-type flip-flops. Multiple gate circuits, equivalent logic functions and specialised logic functions. Introduces sequential logic including clocks and clock circuitry, counters, binary coded decimal and shift registers. A/D and D/A converters, traffic light controllers, memories and microprocessors – architecture, bus systems and their arithmetic logic units. Sections on Boolean Logic and Venn diagrams, displays and chip types have been expanded in Version 2 and new sections include shift registers, digital fault finding, programmable logic controllers, and microcontrollers and microprocessors. The Institutional versions now also include several types of assessment for supervisors, including worksheets, multiple choice tests, fault finding exercises and examination questions.

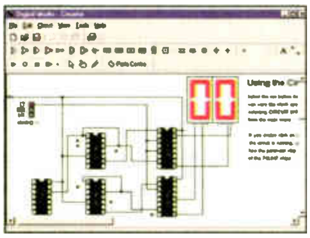
## FILTERS



Filter synthesis

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

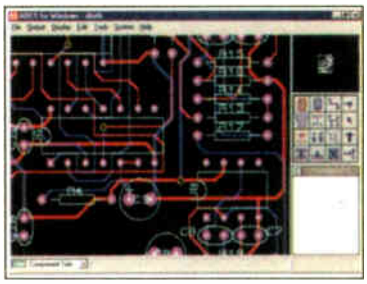
## DIGITAL WORKS 3.0



Counter project

*Digital Works Version 3.0* is a graphical design tool that enables you to construct digital logic circuits and analyze their behaviour. It is so simple to use that it will take you less than 10 minutes to make your first digital design. It is so powerful that you will never outgrow its capability. • Software for simulating digital logic circuits. • Create your own macros – highly scalable. • Create your own circuits, components, and i.c.s. • Easy-to-use digital interface. • Animation brings circuits to life. • Vast library of logic macros and 74 series i.c.s with data sheets. • Powerful tool for designing and learning.

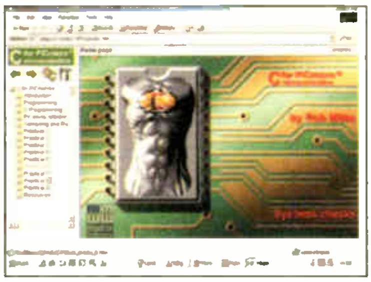
## ELECTRONICS CAD PACK



PCB Layout

Electronics CADPACK allows users to design complex circuit schematics, to view circuit animations using a unique SPICE-based simulation tool, and to design printed circuit boards. CADPACK is made up of three separate software modules. (These are restricted versions of the full Labcenter software.) **ISIS Lite** which provides full schematic drawing features including full control of drawing appearance, automatic wire routing, and over 6,000 parts. **PROSPICE Lite** (integrated into ISIS Lite) which uses unique animation to show the operation of any circuit with mouse-operated switches, pots. etc. The animation is compiled using a full mixed mode SPICE simulator. **ARES Lite** PCB layout software allows professional quality PCBs to be designed and includes advanced features such as 16-layer boards, SMT components, and an autorouter operating on user generated Net Lists.

## "C" FOR PICMICRO MICROCONTROLLERS



C for PICmicro Microcontrollers is designed for students and professionals who need to learn how to use C to program embedded microcontrollers. This product contains a complete course in C that makes use of a virtual C PICmicro which allows students to see code execution step-by-step. Tutorials, exercises and practical projects are included to allow students to test their C programming capabilities. Also includes a complete Integrated Development Environment, a full C compiler, Arizona Microchip's MPLAB assembler, and software that will program a PIC16F84 via the parallel printer port on your PC. (Can be used with the *PICtutor* hardware – see opposite.)
Although the course focuses on the use of the PICmicro series of microcontrollers, this product will provide a relevant background in C programming for any microcontroller.

## PRICES

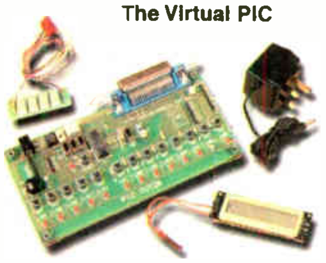
**Prices for each of the CD-ROMs above are:**

**Hobbyist/Student** .................................................. **£45 inc VAT**
**Institutional (Schools/HE/FE/Industry)** .............. **£99 *plus* VAT**
**Institutional 10 user (Network Licence)** .......... **£199 *plus* VAT**
**Site Licence** ..................................................... **£499 *plus* VAT**

***(UK and EU customers add VAT at 17.5% to "plus VAT" prices)***

# *Interested in programming PIC microcontrollers? Learn with* PICtutor

The Virtual PIC



Deluxe PICtutor Hardware

This highly acclaimed CD-ROM by John Becker, together with the PICtutor experimental and development board, will teach you how to use PIC microcontrollers with special emphasis on the PIC16x84 devices. The board will also act as a development test bed and programmer for future projects as your programming skills develop. This interactive presentation uses the specially developed **Virtual PIC Simulator** to show exactly what is happening as you run, or step through, a program. In this way the CD provides the easiest and best ever introduction to the subject. Nearly 40 Tutorials cover virtually every aspect of PIC programming in an easy to follow logical sequence.

**HARDWARE**

Whilst the CD-ROM can be used on its own, the physical demonstration provided by the **PICtutor Development Kit**, plus the ability to program and test your own PIC16x84s, really reinforces the lessons learned. The hardware will also be an invaluable development and programming tool for future work.

Two levels of PICtutor hardware are available – Standard and Deluxe. The **Standard** unit comes with a battery holder, a reduced number of switches and no displays. This version will allow users to complete 25 of the 39 Tutorials. The **Deluxe** Development Kit is supplied with a plug-top power supply (the **Export** Version has a battery holder), all switches for both PIC ports plus l.c.d. and 4-digit 7-segment l.e.d. displays. It allows users to program and control all functions and both ports of the PIC. All hardware is supplied **fully built and tested** and includes a PIC16F84.

## *PICtutor CD-ROM*

**Hobbyist/Student** .................... £45 inc. VAT
**Institutional (Schools/HE/FE Industry)** . . . £99 *plus* VAT
**Institutional 10 user (Network Licence)** . £199 *plus* VAT

## *HARDWARE*

**Standard Development Kit** . . . . £47 inc. VAT
**Deluxe Development Kit** . . . . . £99 *plus* VAT
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# SHOP TALK

**with David Barrington**

## PIC Big Digit Display

It is important that constructors keep to the specified semiconductor devices when putting together parts of the *PIC Big Digit Display* project. The L293DN 16-pin Half-H driver chip (also known as a stepper motor driver i.c.) was purchased from **Rapid Electronics** (☎ **01206 751166** or ***www.rapidelectronics.co.uk***), code 82-0192. The "D" denotes it is a 16-pin device and has diode protection. Do **not** use other L293 device types as they may not have the same characteristics – for instance, the L293E has 20 pins and cannot be used. (Check out the Texas web site at: **www.ti.com**).

Bulk purchasing has enabled **Display Electronics** (☎ ***0208 653 3333*** or ***www.distel.co.uk***) to offer the "British Rail" giant 10 inch 7-segment electromechanical display at a very reasonable price; claimed to be less than 30 per cent of the original. A single display module (code RW44) cost just £29.95 plus VAT and £99 plus VAT for four units (code PH26). A carriage charge will need to be added to these prices – see their advertisement in this issue for details.

The 7-stage Darlington line driver type ULN2004A was also purchased from **Rapid** (see above), code 82-0622. It is also listed by **RS** (☎ ***01536 444079*** or ***rswww.com***), code 652-825.

For those readers unable to program their own PICs, a ready-programmed PIC16F84 microcontroller can be purchased from **Magenta Electronics** (☎ ***01283 565435*** or ***www.magenta2000.co.uk***) for the inclusive price of £5.90 each (overseas add £1 p&p). The software is available on a 3·5in. PC-compatible disk (EPE Disk 5) from the *EPE* Editorial Office for the sum of £3 each (UK), to cover admin costs (for overseas charges see page 379). It is also available Free from the *EPE* web site: **ftp://ftp.epemag.wimborne.co.uk/pub/PICS/PICbigdigit**.

The printed circuit board is available from the *EPE PCB Service*, code 341 (see page 379). Finally, the optional 4x4 matrix data entry keypad came from **RS** (see earlier), code 331-304.

## Washing Ready Indicator

Some readers may experience difficulty in tracking down the specified quad op.amp used in the *Washing Ready Indicator* project. We have found that the Harris Semiconductors CMOS ICL7642ECPD quad op.amp is stocked by **RS** (code 630-623) and can be ordered through any *bona fide* stockists, including some of our advertisers. You can order direct (credit card only) from RS on 01536 444079 or through the web at **rswww.com**. A post and handling charge will be made.

The sub-miniature, omni-directional electret microphone insert used in the model was obtained from **Maplin** (☎ ***01283 565435*** or ***www.maplin.co.uk***), code FS43W. You could possibly use their ultra-miniature version, code QY62S. This has not been tried in the unit.

The same company also supplied the 3V to 24V d.c. 10mA max. piezoelectric buzzer, code KU56L. Most of our components advertisers should be in a position to offer an identical buzzer.

The small printed circuit board is available from the *EPE PCB Service*, code 342 (see page 379).

## Teach-In 2002 – Lab 7

Like most of the *Lab Works* in the *Teach-In 2002* series, it's the sensor elements that are usually "specials" and cause most purchasing problems. However, this is not the case with the first simple comparator demonstration circuits, Lab 7.1, where the light-dependent resistor (l.d.r.) type ORP12 is needed. This is widely stocked and advertisers such as **ESR**, **Bardwell**, **Bowood**, **Cricklewood** and **Sherwood Electronics** should be able to supply.

For the Anemometer (Wind Speed/Force) – Lab 7.2 and the Wind Direction Indicator – Lab 7.3, the miniature reflective opto-switch type SG2BC was ordered from **Farnell** (☎ ***0113 263 6311*** or ***www.farnell.com***) code 491-366. They also supplied the TLC7524 8-bit DAC chip, code 397-246.

It may be well worth investigating the possibility of using the "wind cup" hardware stocked by **Magenta Electronics** (☎ ***01283 565435*** or ***www.magenta2000.co.uk***).

## Freezer Alarm

The circuit for the *Freezer Alarm* project uses the "baby" of the PIC family, the "one-time-programmable" PIC12C508 microcontroller. The rest of the components should be readily available.

For those readers unable to program this type of PIC, a ready-programmed PIC12C508 microcontroller can be purchased from **Magenta Electronics** (☎ ***01283 565435*** or ***www.magenta2000.co.uk***) for the inclusive price of £5.90 each (overseas add £1 p&p). The software is available on a 3·5in. disk (*EPE* Disk 5) from the *EPE* Editorial Office for the sum of £3 each (UK), to cover admin costs (for overseas charges see page 379). It is also available Free from the *EPE* web site: **ftp://ftp.epemag.wimborne.co.uk/pub/PICS/PICfreezer**.

## Simple Audio Circuits – 1

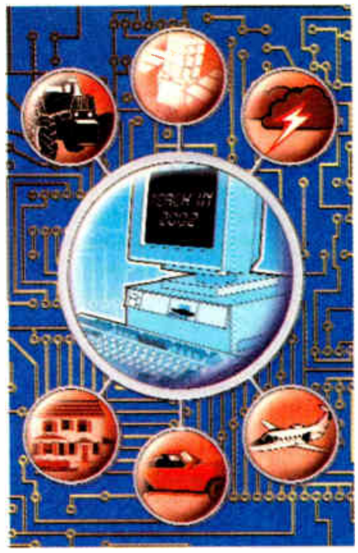
We do not expect any component buying problems to be encountered when shopping for parts for the various amplifier modules called-up in this month's *Simple Audio Circuits* projects. All the audio amp i.c.s should be "shelf" items.

All the small printed circuit boards are available from the *EPE PCB Service*. See page 379 for individual ordering codes and prices.

EPE Tutorial Series

# TEACH-IN 2002

## Part Seven – More on Noise, plus Comparators and Digital Optical Sensing




IAN BELL AND DAVE CHESMORE


**Making Sense of the Real World: Electronics to Measure the Environment**

IN many applications we use sensors to measure the quantity that they are sensitive to – temperature, humidity, strain etc. We may simply be interested in monitoring or recording this value (e.g. the temperature of a room) or we may be using it in a more complex way – for example, to control the environment of an enclosure.

This may require sophisticated manipulation of the sensor data using a microcontroller or PC. In other cases we do not need to know the value measured by the sensor, but simply have to switch an output when the level crosses a preset threshold (e.g. to switch on lights at night).

### COMPARABLE

Such applications often require comparators which will form one of the topics of our discussion this month. The sensor/comparator combination provides a digital signal which has uses beyond that of the simple level-switching just mentioned, and provides a means of measuring quantities other than those directly detected by the sensor.

The most common use of this approach is in motion sensing – e.g. position, direction and speed and the sensors most commonly used are optical sensors (hence the phrase *Digital Optical Sensing* in this part's sub-title). Although magnetic sensors are also used in this way, digital optical sensing is our main sensor topic this month and we will be building wind speed and direction instruments.

You may be thinking that digital sensing and use of comparators rather than accurate amplification and measurement of a sensor signal means that we can relax and forget about the nasty problems of noise and errors that we have discussed in the last few parts. Unfortunately this is not the case.

### NOISE RETURNS

As we will see later, noise may cause a comparator to switch multiple times as a threshold is crossed. Furthermore, offsets and other errors may shift the threshold level.

Last month we introduced the fact that there is noise that originates from within the components themselves. We now move on to see that there is a variety of types of noise generated within electronic sensors and associated circuitry, these are **thermal noise, shot noise, flicker noise, burst noise** and **avalanche noise**.

We will have a quick look at each of them in turn.

### THERMAL NOISE

Thermal noise (also known as **Johnson noise**) is a fundamental property of resistors (including the internal resistances of sensors and semiconductor devices), which results in a **white-noise** voltage across its in-circuit terminals.

This is a fundamental property of any resistor and therefore sets the lower limit of the noise from any sensor – whatever we do, we cannot get lower noise than the thermal noise.

Thermal noise cannot be reduced by improved component manufacture. However, as it is temperature-dependent, reducing the temperature will reduce the noise. Cooling sensors to very low temperatures may be appropriate for some situations, such as physics experiments, but in most cases it would be too difficult and expensive to be justifiable.

The thermal noise r.m.s. voltage across a resistor is given by:

$$V_{N,rms} = \sqrt{4kTR\Delta f}$$

Where:

$k$ is a physical constant known as **Boltzmann's Constant** ($1{\cdot}38 \times 10^{-23}\mathrm{JK}^{-1}$ (Joules per Kelvin))

$T$ is the temperature in Kelvin (K)

$R$ is the resistance in ohms ($\Omega$)

$\Delta f$ is the bandwidth of interest in Hertz (Hz), i.e. the range of frequencies over which you are measuring the noise.

$\Delta f$ is pronounced "delta f", the delta symbol means "change in" and so $\Delta f$ represents a range of frequencies.

The fact that a bandwidth has to be specified in order to get a noise voltage means that noise figures are often expressed in "volts per bandwidth unit" form, rather than simply as voltages (have a look on data sheets for i.c.s. such as op.amps and you will see noise figures expressed this way). This value is known as **noise density**.

If we divide both sides of the first equation by the square root of the bandwidth ($\sqrt{\Delta f}$) we get:

$$\frac{V_{N,rms}}{\sqrt{\Delta f}} = \sqrt{4kTR}$$

The value $\sqrt{4kTR}$ has units "volts per root Hertz", often written as $\mathrm{V/Hz}^{1/2}$ or $\mathrm{V}/\sqrt{\mathrm{Hz}}$. So, for example, the noise from a $100\mathrm{k}\Omega$ resistor at 20°C (293K) is:

$\sqrt{4 \times 1{\cdot}38 \times 10^{-23} \times 293 \times 100 \times 10^3} = 40\mathrm{nV/Hz}^{1/2}$.

If we were interested in a bandwidth of say 20kHz, the thermal noise voltage from this resistor would be $40\mathrm{nV} \times \sqrt{20 \times 10^3} = 5{\cdot}7\mu\mathrm{V}$. Statistical analysis of the properties of thermal noise shows that the instantaneous peak noise voltage will be less than five times the r.m.s. (average) value for 99 per cent of the time.

The equation for thermal noise indicates that we can reduce noise voltage by reducing resistance (source or internal resistance in the case of a sensor) or by reducing bandwidth. Reducing source resistance may not be possible, as it will often be fixed for a particular sensor. However, effective reduction in bandwidth can be achieved by making many measurements and averaging, or measurement over a longer period of time.

Why does making multiple measurements reduce effective $\Delta f$? If we make a measurement over a certain period of time those random variations which occur many times during this period will be averaged out. However, variations much longer than our period of making measurements will not "be seen" by our measurement process. Thus we have effectively removed some of the noise in the high frequency end of $\Delta f$, reducing its range and hence reducing the noise.

This approach is useful, but of course we pay for it by reduction in the speed with which we make our measurement. We also cannot extend our measurement period for longer than the time for which the quantity being measured will have a "constant" value, and as we increase measurement time other errors such as drift become more significant.

## SHOT NOISE

When current flows through a resistance it will generate additional white noise above the thermal noise due to the quantum nature of electric current at the atomic level. Electric current is the flow of discrete charge carriers (e.g. electrons), rather than a "continuous" flow. This noise is known as **shot noise** and like thermal noise is due to fundamental physics and cannot be reduced. For an applied current of $I$ in amps (A) the shot noise is given by:

$$I_{N,rms} = \sqrt{2eI\Delta f}$$

where $e$ is the electronic charge (charge on one electron = $1{\cdot}6 \times 10^{-19}$C (Coulombs)) and $\Delta f$ is the bandwidth as before. For a current of $1\mu$A this is $0{\cdot}57$pA/Hz$^{1/2}$, which is about 80pA over a 20kHz bandwidth. 80pA noise on $1\mu$A is a variation of 0·008%, which is an SNR (signal-to-noise-ratio) of around 82dB.

For very low currents the effect of shot noise becomes increasingly significant, limiting the accuracy of low-level measurements. Shot noise is an important source of noise in semiconductor devices such as diodes and transistors.

## YET MORE NOISE

In addition to thermal noise and shot noise, resistors and active devices produce yet more noise for various and often complex reasons. This noise is called **flicker noise**, also known as **1/f noise** or **pink noise**, as it typically has a $1/f$ relationship with frequency ($f$) (as defined last month).

Unlike thermal and shot noise, flicker noise in resistors (and other devices) depends on the component type and manufacture, and can even vary quite widely for components of same type. For a decade bandwidth (frequency range of 1 to 10 times) the flicker noise for typical resistors varies from tens of nanovolts to a few microvolts, depending on type and quality.

Carbon composition resistors produce the highest flicker noise and wirewound resistors the lowest. As flicker noise is more prominent at lower frequencies, unlike white noise, its effect is not reduced by longer sampling times.

**Burst noise** (also known as **popcorn noise**) occurs in transistors and results in pulses often in the audio frequency range, which can lead to a popping sound (hence the name *popcorn noise*).

**Avalanche noise** is produced by Zener diodes (or other diode junctions undergoing Zener or avalanche reverse breakdown). Avalanche noise is much larger than shot noise and so Zener diodes can introduce a lot of noise into a circuit. For this reason they should be avoided in low noise circuits even though they are a temptingly easy way to produce a stable voltage reference.

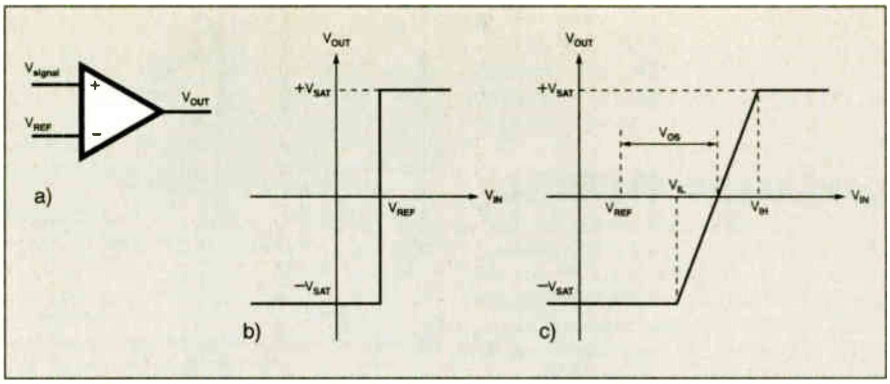



*Fig.7.1. Comparator input-output characteristics, (a) schematic, (b) ideal response, (c) realistic response.*

## COMPARATORS

Earlier in the series we discussed how an op.amp that is used without negative feedback has very high gain. Thus, for all but a small range of input voltage differences, the output will be saturated (see Fig.7.1). These two voltages (e.g. $-V_{sat}$ and $+V_{sat}$) may represent logic 0 and 1 and will indicate which of the two inputs is at the higher voltage. An op.amp used in this way is known as a **comparator**.

One input of the comparator is usually connected to a fixed reference level ($V_{REF}$ in Fig.7.1, sometimes called the **threshold**) and the other input is connected to the signal of interest (e.g. from a sensor). A real op.amp may not switch when the input is at exactly $V_{REF}$ due to offsets. Furthermore, for a range of input voltages, the op.amp will be in normal "linear" mode and will output intermediate voltages (see Fig.7.1c). This range of inputs is very small, however, and the situation is much better using an op.amp than, say, a single transistor, as we will see in this month's *Lab Work*.

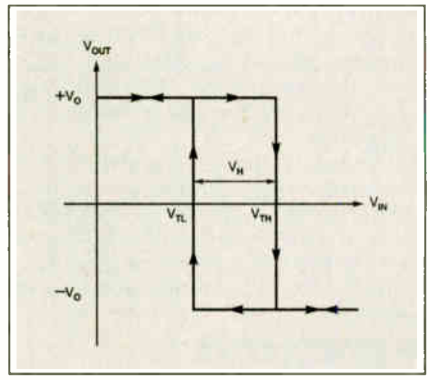


*Fig.7.2. Response of an inverting regenerative comparator.*

The simplest use of a comparator with a sensor is to switch a load on or off when the sensor output goes above or below a particular level. For example, to produce an over- or under-temperature alarm. A **window comparator** uses two comparators to indicate when a signal is between two levels. These circuits are often used to determine if a measured value is between acceptable limits.

An ideal comparator would switch instantaneously when the *input* signals cross the comparison threshold. A real comparator takes a finite time before it reacts. This time is known as the **propagation delay**.

An ideal comparator's *output* voltage switches between its two possible output states instantaneously. Again, a real comparator takes a finite time. The rate of

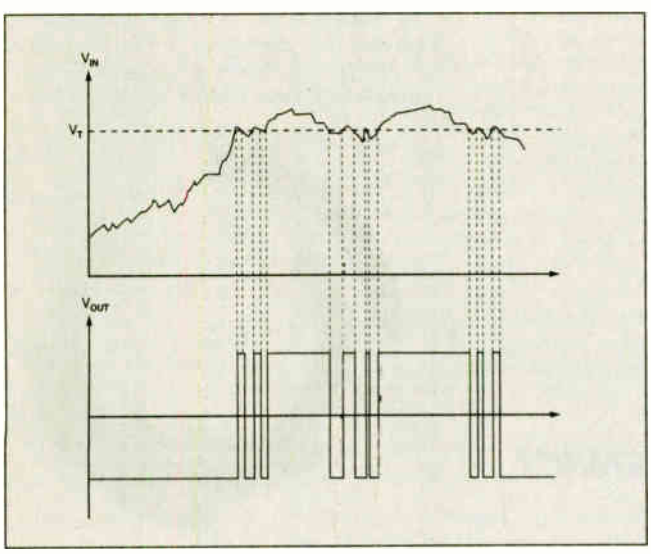


*Fig.7.3. Comparator without hysteresis.*

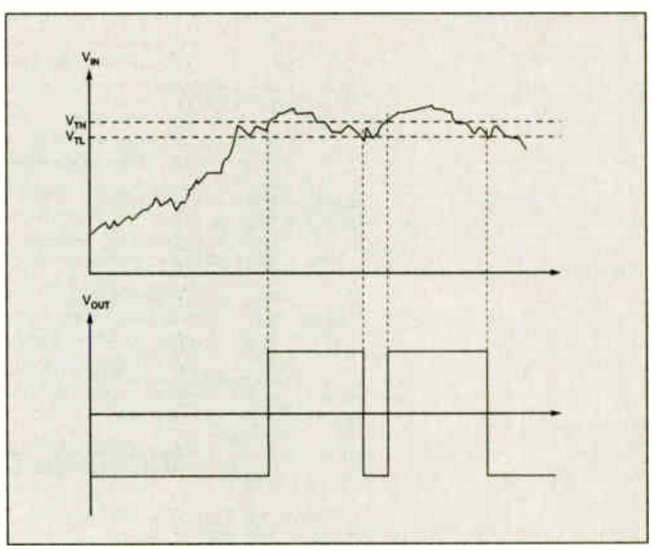


*Fig.7.4. Comparator with hysteresis.*

change of the comparator's output voltage as it switches is known as its **slew rate**.

Any op.amp may be used as a comparator, but the best performance is obtained by using devices that have been *specifically designed* as comparators.

## COMPARATOR HYSTERESIS

A comparator with a single threshold value may switch states many times as a noisy, slowly changing input crosses the threshold. This is often undesirable, for example, if the number of threshold-crossings is to be counted. The problem may be overcome by using two thresholds, e.g. $V_{TH}$ and $V_{TL}$.

The difference between $V_{TH}$ and $V_{TL}$ is called the **hysteresis**. When the input increases past $V_{TH}$ the comparator switches, but it does not switch if the input *decreases* past $V_{TH}$. The input must decrease past a lower threshold, $V_{TL}$, before the comparator switches again. This is illustrated in Fig.7.2.

If the input noise level is known, the hysteresis can be set slightly larger than this. The comparator will then not switch as a result of the noise. Fig.7.3 and Fig.7.4 show the result of applying the same noisy signal to a simple comparator and one with hysteresis.

## REGENERATIVE COMPARATORS

Comparators with hysteresis are also known as **regenerative comparators** and **Schmitt triggers**. A comparator with hysteresis can be made using a single-threshold comparator by setting the threshold depending on the comparator's present output state. The comparator has two output states so these can be used to set the two thresholds as required, by using **positive feedback** (hence the name *regenerative*).

A regenerative comparator can be made using an op.amp as shown in Fig.7.5. The switching point, $V_{comp}$ depends on $V_{REF}$ and $V_{out}$. $V_{REF}$ will usually be fixed, but $V_{out}$ depends on the current state of the comparator. One of two values can be taken by $V_{out}$, that is, $\pm V_O$ (basically the op.amp positive and negative saturation voltages, which for simplicity we will assume to have the same magnitude).

To follow the operation of the circuit start by assuming that $V_{in}$ is less than $v_{comp}$ so $V_{out} = +V_O$. As $V_{in}$ is slowly increased, this condition remains until $V_{in} = V_{comp} = V_{TH}$ (upper threshold), where:

$$V_{TH} = \frac{R_2}{R_1 + R_2} V_{ref} + \frac{R_1}{R_1 + R_2} V_o$$

On switching at $V_{comp} = V_{TH}$ the output changes to $V_{out} = -V_O$. Changing the threshold to a new value, $V_{comp} = V_{TL}$ (lower threshold), where:

$$V_{TL} = \frac{R_2}{R_1 + R_2} V_{ref} - \frac{R_1}{R_1 + R_2} V_o$$

$V_{out}$ will now stay at $-V_O$ until the input falls below the new $V_{comp}$ value. The difference in the switching points, i.e. the hysteresis, $V_H$, is:

$$V_H = V_{TH} - V_{TL} = \frac{2R_1}{R_1 + R_2} V_o$$

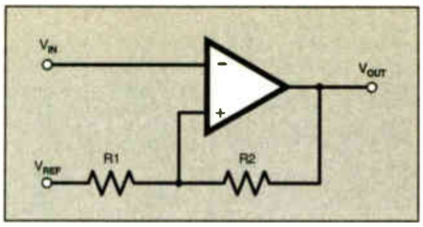



*Fig.7.5. Inverting regenerative comparator circuit.*

An inverting version of the circuit is shown in Fig.7.5. A non-inverting version can also be made. The equations are slightly different, but the basic operation of the circuit is the same.

## OPTICAL MOTION SENSING

Consider a rotating disc marked with black and white sections above which an optical sensor has been placed (see Fig.7.6). Assume that light is shining onto the disc so that when the sensor is above a white area we get a relatively large signal compared to when it is above a black area.

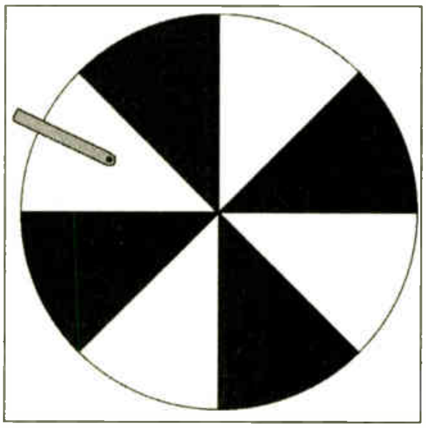


*Fig.7.6. Optical sensing of motion. The grey bar represents the fixed sensor mounting and the black dot indicates the location of the sensor. The disc is free to rotate past the sensor.*

Assume that this signal is passed through a suitable comparator circuit so that a clean digital output signal is obtained, with 0 representing a black area and 1 a white area. As the disc rotates we will get an alternating 1 and 0, the frequency of this pulsed signal indicating the speed of rotation.

We are not restricted to rotary motion with this technique – we can pattern a linear bar and measure movement in a similar way. We can also use holes in the disc, or bar, or other object rather than black and white areas to switch the level of light falling on the sensor as movement occurs.

More sophisticated measurement of the disc's movement can be achieved by using more complex patterns on the disk and multiple sensors. If we use several sensors and arrange the black and white areas appropriately, we can provide a binary coded output that indicates the location (angle of rotation) of the disc. Fig.7.7 provides an example of this using a 3-bit number, giving us an angular resolution of 45 degrees.

## AVOIDING UNCERTAINTY

This seems fine, but actually it is not a sensible way of patterning the disc. The problem is that, unless the sensors are perfectly aligned, as we move from one segment to the next the bits which change may not do so at the same instant, leading to unwanted "intermediate" codes.

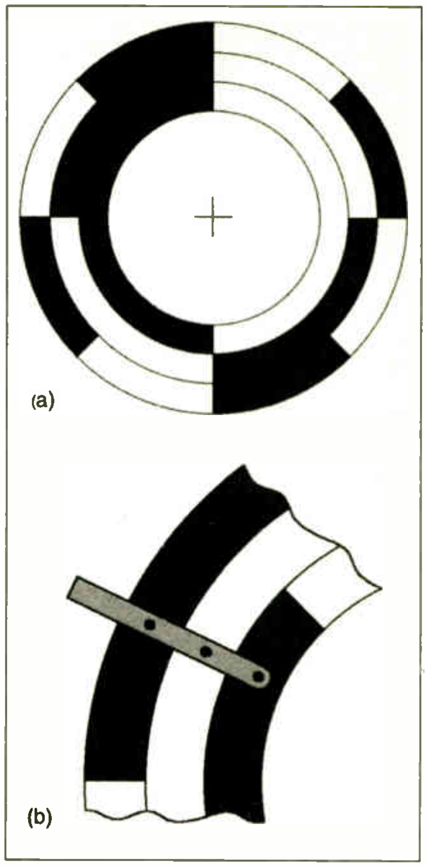



*Fig.7.7. (a) Disc patterned with binary code, (b) arrangement of sensors.*

The worse case in the Fig.7.7 example is the change from 000 to 111 or vice versa, where any 3-bit number (or even a sequence of two numbers) could appear as an intermediate code. The solution is to pattern the disc so that only one bit changes as we move from one segment to the next, as shown in Fig.7.8.

This type of binary code is called a **Gray code** and a 3-bit Gray code is shown in Table 7.1. We can use a logic circuit to convert it to standard binary numbers as shown in Fig.7.9.

Using code-patterned discs is useful where the disc position is simply an angle, but if the movement of the disc over multiple revolutions must be measured it is less useful. Furthermore if high resolution is required the printing of the disc becomes complex and difficult, and a potentially large number of sensors is required (one per bit).

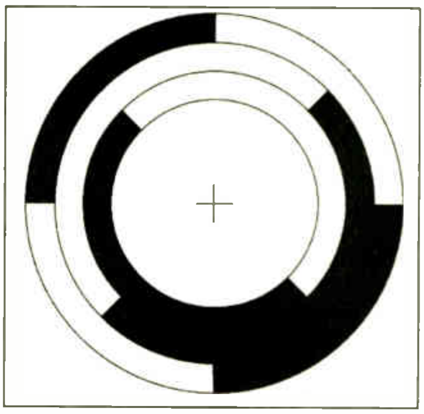


*Fig.7.8. Gray coded disc.*

**Table 7.1. 3-bit Gray Code**

| Output Codes | | |
|---|---|---|
| *A* | *B* | *C* |
| 0 | 0 | 0 |
| 0 | 0 | 1 |
| 0 | 1 | 1 |
| 0 | 1 | 0 |
| 1 | 1 | 0 |
| 1 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 0 | 0 |

A = inner ring of Fig.7.8
B = middle ring of Fig.7.8
C = outer ring of Fig.7.8

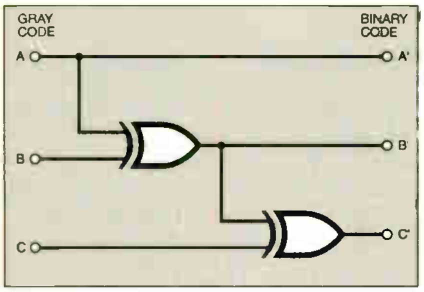



*Fig.7.9. Gray code to binary code converter.*

## INCREMENTAL ENCODING

An alternative approach, called **an incremental encoder**, uses two sensors that generate a quadrature signal – that is, two waveforms offset by a 90 degree phase shift. Movement is indicated by the output of either sensor switching and direction is indicated by the relative phase (plus or minus 90 degrees) of the signals.

These signals can be used to control a counter to obtain a binary representation of position. As this approach, unlike the Gray code disc, does not directly indicate absolute location, a third sensor may be used to provide an index or reference point.

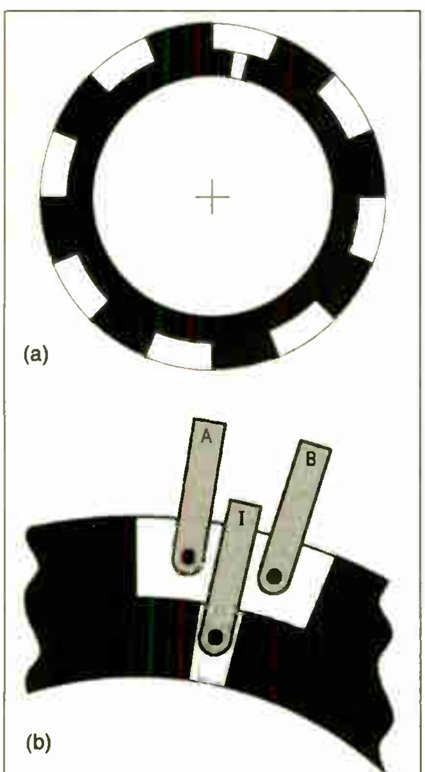



*Fig.7.10. Incremental encoder for motion sensing (a) disc pattern, (b) sensor locations.*

An incremental encoder disc pattern and its sensor locations are shown in Fig.7.10. The quadrature signal is obtained from sensors A and B and the reference signal from sensor I.

The spacing of the alternate black and white zones determines the resolution with which location can be measured. The separation distance between sensors A and B is half the length of the black and white sections. The waveforms obtained from the sensors are shown in Fig.7.11.

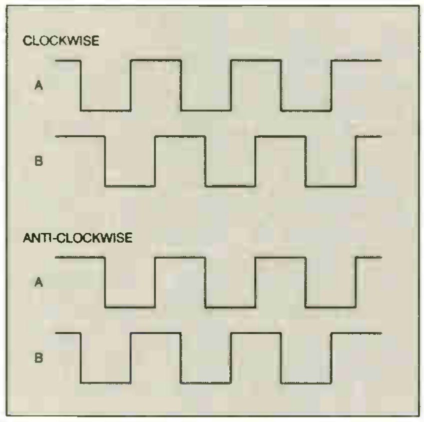



*Fig.7.11. Quadrature signals from the incremental encoder in Fig.7.10.*

We can build logic circuits to determine the direction of movement from the A and B signals in Fig.7.11. The simplest approach is to look at the level of (say) B when there is a positive edge on A (i.e. at the *instant* that it changes from low to high). Checking Fig.7.11 will show that a 0 indicates clockwise and a 1 indicates anticlockwise in this arrangement.

We can check the direction at any of the edges of the two waveforms in this way. Each edge also represents a definite indication of movement and can therefore be used to increment or decrement a counter circuit depending on the direction. The binary value in the counter will then represent the relative movement of the disc since the counter was last set to a particular value (e.g. reset).

## RESPONSE TIME

The logic design for an incremental encoder can be a little tricky due to the need to prevent races between the direction discrimination and the counting. It is further complicated by the need to distinguish between definite movement in a particular direction and vibration about a basically fixed point, which can continuously switch one of the sensors.

The latter problem prevents us from using the simple solution of connecting (say) A to the clock of an up/down counter and B to the up/down control. The best approach is to sample the quadrature waveform using an external clock running at a faster rate than the fastest possible input signals and use a state machine to work out what is going on. The state machine then controls the position counter.

A state machine is a sequential logic system whose outputs depend on the previous and present inputs (as in a counter, for instance) as opposed to processes that are functions of present inputs alone.

Fortunately, incremental position sensor decoder i.c.s are available, for example the HCTL-200xx series from Agilent Technologies (formerly Hewlett Packard). These chips also include simple digital filters to remove glitches from the input waveforms. Specialist motion control processors, such as the LM628 from National Semiconductor, also have built-in quadrature decoders and counters.

## OPTICAL ENCODING SENSORS

As we have seen, it is possible to detect the rate and angle of rotation using specially designed discs and optical sensors. There are several techniques and a number of readily available sensors that we can use:

- **Photodiode (or phototransistor) and l.e.d.**. As shown in Fig.7.12, the l.e.d. and photosensor are mounted on opposite sides of the encoding disc that has alternating transparent and opaque areas. The photosensor will detect light shining through the transparent area.

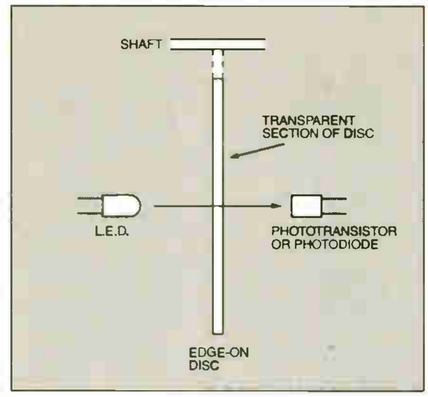



*Fig.7.12. Sensing using a separate l.e.d. and photosensor.*

- **Slotted optosensors**. A slotted optosensor has a built-in phototransistor and l.e.d. mounted facing each other across a small gap, as indicated in Fig.7.13. Again a disc that has alternating transparent and opaque areas is used. The sensor is mounted at the edge of the disc so that the light beam is interrupted when the disc rotates. Another name given to this type of sensor is a **photointerrupter**.

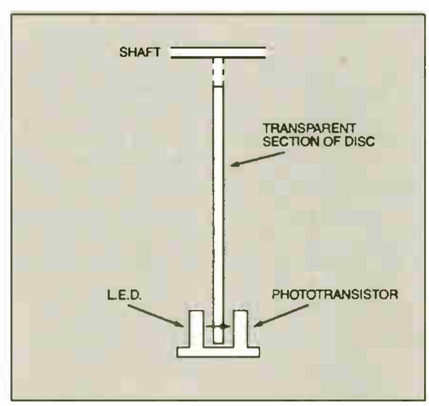



*Fig.7.13. Slotted photosensor.*

- **Reflective optosensors**. These also have a built-in l.e.d. and phototransistor but which are mounted side by side on one side of the disc only, which does not need to be transparent. Light is reflected back to the phototransistor by a reflective surface placed close to the sensor as shown in

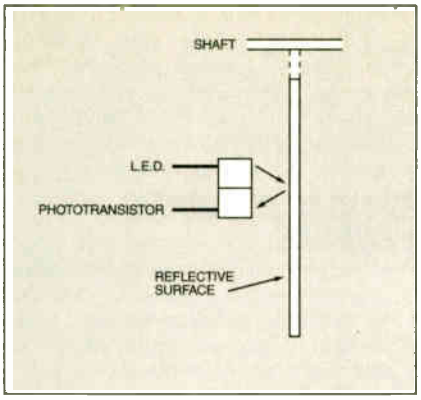



*Fig.7.14. Reflective photosensor.*

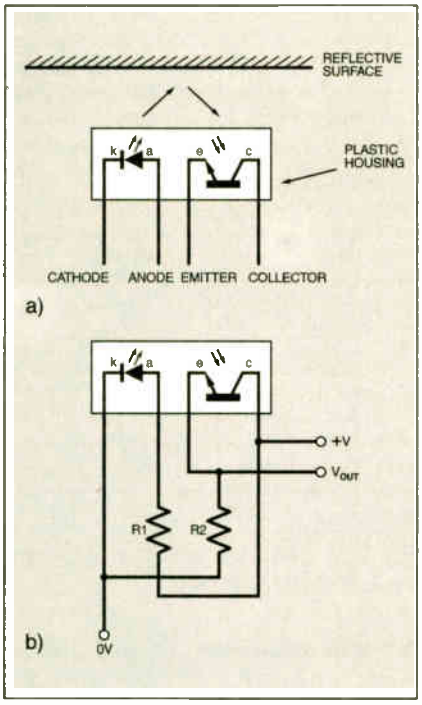



*Fig.7.15.(a) Schematic of slotted optosensor and (b) connections.*

Fig.7.14. We use this type of sensor in the *Lab Work* experiments this month. Another application of reflective optosensors is for proximity sensing, i.e. to sense when an object is close to the sensor.

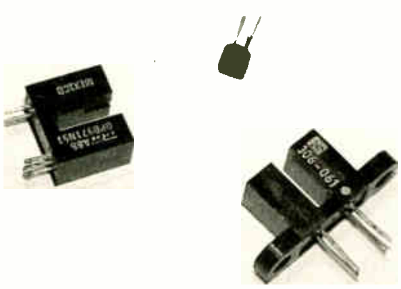
The schematic diagram of a typical reflective optosensor which consists of an infra-red (IR) l.e.d. and a phototransistor is shown in Fig.7.15a. The components are mounted in a plastic that is transparent to IR so as to reduce interference from ambient light (e.g. a.c. powered room lighting).

This does not mean that they are totally immune to ambient light since there is quite a lot of IR around, especially in tungsten lamps, so precautions must still be taken to reduce ambient light as much as possible.

A typical circuit for operating an optosensor is shown in Fig.7.15b, where the l.e.d. is forward biased via resistor R1, the value of which depends on the required current for the l.e.d. (typically 5mA to 20mA). The phototransistor can be used with its collector connected to the power supply voltage and the emitter to ground via resistor R2, as shown.

The value of R2 can be calculated from datasheets – the relevant data for the reflective device we will be using this month is given in Table 7.2.

In Lab Work, we illustrate the use of optosensors, and describe a rotation sensor that uses one in a circuit for measuring wind speed. Before that, though, let's discuss a few basics about wind sensing.



*Typical examples of slotted and reflective photosensors.*

**Table 7.2. Data for the SG-2BC Reflective Photointerrupter**

| | Parameter | Value |
|---|---|---|
| L.E.D. | Forward Voltage (I = 4mA) | 1·2V (max) |
| | Power Dissipation | 75mW (max) |
| | Peak Wavelength | 940nm |
| Phototransistor | Collector Dark Current | 0·1μA |
| | Light Current (diode current = 4mA) | 100μA |
| | Leakage Current | 0·1μA |
| | Risetime ($V_{CC}$ = 2V, $I_c$ = 100μA $R_L$ = 1kΩ | 30μs |
| | Falltime (as above) | 30μs |
| | Collector Current | 20mA (max) |
| | Collector-emitter Voltage | 30V (max) |
| | Emitter-collector Voltage | 3V (max) |

## WIND SPEED MEASUREMENT

The speed of the wind is measured in distance per unit time, such as miles per hour (mph), kilometres per hour (kph), metres per second ($ms^{-1}$) or knots. Another, subjective, measurement uses the Beaufort Scale, a numbering system that goes from 0 representing calm, to 12 representing hurricane force. The scale actually goes to 17 (126mph to 136mph) but such high wind speeds are extremely rare.

Table 7.3 gives the basic Beaufort Scale and corresponding wind speeds in miles per hours. It is often useful to be able to convert between the other different wind speed units; this is given in Table 7.4. To use the table, choose the units, e.g. 30mph to change to kph, read the FROM-TO multiplication factor (1.609) and multiply – 30mph = 48·3kph. To convert back use the TO-FROM multiplier, e.g. 100kph = 360$ms^{-1}$.

There are many commercial wind speed meters available (anemometers) which fall into three categories:

- **Cup anemometers**. These are probably the most familiar and operate by the wind blowing three or sometimes four cups around on a spindle. In a variation on the separate cups concept, the cups are replaced by an S-shaped arrangement. Cup anemometers suffer from stalling at very low speed due to friction, i.e. they will not start until a particular minimum wind speed.
- **Hot-wire anemometers**. If a wire is heated to a given temperature and air is allowed to flow across the wire, some of the heat will be removed. Hot-wire anemometers use this principle and can be extremely sensitive. They are, however, quite fragile since the wire is very thin.
- **Acoustic anemometers**. The speed of sound in air depends on the relative direction of the sound in relation to the direction of the wind, and to a lesser degree on temperature and barometric pressure.

It is possible to use ultrasonic pulses to measure changes in sound velocity and hence determine wind speed. These can be highly sensitive and have no moving parts, thus making them robust. It is also possible to have three or four sensors mounted at fixed angles to each other to obtain the wind's direction.

**Table 7.3. Beaufort Scale for Wind Speed**

| Beaufort Scale | Description | mph |
|---|---|---|
| 0 | calm | 1 |
| 1 | light air | 1-3 |
| 2 | slight breeze | 4-7 |
| 3 | gentle breeze | 8-12 |
| 4 | moderate breeze | 13-18 |
| 5 | fresh breeze | 19-24 |
| 6 | strong breeze | 25-31 |
| 7 | near gale | 32-38 |
| 8 | gale | 39-46 |
| 9 | strong gale | 47-54 |
| 10 | storm | 55-63 |
| 11 | violent storm | 64-72 |
| 12 | hurricane | 73-82 |

**Table 7.4. Conversion between Wind Speed Units**

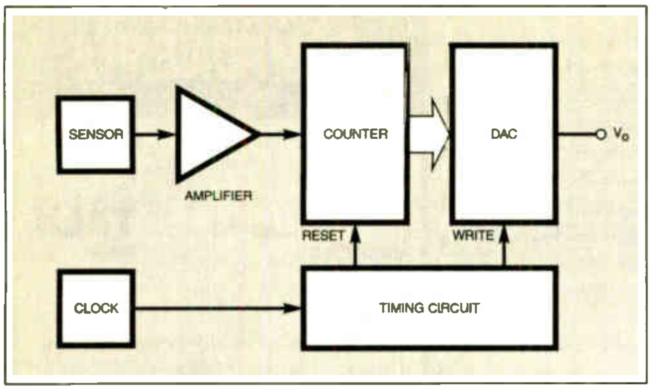
| Unit 1 | Unit 2 | From-To | To-From |
|---|---|---|---|
| mph | kph | 1·609 | 0·621 |
| mph | $ms^{-1}$ | 0·447 | 2·237 |
| mph | knots | 0·869 | 1·151 |
| $ms^{-1}$ | knots | 1·944 | 0·514 |
| $ms^{-1}$ | kph | 3·6 | 0·278 |
| knots | kph | 1·852 | 0·54 |

## OPTICALLY MONITORED ANEMOMETER

Last month we designed a simple rotation speed circuit using a magnetic sensor and a pulse width-to-voltage converter. This suffers from two disadvantages:

- One pulse per revolution means that low speeds are difficult to measure as the voltage on the capacitor in the frequency-to-voltage converter will decay and the output will not be a linear function of rotation rate.
- The frequency-to-voltage converter does not follow rapid changes in rotation rate.

We can overcome these problems by increasing the number of pulses per revolution and using a different



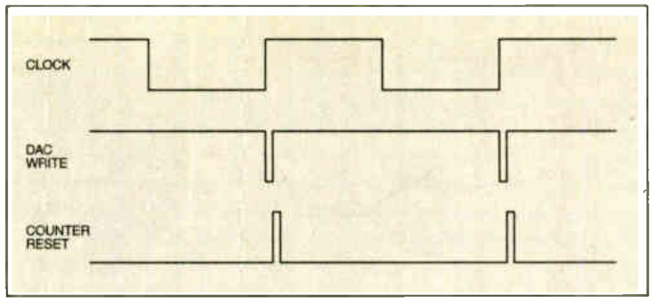




*Fig.7.17 (above). Timing diagram of anemometer circuit.*

*Fig.7.16 (left). Block diagram of anemometer circuit.*

type of frequency-to-voltage converter employing a counter and a digital-to-analogue converter (DAC).

To illustrate the theory (that we put into practice in *Lab Work*), we can use a reflective optosensor and the disc shown in Fig.7.10 to create eight pulses per revolution. These are counted over a defined interval by an 8-bit binary counter and the count is converted into a voltage using a DAC as indicated in the block diagram in Fig.7.16.

We need to control the counter and DAC so that at the end of each timing period (e.g. one second) the value on the counter outputs is transferred to the DAC, after which the counter is reset ready for the next counting interval, as shown in Fig.7.17.

A well-designed circuit can produce a stable voltage output as a linear function of shaft rotation speed which changes at regular intervals.

However, we need to work out several values before the circuit can be finalised. These will depend on the intended output (e.g. $ms^{-1}$, mph or kph), the design of the anemometer cups (number of cups, relative size, etc) and the relationship between output voltage and wind speed.

In the Lab Work design, we produce an output voltage of 3·0V for a wind speed of $30ms^{-1}$. From comparative measurements using the 3-cup anemometer and a commercial device, the number of pulses per second (pps) obtained from the circuit is 30·3pps for a wind speed of $6ms^{-1}$, which gives 5·05pps per $ms^{-1}$. At the maximum wind speed of $30ms^{-1}$ (67mph) we get 151·5pps.

The output of the DAC is determined by:

$V \times (D / N)$

where:

*V* is the maximum voltage that the DAC can output (frequently, but not always, the same voltage as on the positive supply line)

*D* is the digital input value, usually in binary form

*N* is the number of input bits that the DAC has been designed to accept, typically having a decimal value range of 0 to 255 (8-bit), although DACs having other input ranges are available.

Using an 8-bit DAC (as we do in *Lab Work*), to achieve an output voltage of 3·0V for $30ms^{-1}$, the input value required is $D = 3 \times 256 / 5 = 154$, to the nearest integer. This means we need to count 154 pulses every interval to make the output read 3·0V at $30ms^{-1}$ which makes the interval very close to one second, precisely calculated as 1·016s.

## WIND SPEED CALCULATION

Unfortunately, wind speed is not the easiest parameter to calibrate unless you possess a wind tunnel! The main reason for this is that the relationship between cup design and rotation speed with wind speed is not straightforward, so we cannot perform simple calculations. There are two main options for calibration:

- Compare with a commercial anemometer. This is the way we determined the number of pulses per second in the Lab Work design.
- Place the anemometer on a long pole and put it (vertically!) out of a car window and drive at a known speed. The anemometer needs to be away from the slip stream of the vehicle. This requires considerable care (*remember you are not jousting. Ed*)!

## WIND DIRECTION SENSING

Measuring wind direction requires a binary or Gray coded disc and multiple sensors – the more bits in the code, the higher the resolution but the more complex the circuit. The main part of a wind direction sensor is a vane and counter weight (to ensure balance).

The vane points into the wind and turns a coded disc. All one needs to do is ensure the code's origin is aligned with North and the instrument can be calibrated in relation to the number of bits and the angular displacement that each represents.

We discuss wind sensing in a practical sense in Labs 7.2 and 7.3. First, though, we experiment with comparators.

# TEACH-IN 2002 – Lab Work 7

## DAVE CHESMORE

## Comparator and Optosensing Experiments, plus Anemometer Assembly

**Lab 7.1 Comparators**

IN this Lab we examine the characteristics of comparators by building an op.amp version of the light switch in Part 2. Fig.7.18 shows the circuit diagram using an OP177 op.amp and a light dependent resistor (l.d.r.).

Since we are using a single +5V supply rail (rather than a dual ±5V supply), we need to generate a reference voltage. This is achieved using Zener diode D1 to give a 2·7V reference. Resistor R2 provides sufficient current for the Zener diode to reach its Zener voltage.

Build the circuit on your breadboard and connect the Picoscope to the op.amp's output. You should be able to see the output change state when the light level changes sufficiently for the voltage at the op.amp's non-inverting input (pin 3) to cross the reference threshold voltage at the inverting input (pin 2).

Use the Picoscope on a small sampling interval and see if the output changes like that shown in Fig.7.19. This rapid changing of state at the switching point is obviously not a good thing!

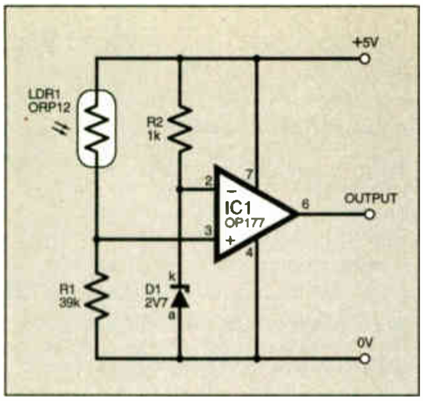



*Fig.7.18. Comparator circuit without hysteresis.*

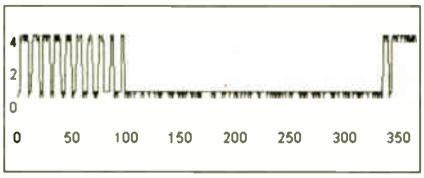



*Fig.7.19. Typical noisy output from circuit in Fig.7.18.*

Now modify the circuit in Fig.7.18 to become that in Fig.7.20 and repeat the above experiments. The multiple switching should have disappeared (see Fig.7.21). You should also notice that the point at which the output changes state will be different when the light level increases to that when it decreases – this is due to the hysteresis now introduced by the inclusion of resistors R3 and R4.

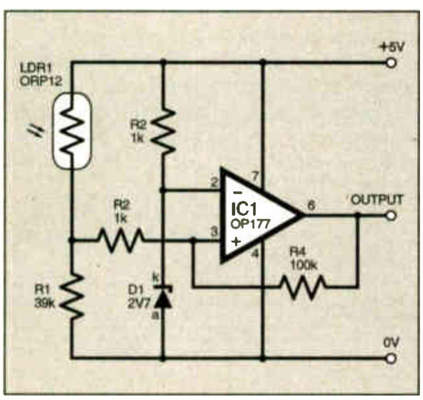



*Fig.7.20. Comparator circuit with hysteresis.*

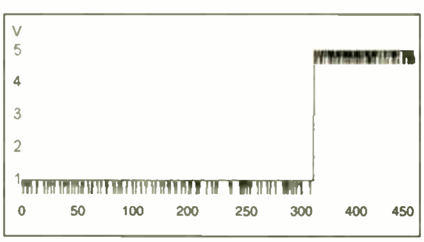
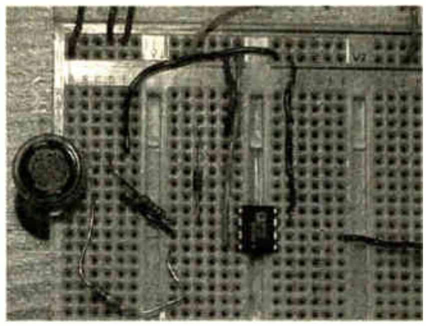
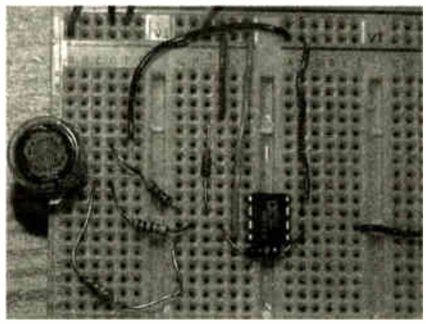



*Fig.7.21. Typical clean switching output from circuit in Fig.7.20.*

You can vary the amount of hysteresis by changing the values of these resistors as described in this month's tutorial section. Try increasing R4 to 1MΩ and then R3 to 100kΩ and see the difference. You may be able to see the hysteresis better by replacing the l.d.r. with a 100kΩ variable resistor (potentiometer) which will allow you to vary the input voltage in a controlled way.



*Breadboard assembly for circuit in Fig.7.18.*



*Breadboard assembly for circuit in Fig.7.20.*

If you compare the results from this experiment with the transistor-based light switch in Part 2, then it is obvious that a well-designed comparator is much better.

**Lab 7.2 Anemometer using an Optical Sensor**

For this anemometer we use the incremental encoder disc in Fig.7.10 and a single reflective optosensor to measure wind speed in a similar manner to that used with the magnetic sensor design in last month's *Teach-In*.

The general principle of operation was illustrated in Fig.7.16, where a counter is used to accumulate pulses over a known period of time and then the count is converted into an analogue voltage using a digital-to-analogue converter (DAC). The complete circuit diagram of the anemometer is shown in Fig.7.22.

The output of the photosensor (X1) is amplified by transistor TR1 and then input to an 8-bit binary counter formed using the two 4-bit counters, IC1a and IC1b. The counter increments on the positive-going edges received at IC1a's clock input CPOA (pin 1). When IC1a rolls over from 15 to 0 (overflow), the negative-going output at OA3 (pin 6) triggers the second counter, IC1b, via its $\overline{CP1B}$ input (pin 10), causing it to increment.

The eight outputs are connected to a TLC7524 8-bit DAC (IC2) connected to produce an output voltage at its pin 15 (REF). As discussed in the tutorial section, the output voltage is 5V × D / 256 where D is the digital input value (between 0 and 255).

In the prototype, the photosensor used was a type SG-2BC, chosen for its small size. Other common reflective optosensors that could be used include the SY-CR102 and OPB706B.

## TIMING

The circuit based around the four 2-input Schmitt NAND gates within IC3 performs all timing logic.

# COMPONENTS

N.B. Some components are repeated between Lab Works

**See SHOP TALK page**

### Lab 7.1

**Resistors**

| | |
|---|---|
| R1 | 39k |
| R2, R3 | 1k (2 off) |
| R4 | 100k |
| LDR1 | ORP12 light dependent resistor |

Resistors R1 to R4 0·25W 5% carbon film.

**Semiconductors**

| | |
|---|---|
| D1 | BZY88C 2·7V Zener diode |
| IC1 | OP177 op.amp |

### Lab 7.2

**Resistors**

| | |
|---|---|
| R1 | 560Ω |
| R2 | 56k |
| R3 | 390Ω |
| R4 | 4k7 |
| R5 | 10k |
| R6, R7 | 39k (2 off) |

All 0·25W 5% carbon film.

**Potentiometer**

| | |
|---|---|
| VR1 | 22k preset, min. round |

**Capacitors**

| | |
|---|---|
| C1 | 47µ tantalum 16V |
| C2, C3 | 10n ceramic (2 off) |

**Semiconductors**

| | |
|---|---|
| TR1 | BC548 or similar small signal *npn* transistor |
| IC1 | 4520 dual binary counter |
| IC2 | TLC7524 8-bit digital-to-analogue converter |
| IC3 | 4093 quad 2-input Schmitt NAND gate |

**Miscellaneous**

| | |
|---|---|
| X1 | SG-2BC reflective photointerrupter (see text) |

### Lab 7.3

**Resistors**

| | |
|---|---|
| R1 to R3 | 560Ω (3 off) |
| R4 to R6 | 56k (3 off) |
| R7 to R9 | 390Ω (3 off) |
| R10 to R12 | 4k7 (3 off) |
| R13 to R20 | 470Ω (8 off) |

All 0·25W 5% carbon film.

**Semiconductors**

| | |
|---|---|
| D1 to D8 | red l.e.d. (8 off) (see text) |
| TR1 to TR3 | BC548 or similar small signal *npn* transistor (3 off) |
| IC1 | 74HC138 or 74LS138 3-to-8 line decode |

**Miscellaneous**

Materials for wind cups and vane (see text).

*Approx. Cost Guidance Only* **£15** excl. hardware

IC3a is configured as an oscillator with a period of one to three seconds, controllable by preset VR1 (a fixed resistor was used in the test model). Its output is passed to IC3b via a pulse-shaping *C-R* (capacitor-resistor) network formed by C2 and R6. This causes the output of IC3b to go low for a short period (about 5ms) when the input to C2 goes high – this is the Write signal for DAC IC2.

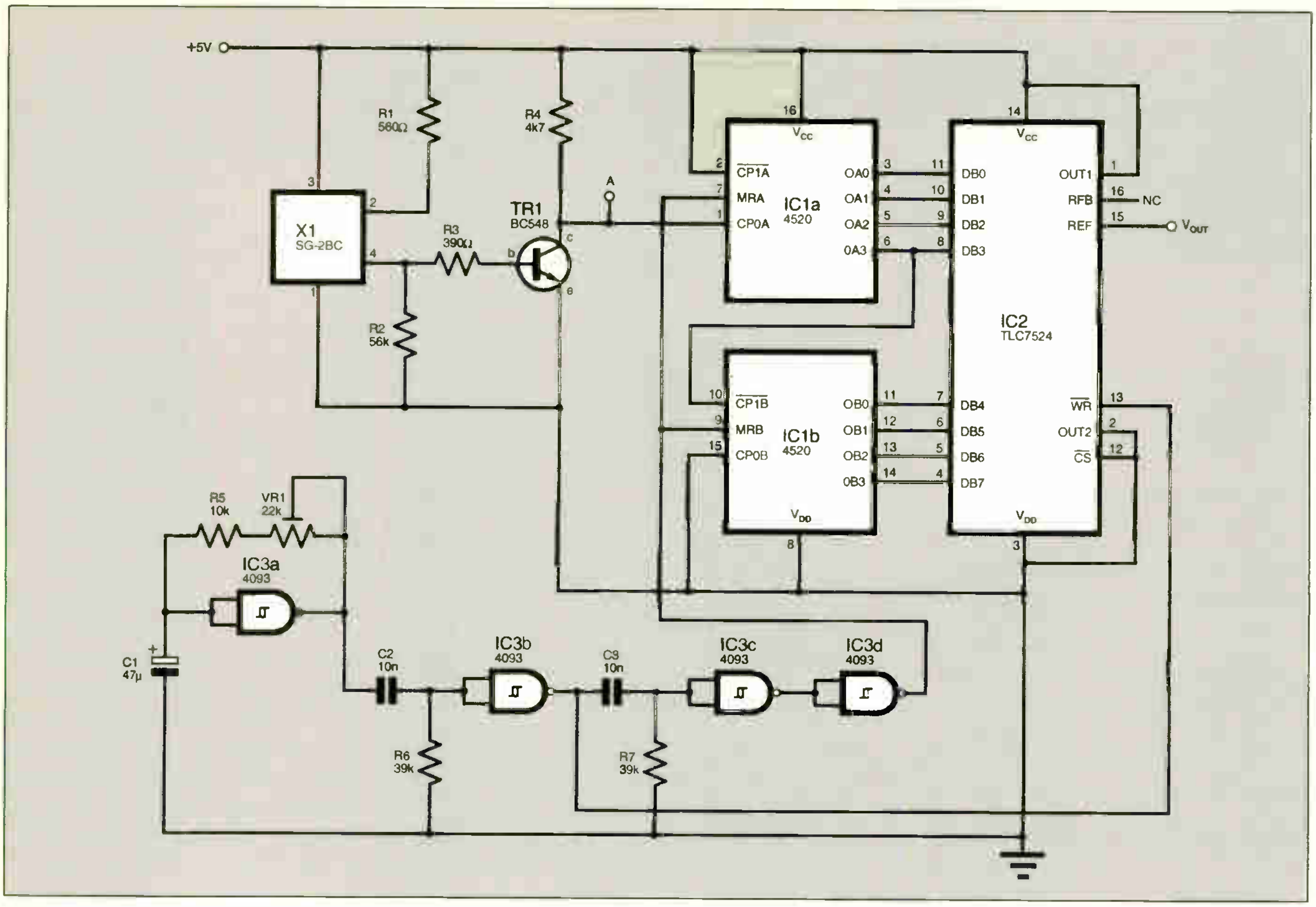
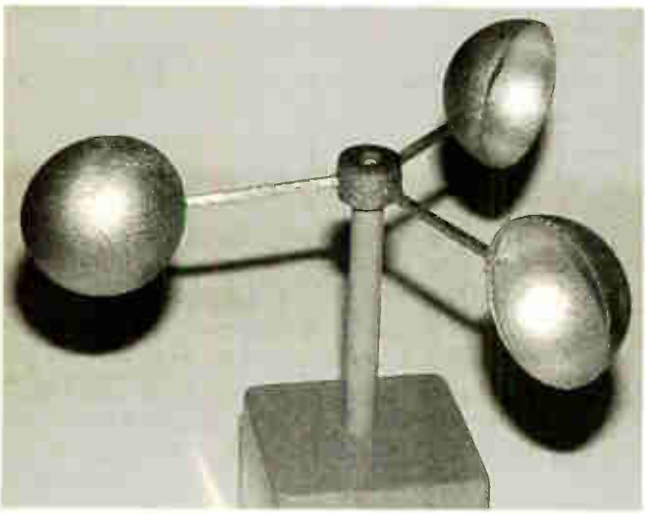



*Fig.7.22. Circuit diagram for the anemometer.*



*Prototype "homemade" anemometer assembly.*

Similarly, IC3c produces a short negative-going pulse, having a period set by C3 and R7, when the output of IC3b goes high. This is inverted by IC3d and produces the Reset pulse for the counters.

## ANEMOMETER MECHANICS

The anemometer is constructed using three half ping-pong balls to make the cups (they can easily be cut using a hacksaw) connected to a central hub with short lengths of plastic as shown in Fig.7.23. Larger cups may be used if you require.

One suggestion is to use plastic scoops available with washing powder. The basic rule for calculating how far the cups should be away from the hub is that the distance from the hub to the centre of the cup should be equal to the cup's diameter.

The hub is attached to a length of plastic or aluminium rod which passes through the barrel of an old felt pen. If the hub is made of plastic then it should ride on the pen with little friction. The pen is attached to a box which contains the disc and electronics. The bottom of the shaft should reach the base of the box and

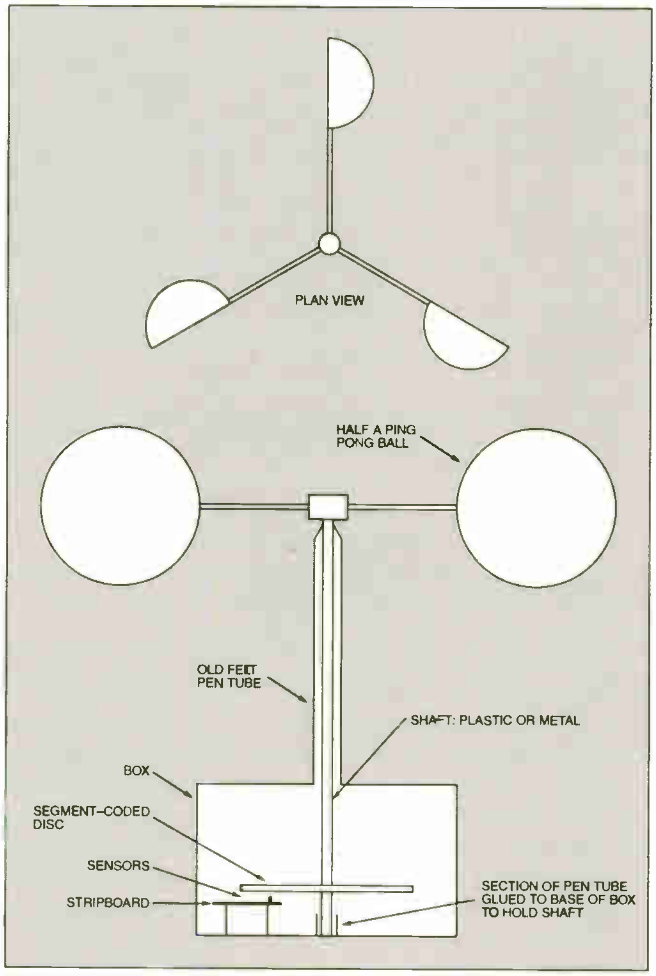



*Fig.7.23. Basic format for a suggested anemometer assembly (see text).*

*Mounting of the sensor in the prototype anemometer.*

a short length of pen tube is used to stop the shaft from moving sideways. The encoded disc is secured to the shaft at a position a couple of millimetres away from the top of the sensor.

You should note that the design is very crude and many modifications can be made. For example, using a ball race as the top bearing to ensure that the friction is low and the shaft is secured (in our design, the cup assembly can simply be lifted off the rest).

## SENSOR DISK

Since the sensor is a reflective type, we can use a black and white disc such as that in Fig.7.10. We suggest you get an enlarged photocopy of the disc and paste it onto a piece of stiff card. The sensor needs to be within a few millimetres of the surface of the disc.

Build the circuit on breadboard (but with the sensor mounted on a small bit of stripboard) and set the oscillator period to about one second using VR1. Use the Picoscope to measure the period. Monitor the voltage at point A in Fig.7.22 and rotate the disc. The output should be similar to that in Fig.7.24. If it is not then try moving the sensor closer to the disc.

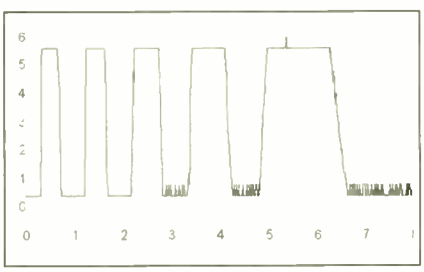


*Fig.7.24. Example of output pulses at point A in Fig.7.22.*

Once you get a good series of pulses at point A, connect a voltmeter (or the Picoscope) to the output of the circuit. You should get a voltage which changes approximately once per second and which is proportional to the speed of rotation. Fig.7.25 shows a typical output captured using the Picoscope (note that the "noise" is due to the limited resolution of the Picoscope ADC-40 and not the DAC).

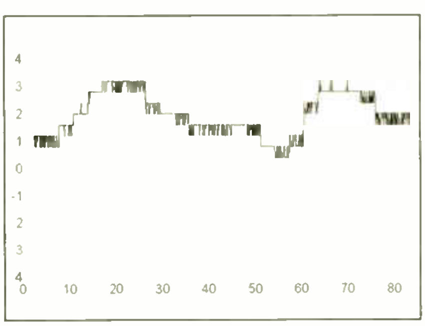


*Fig.7.25. Output of anemometer showing wind speed variation.*

If the oscillator is set to 1·016s then 0.1V at the DAC's output should be roughly equal to $1ms^{-1}$ (i.e. 3·0V equals $30ms^{-1}$). Accurate calibration is not easy, as discussed earlier in the theory section.

### Lab 7.3 Wind Direction Meter

Measuring wind direction can be done using a binary or Gray coded disc and multiple sensors. In this Lab we show you how to build an instrument to indicate eight points on the compass – north, north-east, east, etc, so we need a 3-bit Gray coded disc.

The circuit diagram is shown in Fig.7.26. The outputs of the sensors are amplified by transistors TR1 to TR3 and input to a 3-to-8 line decoder, IC1. The decoder takes a 3-bit binary input and sets the corresponding output low. For example, if the input is binary 000, output Y0 goes low; an input of binary 110 causes output Y6 to go low.

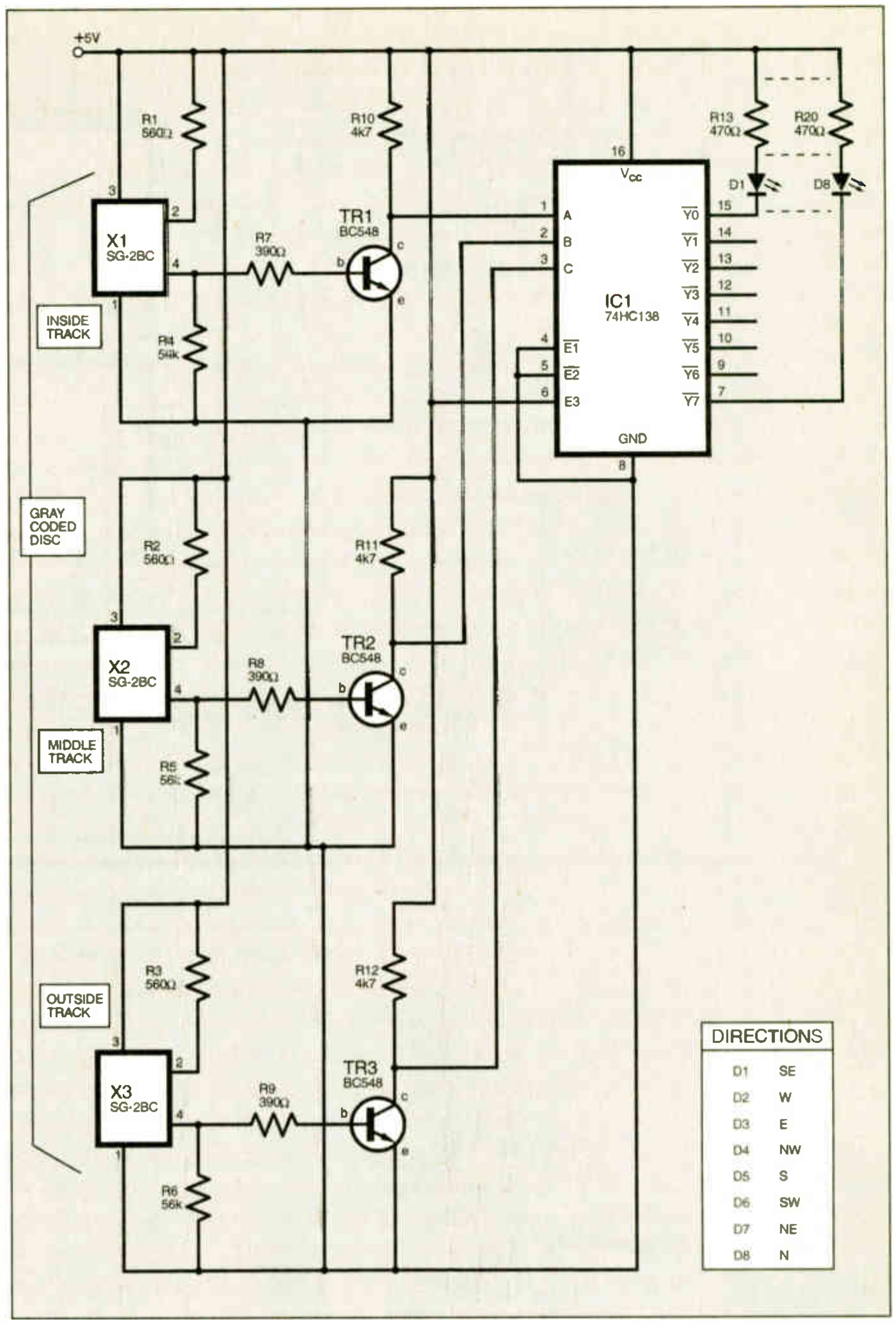



*Fig.7.26. Circuit diagram for the wind direction sensor.*

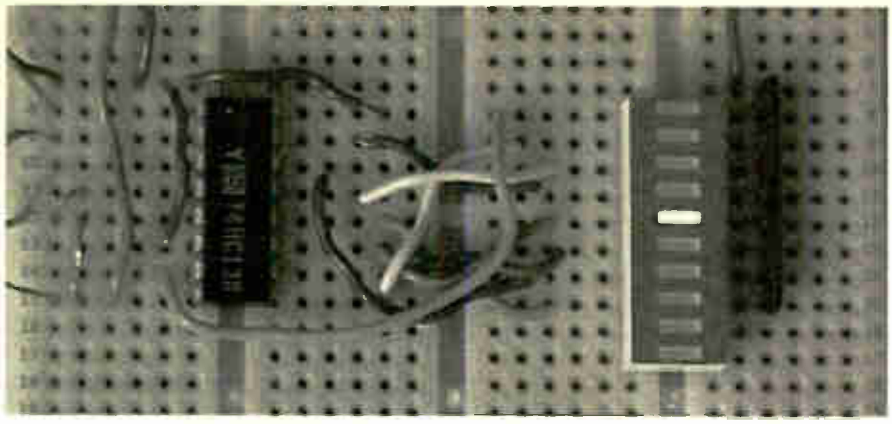
**Table 7.5. Relationship between Outputs and Compass Points for Lab 7.3**

| *Output/L.E.D.* | *Compass point* |
|---|---|
| Y0-D1 | South East |
| Y1-D2 | West |
| Y2-D3 | East |
| Y3-D4 | North West |
| Y4-D5 | South |
| Y5-D6 | South West |
| Y6-D7 | North East |
| Y7-D8 | North |

The decoder has three enables, two active low and one active high. In this circuit they are set to permanently enable the device. Each output is connected to an l.e d. to indicate whether or not it is low. Since the disc is Gray coded, the outputs Y0-Y7 do not correspond to successive points on the compass as they would if the disc were binary coded. Use Table 7.5 to connect the l.e.d.s in the correct order.

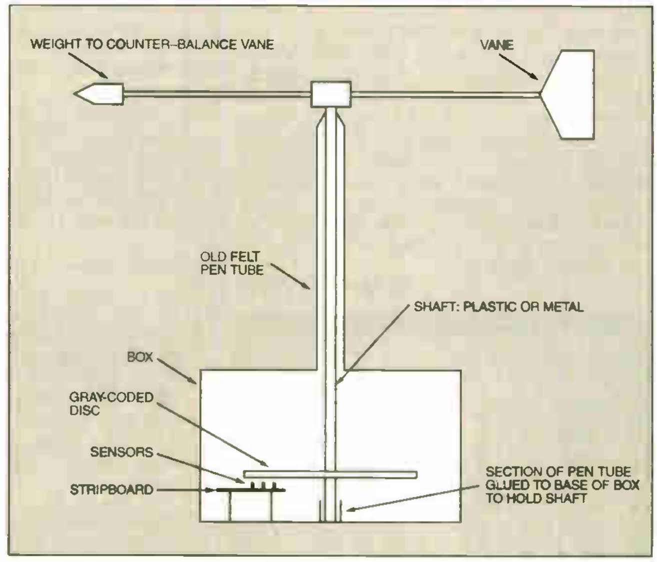
Photocopy the disc in Fig.7.8. Mount the sensors in a similar manner to Lab 7.1.

*Example of a reflective sensor, as used in the wind vane.*



*Breadboard assembly for the display circuit in Fig.7.26. Individual l.e.d.s may be used in place of the bargraph display and discrete resistors in place of the resistor module.*

*Above: Stripboard assembly mounting for the wind vane.*




*Right: Fig.7.27. Basic format for a suggested wind vane assembly (see text).*

There are three points to note in this particular design:

1. The outputs from the sensors are inverted by the transistors so that the black areas correspond to a logic 1. This may not be correct if you use different sensors.

2. The disc in our design faced upwards when the sensor was completed thus making everything occur in the opposite way. If your disc faces down, swap west for east, north west for north east, and south west for south east in Table 7.5.

3. In our prototype we demonstrated the direction indicating principle using an l.e.d. bargraph, but if you choose to use individual l.e.d.s. instead, we suggest you arrange them in a circle.

Most of the construction of the wind vane is the same as for the anemometer, but using the Gray coded disc instead. The vane itself is a horizontal length of aluminium or plastic rod to which is attached a vertical vane at one end and a counterbalance weight at the other. The photograph of a commercial vane should give you a good idea of the design.

Having completed construction, the only thing left to do is use a compass to align north on the disc (centre of the black-black-black area) to magnetic north.

## NEXT MONTH

In Part 8 next month, we examine control-feedback closed-loop systems, filters, sensor actuator combinations, with reference to smoke and gas detectors.

*Example of a commercial wind vane.*

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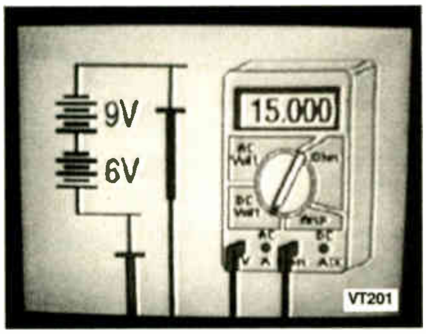


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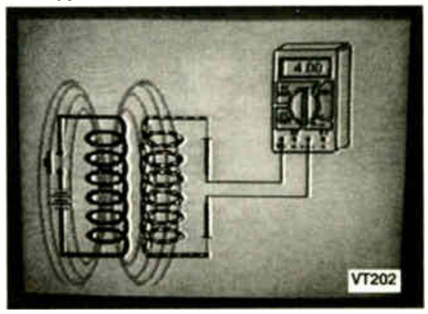


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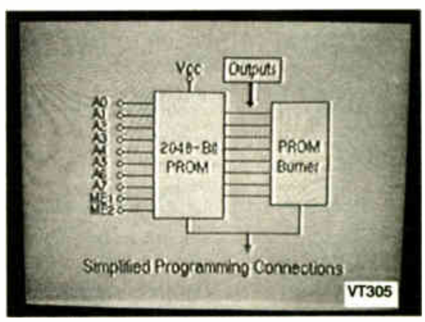


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## 100 WATT ACTIVE SUB BASS AMPLIFIER PANEL

AN ACTIVE SUB BASS AMPLIFIER WITH A TRUE 100W RMS OUTPUT. SUPERB CONSTRUCTION WITH THE FACILITIES TO INTEGRATE SEEMLESSLY INTO MOST HI-FI OR HOME CINEMA SETUPS. USE THIS PANEL PLUS ONE OF OUR LOUDSPEAKERS TO MAKE YOUR OWN SUB WOOFER THAT WILL MATCH OR BEAT MOST COMMERCIALLY AVAILABLE SUB WOOFERS.

FEATURES:- * 100W RMS INTO 8 OHMS * HIGH AND LOW LEVEL INPUTS * TOROIDAL TRANSFORMER * SHORT CIRCUIT PROTECTION * D.C. SPEAKER PROTECTION * FREQUENCY ROLL OFF, LOWER 10Hz, UPPER 60Hz TO 240Hz (FULLY ADJUSTABLE) * AC3 COMPATIBLE FILTER CAN BE BYPASSED FOR 5-1 FORMATS. * AIRTIGHT CONSTRUCTION * TENS OF THOUSANDS OF OUR PANELS ALREADY IN USE. * COMPLETE WITH LEADS

SPECIFICATIONS:-* POWER 100W RMS @ 8 OHMS *FREQ RESP. 10Hz 15KHz -3dB * DAMPING FACTOR >200 * DISTORTION 0.05% * S/N A WEIGHTED >100dB * SUPPLY 230V A.C. *WEIGHT 2.7Kg * SIZE H254 X W254 X D94mm

THERE ARE 2 VERSIONS OF THE ABOVE PANEL AVAILABLE :-BSB100/8 8 OHM VERSION BSB100/4 4 OHM VERSION BOTH PANELS ARE PRICED AT £117.44 + £5.00 P&P INCL. V.A.T. CHECK WEBSITE FOR PANELS UP TO 300W

## OMP MOS-FET POWER AMPLIFIER MODULES

SUPPLIED READY BUILT AND TESTED

These modules now enjoy a world-wide reputation for quality, reliability and performance at a realistic price. Four models are available to suit the needs of the professional and hobby market ie. Industry, Leisure, Instrumental and Hi-Fi etc. When comparing prices, NOTE that all models include toroidal power supply, integral heatsink, glass fibre P.C.B. and drive circuits to power a compatible Vu meter. All models are open and short circuit proof.

THOUSANDS OF MODULES PURCHASED BY PROFESSIONAL USERS

**OMP/MF 100 Mos-Fet** Output Power 110 watts R.M.S. into 4 ohms, frequency response 1Hz - 100kHz -3dB, Damping Factor >300, Slew Rate 45V/uS, T.H.D. typical 0.002%, Input Sensitivity 500mV, S.N.R. 110dB. Size 300 x 123 x 60mm.
Price:- £42.85 + £4.00 P&P

**OMP/MF 200 Mos-Fet** Output Power 200 watts R.M.S. into 4 ohms, frequency response 1Hz - 100kHz -3dB, Damping Factor >300, Slew Rate 50V/uS, T.H.D. typical 0.001%, Input Sensitivity 500mV, S.N.R. 110dB. Size 300 x 155 x 100mm.
Price:- £66.35 + £4.00 P&P

**OMP/MF 300 Mos-Fet** Output Power 300 watts R.M.S. into 4 ohms, frequency response 1Hz - 100kHz -3dB, Damping Factor >300, Slew Rate 60V/uS, T.H.D. typical 0.001%, Input Sensitivity 500mV, S.N.R. 110dB. Size 330 x 175 x 100mm.
Price:- £83.75 + £5.00 P&P

**OMP/MF 450 Mos-Fet** Output Power 450 watts R.M.S. into 4 ohms, frequency response 1Hz - 100kHz -3dB, Damping Factor >300, Slew Rate 75V/uS, T.H.D. typical 0.001%, Input Sensitivity 500mV, S.N.R. 110dB. Fan Cooled, D.C. Loudspeaker Protection, 2 Second Anti Thump Delay. Size 385 x 210 x 105mm.
Price:- £135.85 + £6.00 P&P

**OMP/MF 1000 Mos-Fet** Output Power 1000 watts R.M.S. into 2 ohms frequency response 1Hz - 100kHz -3dB, Damping Factor >300, Slew Rate 75V/uS, T.H.D. typical 0.001%, Input Sensitivity 500mV, S.N.R. 110dB. Fan Cooled, D.C. Loudspeaker Protection, 2 Second Anti Thump Delay. Size 422 x 300 x 125mm.
Price:- £261.00 + £12.00 P&P

NOTE MOS-FET MODULES ARE AVAILABLE IN TWO VERSIONS: STANDARD - INPUT SENS 500mV BANDWIDTH 100kHz OR PEC (PROFESSIONAL EQUIPMENT COMPATIBLE) - INPUT SENS 775mV, BANDWIDTH 50kHz ORDER STANDARD OR PEC

VISA

DELIVERY CHARGES:- PLEASE INCLUDE AS ABOVE, TO A MAXIMUM AMOUNT £30.00. OFFICIAL ORDERS FROM SCHOOL, COLLEGES, GOVT., PLCs ETC. PRICES INCLUSIVE OF V.A.T. SALES COUNTER. CREDIT CARD ORDERS ACCEPTED BY POST PHONE OR FAX.

# B.K. ELECTRONICS

REF D5

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