Electronics & Technology Today

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Canada's Magazine for High-tech Discovery

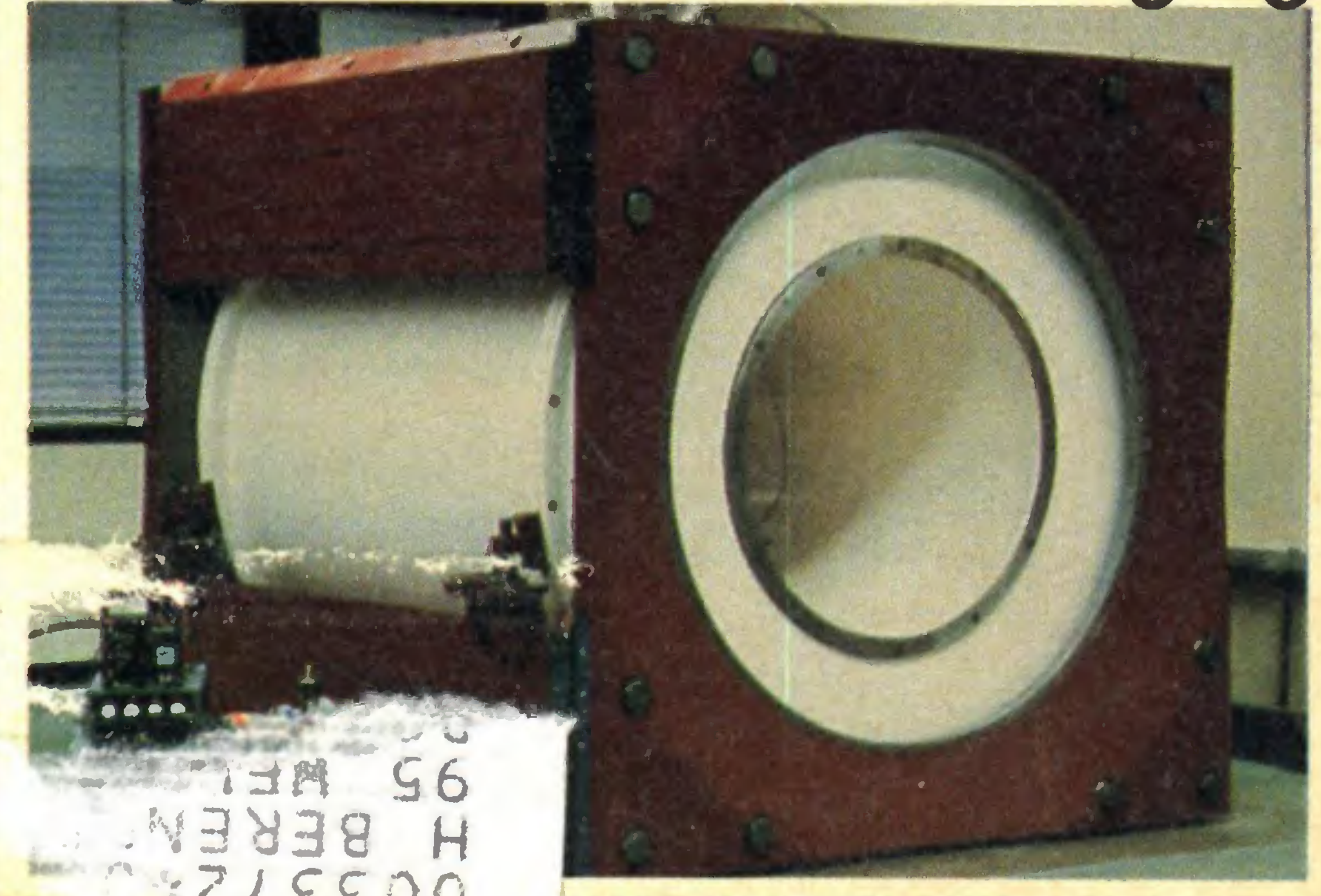
December 1987

Multimeters!
How they're used
Build your own A/D meter
Hioki printing meter review

A Weather Station for the PC

Build an Audio Noise Gate

Magnetic Resonance Imaging



Microcomputer Speed Comparison
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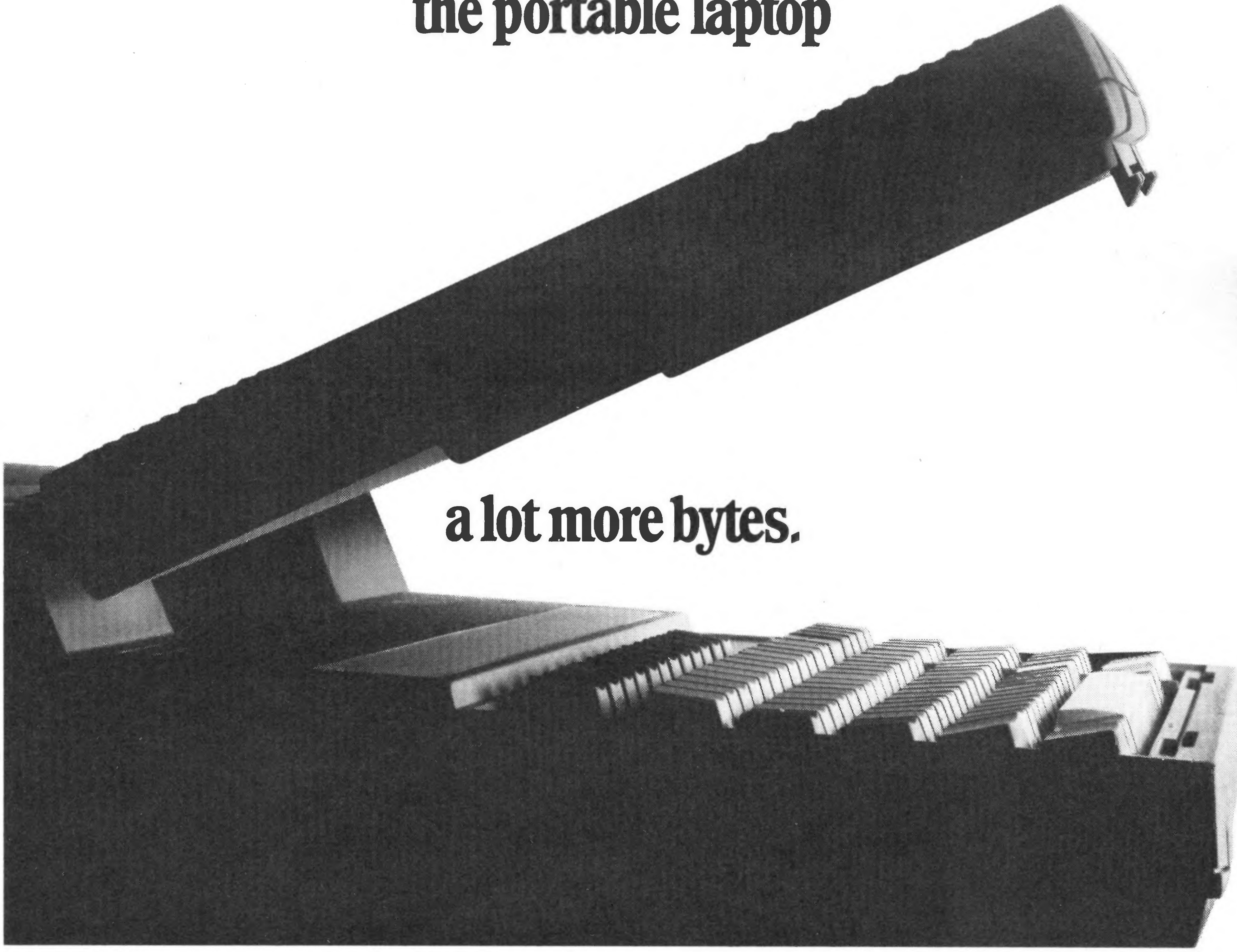
Toshiba has just given the portable laptop



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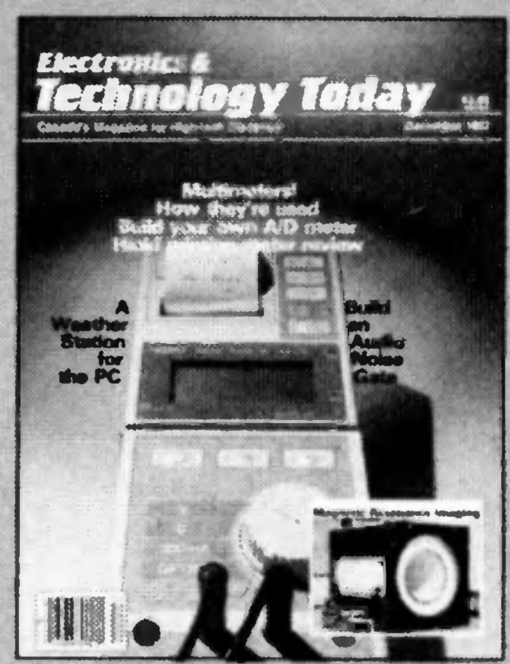
Our Cover



The Hioki printing multimeter was photographed by Bill Markwick; the MRI photograph is courtesy of Siemens.

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Electronics & Technology Today

Canada's Magazine for High-tech Discovery

Volume 11, Number 12 *December 1987*

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For Your Information

Science Mobilizes to Beat Murder in the Air

By Bill Pressdee

The problems confronting airport security are basically the same as those involved in the custody of any major industrial complex of national importance. These include theft, ranging from petty larcency to bullion robbery, illicit incursion, ranging from unauthorized entry to military takeover, and specifically terrorist attack, either in the airport or in the air.

Combating these problems calls for adequate surveillance by man or machine to discover illegal acts, and the appropriate detection of illicit devices or materials in sufficient time to apply remedial action.

Incidents at airports, such as bullion robbery, the smuggling of drugs, or the discovery of explosives in hand luggage, are generally reported in isolation. However to be effective, an airport system must be comprehensive to cover every aspect of security. For each airport the security system must first take account of the particular site problems.

There are many security devices available for use around the airfield, and these should be deployed to monitor various zones of increasing risk, starting at the perimeter fence: microphonic cable to detect break in; closed circuit television (CCTV) cameras to scan various sectors of the airfield (possibly connected to motion detectors); and infrared, microwave and underground pressure detectors to discover intruders and vehicles in unauthorized areas.

Searching The Public

Chubb Alarms is a major British security company marketing a comprehensive range of such devices, and has considerable expertise to advise how an area can best be protected.

Of more critical concern at present, however, are the airport areas to which the public have access — in particular the interfaces between the public areas and those restricted to passengers and airport staff. Through these pass the passengers, their baggage and their hand luggage, each piece of which may be concealing weapons or explosives, or the means for making of assembling them.

It is at these interfaces that, as the criminal and would-be terrorist become more ingenious, the detectors deployed against them need to become more effective.

CCTV is an important general means of monitoring the concourse of the airport and noting irregularities. The recent development of charge coupled device (CCD) cameras using solid state image sensors is a major step towards improved CCTV surveillance. The units are extremely small, allowing covert operation; they have a long life, are robust, need negligible maintenance and work at low voltage with power consumption of just a few watts.

Finding Metal

Coupled via a fiber optic taper to a microchannel plate image intensifier, they are capable of operation over all ranges of ambient illumination from bright sunlight to starlight. The English Electric Valve Company Ltd. has recently announced a comprehensive range of CCD cameras and sensors manufactured in its new factory at Chelmsford , eastern England, the most advanced CCD facility in Europe.

Firearms and most other weapons will incorporate a substantial amount of metal, which may be detected by X-ray machines or metal detectors. Passengers, on entering the airport's departure area, and possibly also before embarking, may be required to pass through an archway incorporating a metal detector and explosives detector.

The threshold sensitivity of the detector will be set to discriminate between, say, a small pistol and loose coins in the passengers' pockets: warnings of significant metal detection may then prompt further investigations by means of a physical body search or hand held metal detector such as the GM2 made by Graseby Dynamics.

Baggage and hand luggage is normally inspected via an X-ray machine, tended by an operator trained to identify suspicious opaque profiles. Recent products from Astrophysics Research, which has supplied over 2000 such machines worldwide, include a combined check in desk and X-ray screening system and mobile systems for spot checks.

Explosives Threat

Detection of illegal objects depends at present on the operator's alertness and experience, but the advent of microprocessors operating at several million instructions per second heralds the development of expert detection systems in which the X-ray responses will be compared automatically with a multitude of those from known weapon types.

Explosives represent the most deadly on the armaments available to the terrorist and also, even when made into improvised bombs, the most difficult to detect. The minimal amount of metal in the detonator or triggering device is unlikely to reach the alarm thresholds for archway or hand held metal detectors.

Accordingly, over the last two decades several types of explosive detectors have been developed. Explosive compounds, their additives and decomposition products emit minute quantities of a characteristic vapour, which it is possible to sample and identify — although with some modern military explosives this is far from easy.

The simplest sniffer devices available relay on direct ionization of the vapour from the explosives in air. These include typically the Graseby Dynamics PD4C and the A.I. Security Model 35, which are light, compact and easy to use. Although they perform a useful; function, their sensitivity is limited, their discrimination medial, and they are unlikely to respond to certain military explosives.

Finer Sampling

A more sensitive and selective range of instruments is available, based on gas chromatography. It includes the A.I. Security Model 97. These devices rely on a constant and very pure supply of inert gas, and the means for introduction of the atmospheric sample into the gas stream. The penalties for increased sophistication, however, appear in terms of increased size, weight, warm up time, response time, and cost.

The only other detectors available are the very complex and accurate instruments mostly confined by their size and lack of portability to laboratories, except for a recent product of Graseby Dynamics, the Ion Mobility Spectroscope (IMS), which shows considerable promise.

The IMS operates by first drawing an air sample through a probe and over a membrane which excludes dust and moisture, but permits the diffusion of the vapour molecules. The molecules are then ionized by a weak Nickel-63 beta emitter and subjected to a 1000 V DC field, controlled by a gating grid which allows the passage of the ions in discrete samples.

The drifting ions become ranged spatially in order of their mobilities, and, on reaching the collector electrode, present a current waveform characteristic of the ions in the sample. The internal air stream is circulated by a pump and dried. Then certain dopant chemicals are added in minute quantities to enhance the sensitivity.

The waveform received by the collector is digitized and fed to a microprocessor, in which its characteristics are assessed against patterns for various explosives, while vapours derived from other substances are disregarded. The PD5 has a hand held unit with digital readout connected by an umbilical to a briefcase, making it ideally portable.

In many aspects the means of ensuring good airport security are becoming better and more sophisticated. It remains only for airport authorities to develop security systems that use these means effectively.

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For Your Information

Digital IC Tester

The microprocessor-based AR-6000 from American Reliance is a high speed efficient IC tester designed to fill the void between basic component testers and costly ATE systems. It can test and identify more than 1600 CMOS and TTL digital ICs with up to 28 pins, including: Texas Instruments 54/74, 55/75 TTL, Motorola 14000 and RCA CD4000 CMOS series. In addition to its use as a valuable R & D tool, this affordable tester will help you control costs in manufacturing, inspection and service functions of even small companies.

Key features include: 16 by 1 character, 9 by 7 dot matrix LCD display; 14 function, 10 numeric keypad; and "open collector", "totem pole", "tri-state" output circuit detection of TTL ICs. As well the unit features Auto Search for identifying unknown ICs, Auto Test checks same ICs without keying in, and Loop Test for examining the durability of ICs. Price: $2310.00 Cdn.

BCS Electronics, 980 Alness Street, Downsview, Ontario M3J 2S2 (416) 661–5585.

Circle No. 50 on Reader Service Card

Continued on page 31

Electronic Analog/Digital Multimeter

A versatile test instrument for the workshop

By Mark Stuart

The Design of an Electronic Analog/Digital Multimeter was a very interesting exercise in compromise. During the course of its development a great deal of respect was gained for the designers of what were considered to be "ordinary" commercial instruments.

The basic electronic circuit for voltage, current, resistance, and AC measurements are fairly easy to deal with when taken individually, but combining them into a compact hand-held unit with a single range switch is another matter.

After some thought, it was concluded that the only solution suitable for home construction would be a bench meter and to incorporate a number of separate range switches. The idea of a single multi-pole multi-way switch was considered, but the price, and the complicated wiring that would be necessary completely ruled this out.

Two advantages of using separate range switches are that the switches can be printed circuit board mounting types — so eliminating wiring and wiring error and that parts of the circuit can be built separately and used individually in other applications.

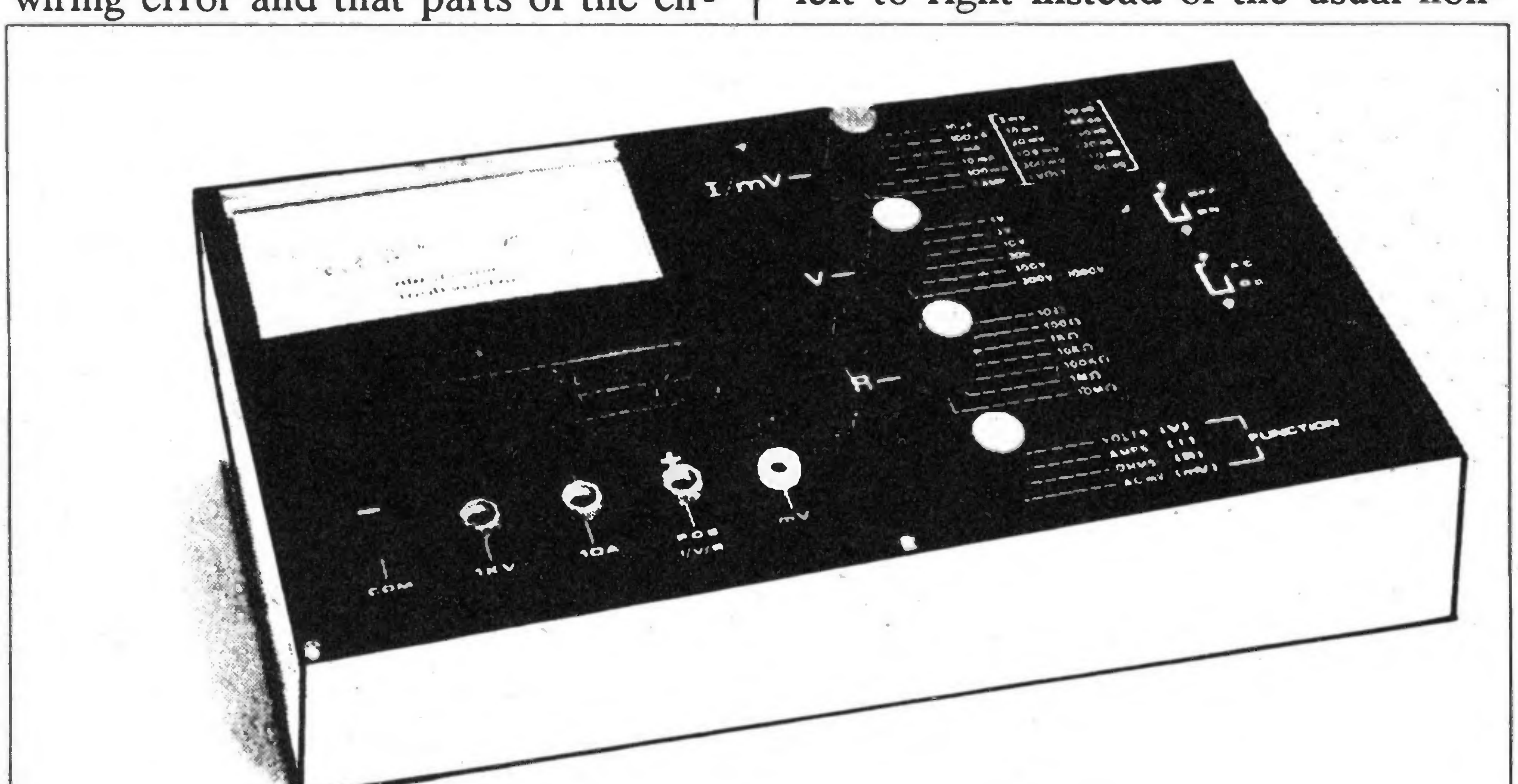
The "indicating device" specified is a panel meter with a 100uA sensitivity. This is modified by means of a series resistor to read 0-1V. Almost any standard panel meter can be used, or instead one of the new digital panel meter modules could be added.

The overall performance of the meter is very good, its frequency range when measuring AC voltages and currents is good up to 50kHz and the input impedance of 10 Megohms on all voltage ranges gives good accuracy in high impedance circuits where a normal analog multimeter would be useless.

In addition to the standard range the meter has an "AC Millivolts" circuit which allows audio frequency measurements from 3mV RMS up to 1V and is very useful for testing amplifier signal levels, microphone and pick-up outputs, frequency responses and general signal tracing.

The resistance ranges have the benefit of a linear scale that reads from left to right instead of the usual non-linear, reverse reading scales. Also, the probes are correctly polarized; red is positive — when making Ohms checks. All resistance measurements are made at a maximum of 100mV so in-situ measurements will not be affected by transistors, ICs and diodes in the circuit.

Other features are that the meter is protected from overloading by a fuse and electronically, and measurements up to 1000V and 10A AC and DC are possible. The meter is built in a fully insulated case for safety.



Circuit Description

The full circuit diagram for the Electronic Analogue/Digital Multimeter is shown in Fig. 1. For clarity each section will be described separately. The low noise diodes specified are types BAS45. Provided that they are "classified" as low noise, almost any general-purpose or signal diodes should work in this circuit. However, there may be some slight variations in meter performance from device to device.

Voltage

Inputs for voltage measurements are applied to the voltage divider chain made up of resistor R2 to R7. Voltage ranges are selected by S1a, which taps off a proportion of the input voltage from the divider chain and passes it to IC1, the input amplifier circuit.

On the 1kV range an extra resistor (R1) is added to the top of the divider. To avoid having high voltages on the circuit board this resistor is made up from a series combination of values which are sleeved and mounted in the lead to the 1kV terminal (SK3).

The input impedance of the circuit is set by the total combined value of R2 to R7 which is 10 Megohms. In order to make accurate measurements on all ranges it is essential that the input amplifier circuit has an impedance which is in excess of 50 Megohms.

Use of a FET input amplifier IC, TL071, and careful board layout ensures that this is achieved. IC1 does not have any gain, but it acts as a buffer circuit with a very high input impedance and a low output impedance.

From IC1 the signal passes to a second amplifier stage IC2 via resistor R32. S1b switches resistor R33 in and out of circuit on alternate ranges to give the 3V, 30V, and 300V ranges.

The combination of resistor R32 and R33 is such that the signal is reduced by 3 to 1 on each of these ranges but remains unaltered on the 1V, 10V, and 100V ranges. The amplifier IC2 has a gain of 10 and its output is applied to the meter movement via switch S5 when DC measurements are selected.

AC Voltage

The circuit as far as the output of IC2 is identical for AC and DC ranges. Capacitors C1, C2, C3, C4 and C5 correct for the effects of stray capacitance and maintain a level frequency response to above 50kHz.

When AC measurements are made the meter is connected via switch S5 to the output of the rectifier circuit IC5. This circuit takes its input from IC2 and produces a half-wave rectified output which is averaged by the meter movement to give a steady DC reading.

Diodes D3 and D4 in the feedback loop around IC3 are connected so that

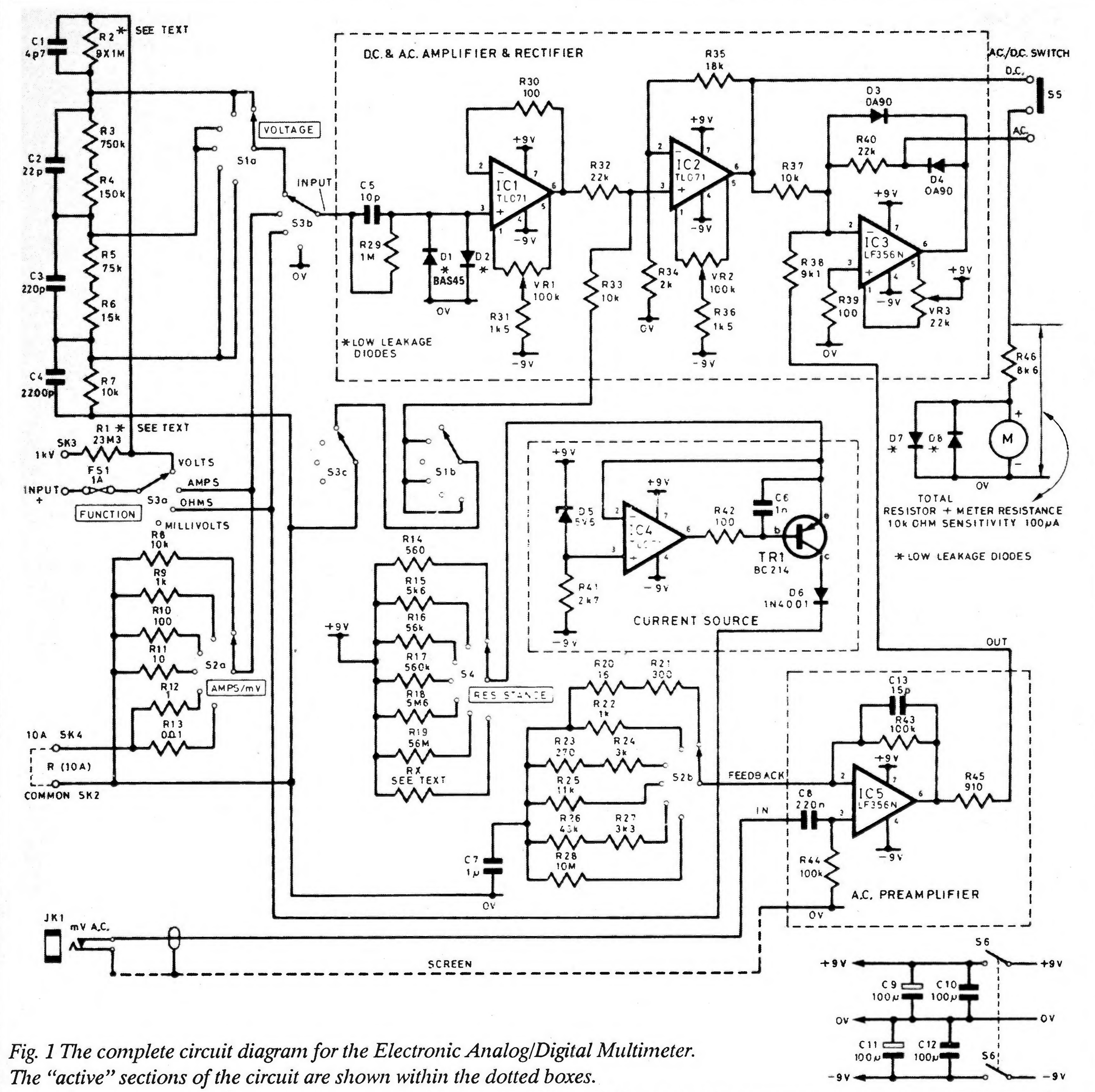


Fig. 1 The complete circuit diagram for the Electronic Analog/Digital Multimeter. The "active" sections of the circuit are shown within the dotted boxes.

on negative half-cycles the output stays at 0V, but positive half-cycles are passed normally with a gain of just over 2.

The value of gain is selected so that the meter reads the average value of the incoming signal and indicates the correct (RMS) voltage. As with all meters the accuracy of AC readings depends on the signal waveform. Sine waves are the most frequently encountered and so the meter is set to read correctly for these.

Diodes D7 and D8 across the meter protect it from being overdriven when switching ranges etc. Diodes D1 and D2 provide similar protection for IC1.

Current

On the current range the shunt resistors R8 to R13 are connected in circuit by S3a and the voltage across them read by the standard voltage circuits. S2a selects the value of shunt resistor and S3b makes the connection between the shunt resistors and the input of IC1.

The values of the shunt resistors are selected to drop 100mV at the full scale current. A shunt of one ohm will give full scale reading on the meter when a current of 100mA is passing and so on.

For the 10A range a shunt value of 0.01 ohm is required, this should be made from a length of wire connected directly between the 10A socket (SK4) and the negative (Common) socket SK2. This is necessary because the range switch is only rated at 1A, and the PCB copper tracks would have to be huge to carry 10A comfortably.

The AC and DC current measurements are treated by the amplifier section in exactly the same way as voltages. The current ranges increase in direct decades (x 10) so that the use of S1b is not involved. Switch S3c ensures that this is switched out of circuit on all ranges except voltage.

Resistance

Resistance is measured by passing a known constant current through the resistor under test and measuring the voltage drop across it using the standard voltage circuits.

The current source consists of IC4, transistor TR1, and associated components.

A reference voltage of 5.6V from Zener diode D5 is connected to the non-inverting input of IC4. Negative feedback around IC4 via TR1 and R42 works in such a way that the emitter voltage of TR1 is made equal to this reference voltage. This means that 5.6V appears across whichever emitter resistor is selected by S4.

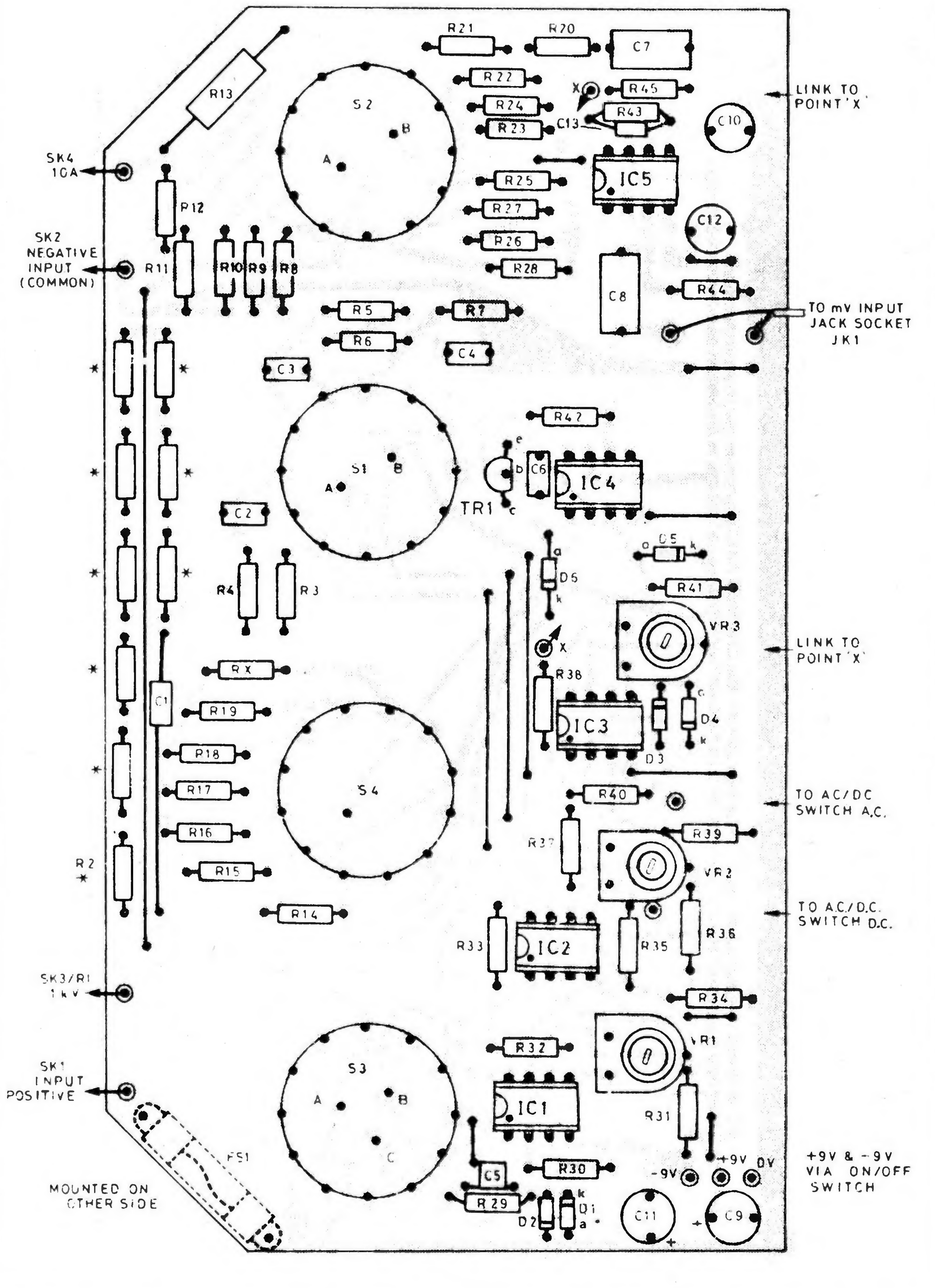


Fig. 2 Component layout on the printed circuit board. Note that the long link wires should be made with plastic insulated connecting wire.

This constant reference voltage across a fixed resistance value gives a constant current output at the collector of TR1. As the reference voltage is 5.6V, a 5k6 range resistor gives a current of 1mA. The standard voltage circuit, which is connected via S3b, gives full scale deflection for 100mV. A range current of 1mA thus gives a full scale reading of 100 ohms. Low value resistors drop less voltage and so the reading is directly proportional to the resistor value.

On the higher resistance ranges the current becomes rather too small for comfort. For example on the 100k range a current of only 1uA is required. The 1M and 10M ranges require 0.1uA and 0.01uA respectively. A current of 0.1uA is just about the limit of the circuit, so readings on this range will not be too accurate, and a 10M range is impractical.

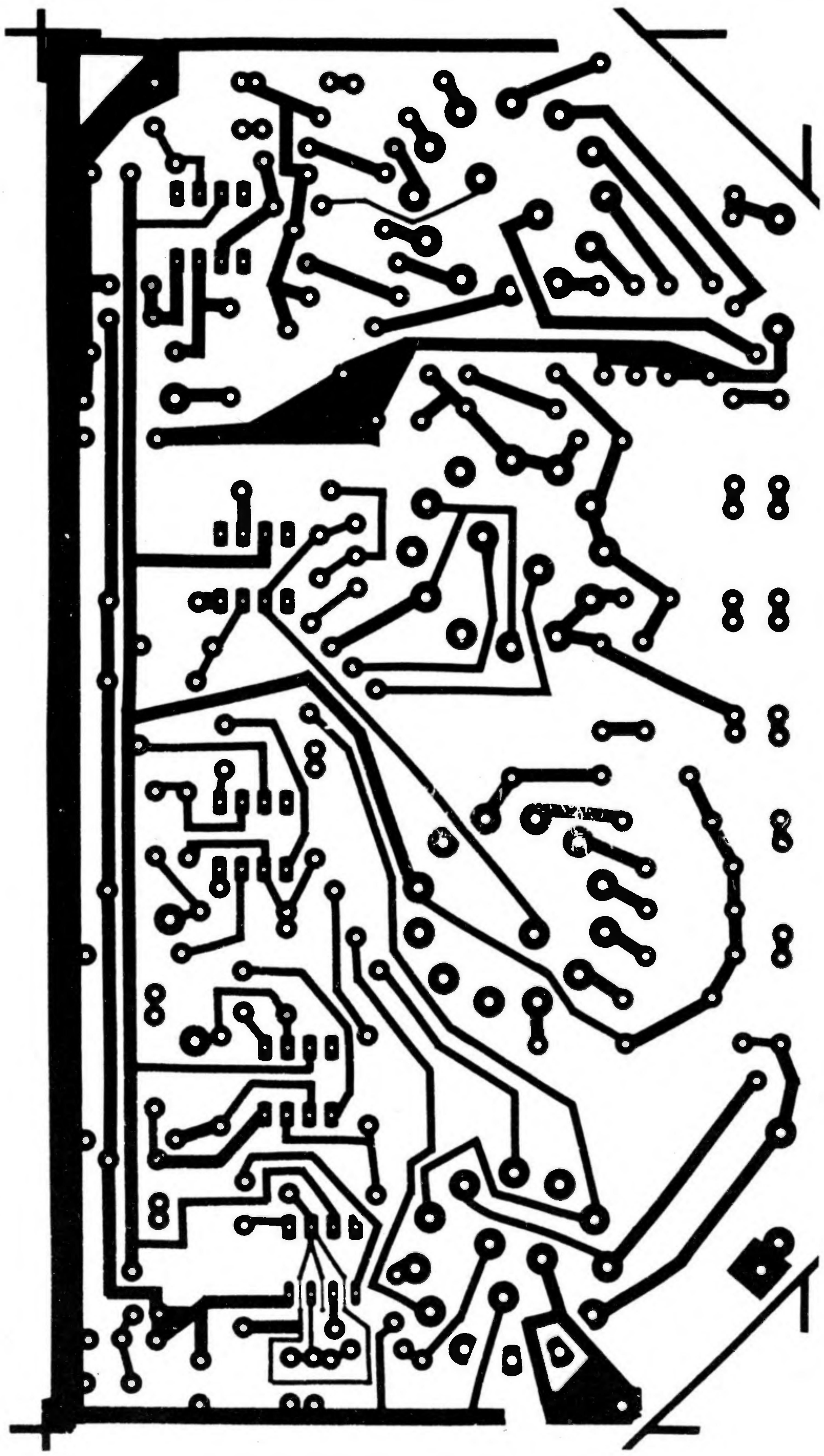


Fig. 3 Full size printed circuit board foil master pattern.

The middle resistance ranges are accurate and linear, and much easier to use than a standard meter. No compensation has been made for wiring and test lead resistance, so on the lower ranges 100 ohm and 10 ohm, an offset zero will be present when the test leads are short circuited. This value should be subtracted from any measured resistance value to give the true reading.

AC Millivolts

The measurement of AC Millivolts is made by first amplifying the input to 1V and using the standard rectifier circuit IC3.

The AC pre-amplifier, IC5, is connected to IC3 via resistor R45 and R38. The gain of IC5 is set by the feedback resistor R43 and the range resistor selected by S2b. The values of resistors R20 to R28 are chosen to given ranges of 1V 300mV, 100mV, 30mV, 10mV and 3mV. The frequency response is level up to 100kHz except on the 3mV range where it is slightly lower.

When making measurements on the mV range the input of IC1 is connected to 0V by S3b so that stray inputs do not interfere. In a similar way the input of the mV range is shorted out when the input lead is disconnected by use of a switched jack socket (JK1).

The input impedance on this range is set to 100 kilohms by the input resistor R44.

Power Supplies

The Multimeter circuit consumes very low current, but as meters tend to be used frequently it is recommended that two sets of six AA cells are used. These can be standard or re-chargeable types, and should give very long life.

AC derived power supplies can also be used, but take care to use double insulated circuits *without* a ground on the output side as this could cause all sorts of problems with ground loops.

Construction

As the circuit is all built on a single printed circuit board the assembly is fairly straightforward. Fig. 2 shows the component layout and Fig. 3 the printed circuit board track pattern, full size.

Begin assembly by fitting the wire links as shown. The longer links should be made with insulated wire while the shorter ones can be made from offcut resistor leads.

As there are a lot of resistors and most of them carry the five-band one per cent colour code system it is necessary to be careful to get the correct values in the right places. Any errors will give "odd" ranges which may not be easy to spot as the meter may appear to be working perfectly.

Sockets should be used for all ICs. The rotary switches are usually supplied with loop tags for direct wiring and these must be cut off leaving as much of the straight stems of the tags as possible.

Switches S1, S2 and S3 will fit more than one way, so take care to set them fully anticlockwise and use the flat part of the shaft as a guide to get them right. Remember that the pointer on the knob is exactly opposite the flat on the spindle. If you get it wrong and don't want to unsolder the switch, screw fix knobs are a good alternative way out.

Capacitor C1 is mounted between two distant points; its leads must be sleeved and may need extending to fit the board centres. Make sure that all diodes, and capacitors C9 and C11 are the right way round.

The final component to be fitted to the board is the fuseholder which is fitted to the track side to keep easy access to the fuse. Once the board assembly is complete connect the necessary wires to the board. The mV input should use screened cable, the other input socket connections should be made with 16/0.2 wire.

Resistors for the 1KV socket should be fitted in a length of sleeving between the board and the input socket. The 10A shunt is made from a 71cm length of 18 SWG enamelled wire connected directly between the 10A socket and the negative (Com) socket SK2. The wire can be loosely wound on a flat piece of insulating material.

The wiring diagram in Fig. 4 shows how the shunt can be fitted and also the wiring to the other parts of the board from the sockets.

Testing and Setting Up

The thorough testing of a meter of this type presents quite a problem. The wide range of accurate voltages and current necessary to check each range fully is not likely to be available even in electronics workshops. The best way is to make comparisons with other meters using whatever sources of voltage and current are available. It is possible that a local training centre, school or college will be able to help, so ask around.

Fine tuning of capacitor values C1, C2, C3, C4, and C5 may be undertaken by those determined to extract the very best from the meter. These components affect the frequency response on the AC Voltage ranges. Capacitors C1 and C5 in particular have a large effect and should be changed only if a good reliable sine wave source of 0-100kHz or more is available.

If no test gear is available it is safe to say that the meter should work accurately first time provided no errors are made in assembly.

There are three presets that must be set up to remove the zero offsets of IC1, IC2 and IC3. To do this, set the AC/DC switch S5 to DC and the Range switch to mV. Link pin 3 of IC2 to 0V and if necessary adjust VR2 to zero the meter. Remove the link and if necessary adjust VR1 for zero. These two are now correctly set.

Next set the AC/DC switch to AC and turn VR3 until the meter deflects to the right. Back off the setting of VR3 to the point where the meter just touches zero and the settings are complete.

The accuracy of the Ohms range depends on the Zener diode D5 which is specified as a five per cent component. More accurate voltage references can be obtained and substituted if required.

The value of resistor R46 depends on the meter being used. Its value can be calculated easily as its function is to make the meter resistance value up to 10 kilohms. A meter of four kilohms resistance thus requires a six kilohms resistor and so on.

It is also possible to use meters of other current ratings, all that is necessary is to set the meter and series resistors so that 1V gives a full scale deflection (FSD). Thus a 1mA meter would need a combined meter plus series resistor value of one kilohm. A 50uA meter, 20 kilohms; a 500uA meter, 2 kilohms etc.

On AC ranges the "averaging" effect of some types of meter may be affected by the diode (D4) in the drive circuit. A 1k resistor from D4 cathode to 0V line overcomes this and allows any type of meter to be used.

Safety

For complete safety an insulated case is essential where high voltage readings are to be made. It is also necessary to add some screening to the meter electronics. The best way to combine these two functions is to use a plastic case with a metal front panel overlaid with an insulating panel. The metal panel should be connected to the 0V point in the circuit.

Decibel Ranges

The dB Range on the meter is set to be accurate on the AC mV Ranges. On the 1V AC Range (mV) the 0dB point represents the universal 1mW in 600 ohms. Each range down from the subtracts exactly 10dB so relative measurements are easy.

The use of dB scales is a difficult subject for beginners and it is not intended to go into details here.

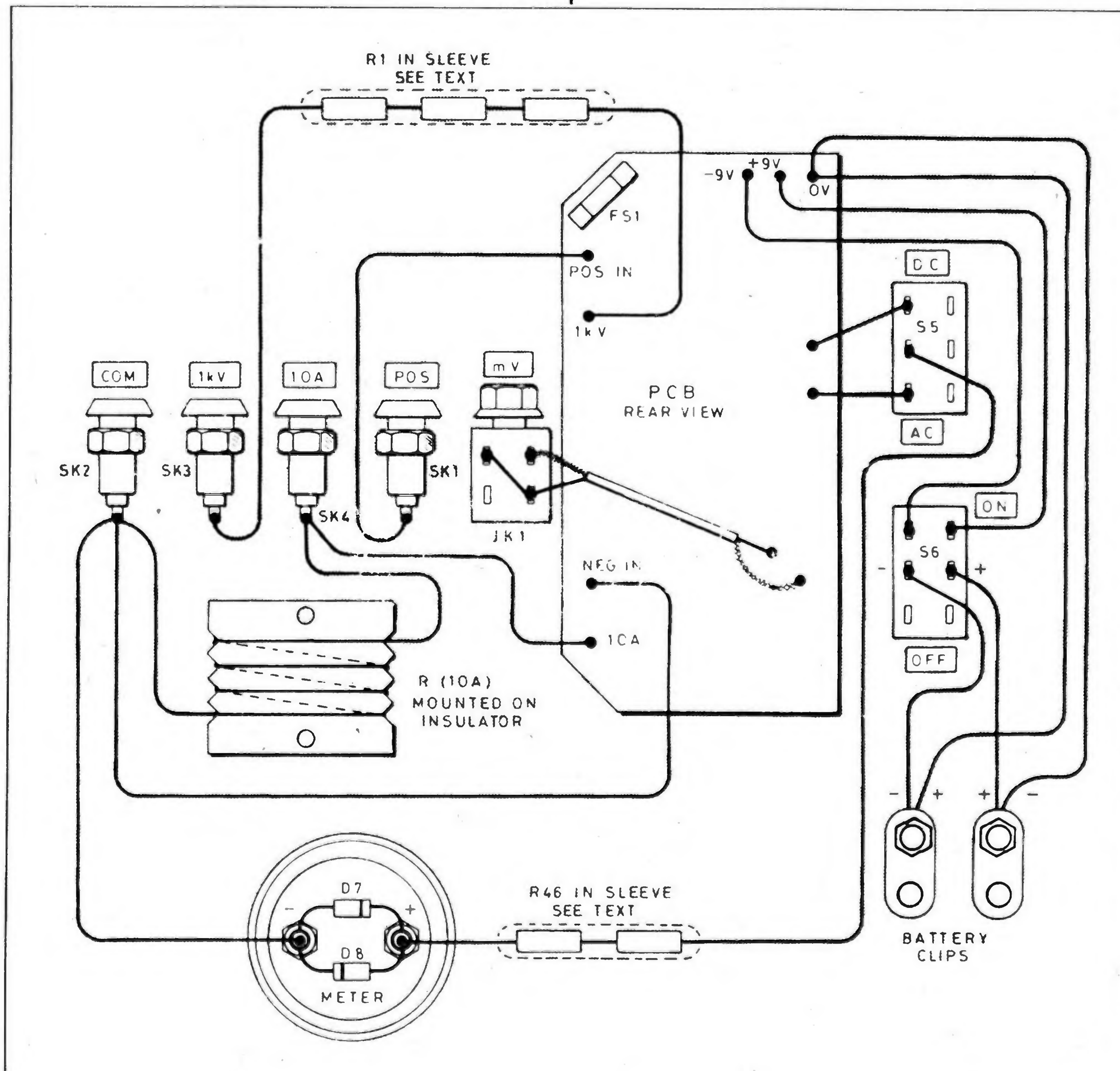


Fig 4 Interwiring details of the off-board components. The circuit board and components are all mounted on the rear of the front panel.

Parts List

Resistors

All 0.25W carbon except where noted

R1	23M3 (2x10M + 3M3 in series, 5%)
R2	9 x 1M in series, see text
R3	750k
R4	150k
R5	75k
R6	15k
R7,8,33,37	10k
R9,22	1k
R10,30,42	100R
R11	10R
R12	1R
R13	0.1R
R14	560R
R15	5k6
R16	56k
R17	560k
R18	5M6
R19	56M (series comb.)
R20	16R
R21	300R
R23	270R
R24	3k
R25	11k
R26	43k
R27	3k3
R28	10M
R43,44	100k
R29	1M
R31,36	1k5
R32	22k
R34	2k
R35	18k
R38	9k1
R39	100R
R40	22k
R41	2k7
R45	910R
R46	8k6 (or value to suit meter)
R(10A)	0.01R made from resistance wire

Potentiometers

VR1,2	100k Horiz. Preset
VR3	22k Horiz. Preset

Capacitors

C1	4p7 axial 500V
C2	22p cer. 50V
C3	220p cer.
C4	2200p polystyrene
C5	10p cer.
C6	1n cer.
C7	1u min. layer 100V
C8	0u22 100V
C9,11	100n disc cer. 50V
C10,12,13	15p cer.

Semiconductors

D1,2,7,8	BAS45 (see text)
D3,4	1N34 or 1N60
D5	5V6 Zener
D6	1N4001
TR1	BC214 or 2N6003
IC1,2,4	TL071
IC3,5	LF356N

Switches

S1,2	2-pole 6-way make-before-break
S3	3-pole 4-way
S4	1-pole 12-way make-before-break
S5,6	DPDT min. slide sw.

Miscellaneous

100uA panel meter, 1k4 resistance (see text); 8-pin IC sockets (5); 1A fuse Q.B.; 20mm chassis fuseholder; knobs, four with colored caps; case to suit with insulated front panel; 4mm sockets (4); insulated jack socket (with N/C switch); test leads and probes (2); 9V battery clips; 6 x AA battery holders (2). ■

Travelling Wave Scope Design

Brightening high-speed scopes with travelling wave tube technology

By Dr. H. Virani

Conventional CRT designs, even those using post-deflection acceleration run into limitations at about 200 MHZ due to the amount of power required. Deflection current has to be high to charge the deflection plate capacitance and, as a result, dissipation in the final amplifier stage is very high requiring custom components which are expensive if not downright beyond the limits of current technology.

Travelling wave deflection provides the only practical alternative in very high frequency oscilloscopes, and also offers the advantage of providing a bright image for single-shot signals.

The basis for travelling wave design has existed for some time; tubes for up to 7 GHZ were produced using such an approach for French Government-sponsored applications including image intensification and signal storage.

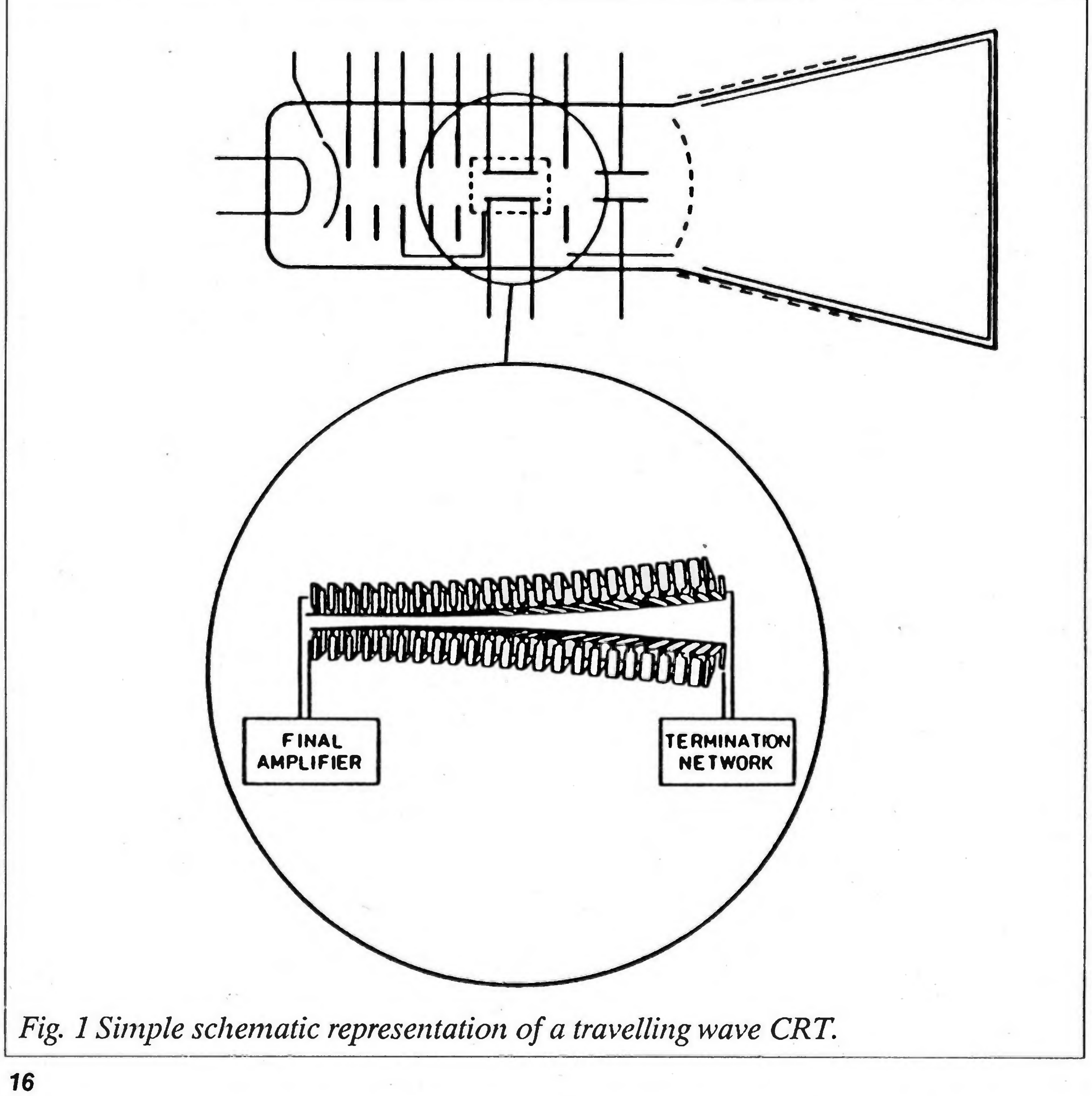


Fig. 1 Simple schematic representation of a travelling wave CRT.

Incorporating Latest CRT Technology

The tube developed for this special kind of oscilloscope uses the latest Phillips gun and domed mesh technology, internal magnetic correction, and the travelling wave deflection system. A schematic view can be seen in Fig. 1.

The performance of a CRT always requires a trade off between the sensitivity and the writing speed and, as far as the user is concerned, a maximum writing speed is the important parameter. Lack of sensitivity in the tube itself can be compensated for by using a more powerful final amplifier. The major problem however for TWSs came in the design of the deflection system. Tube sensitivity can be improved by using long deflection plates, but this requires more power due to the increased capacitance. There are additional problems at very high frequencies, where the input from the circuit under test can change so fast that the travelling time through the deflection plates becomes critical.

In fact three basic requirements have to be met in the design of the deflection system for very high frequencies:
There must be a constant impedance, at all frequencies throughout the deflection system, to prevent reflections.

Signals must have the same travelling time through the structure, at all frequencies to prevent phase distortion particularly noticeable in step functions.

Signal speed must match electron speed through the structure; if the signal changed while the electron was passing, there would be distortion on the screen.

The final requirement means slowing down the signal. The speed of the signal along the deflection line is that of the light; with an acceleration of 3KV before the deflection structure, the electron is travelling at only 10% of this speed. So the length of the signal path in the deflection system has to be ten times that of the electron's.

Travelling Wave Deflection

The most effective method of matching the speed of the electron through the deflection plates to that of the signal is to use a travelling wave deflection system. Various approaches are available for this, but the two most widely used are the meander line and the helical slow-wave structures. The former is slightly easier to make but, as its impedance is much lower in general, it is more difficult to drive. Both structures can be used either single ended or balanced. At first, the single-ended approach shown in Fig. 2 appears simpler. It could be matched to 50 ohms for example, allowing it to be fed directly using a coaxial line.

In practice, however, the balanced structure shown in Fig. 3 is more advantageous; driving a balanced system from two push pull amplifiers reduces driving power and only needs half the voltage rating.

In such a case the beam can be trimmed to dead centre of the CRT when there is no input signal and deflection is symmetric (positive and negative) in both x and y axes. Maximum deflection potential is reduced and defocussing of the spot towards the screen edges is eliminated due to the balanced approach.

Practical Deflector Design

The basis design of the travelling wave deflector structure is shown in Fig. 4.

It consists of a double helix driven by a push-pull amplifier stage and terminated with a matching impedance to avoid reflection. Impedance of the structure is 2 x 165 ohms requiring a 330 ohm terminator. The design of the CRT enables it to be produced to very tight tolerances; this is achieved by trimming of the deflection structure using a time domain reflectometer before the gun is mounted and sealed in the tube. As well, careful component selection during assembly of the oscilloscope minimizes the effect of reflections.

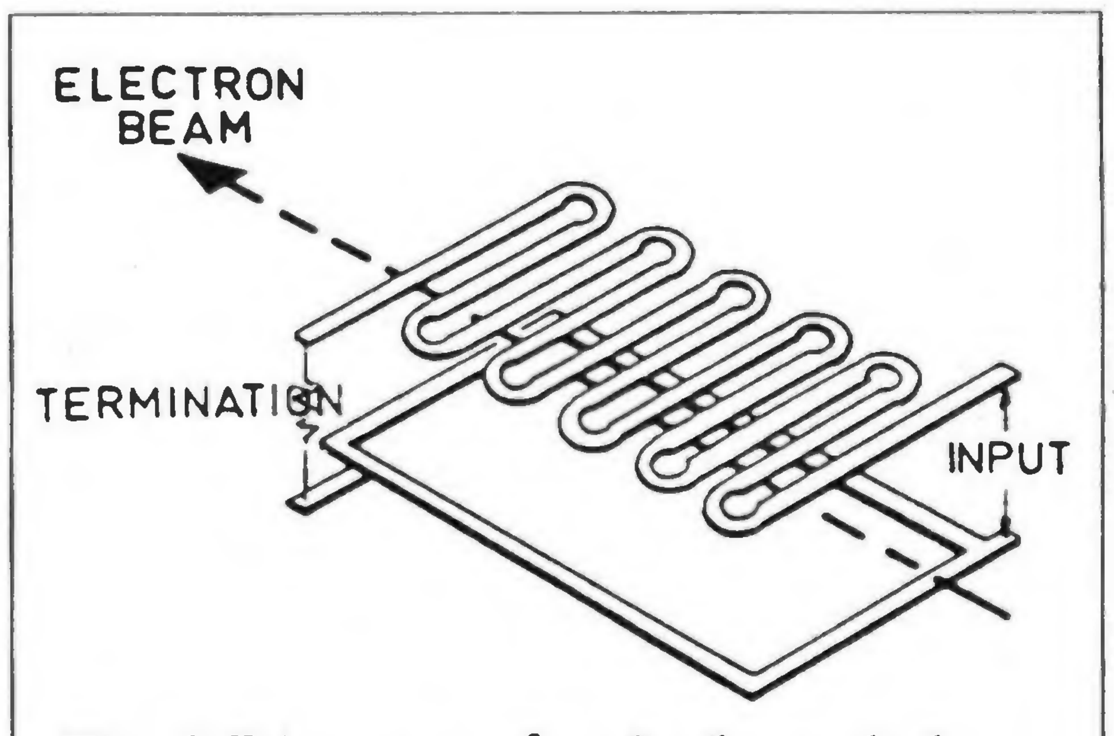


Fig. 2 Diagram of a single-ended helix system.

Special attention has been paid to the cable connections to reduce inductance. This isn't so simple because as at very high frequencies the effect of the change of dielectric from air, to glass, to vacuum is noticeable. One action here, for example, was the use of thinner wires through the glass.

The output amplifier itself is built using standard available components mounted on a thin film substrate to keep inter- connections as short and as symmetrical as possible. Output transistors are high-power components having low feedback capacitance at their collectors and very good thermal characteristics.

Internal Magnetic Correction

Many electronic companies here and abroad have had extensive experience in the design of televisions and specialized instrumentation applications such as the internal magnetic correction technology used in the 350 MHZ tube.

Internal magnetic correction depends on the use of permanently magnetized wire rings in the electron gun. These replace the more conventional external multipole magnets normally required for static convergence correction.

Two rings are applied in the oscilloscope CRT: one is used for scan magnifications, beam centering and orthogonality; the other mainly handles beam shaping. The rings are magnetized towards the end of the manufacturing process, and the internal magnetic fields developed by the rings are unaffected by external metal shieldings.

A high initial acceleration system is used with a potential difference of 3kv between the cathode and the deflection system. This is important because accelerating the electrons this much lessens the influences of space charge repulsion between them.

The section of the tube following the deflection system is a conventional

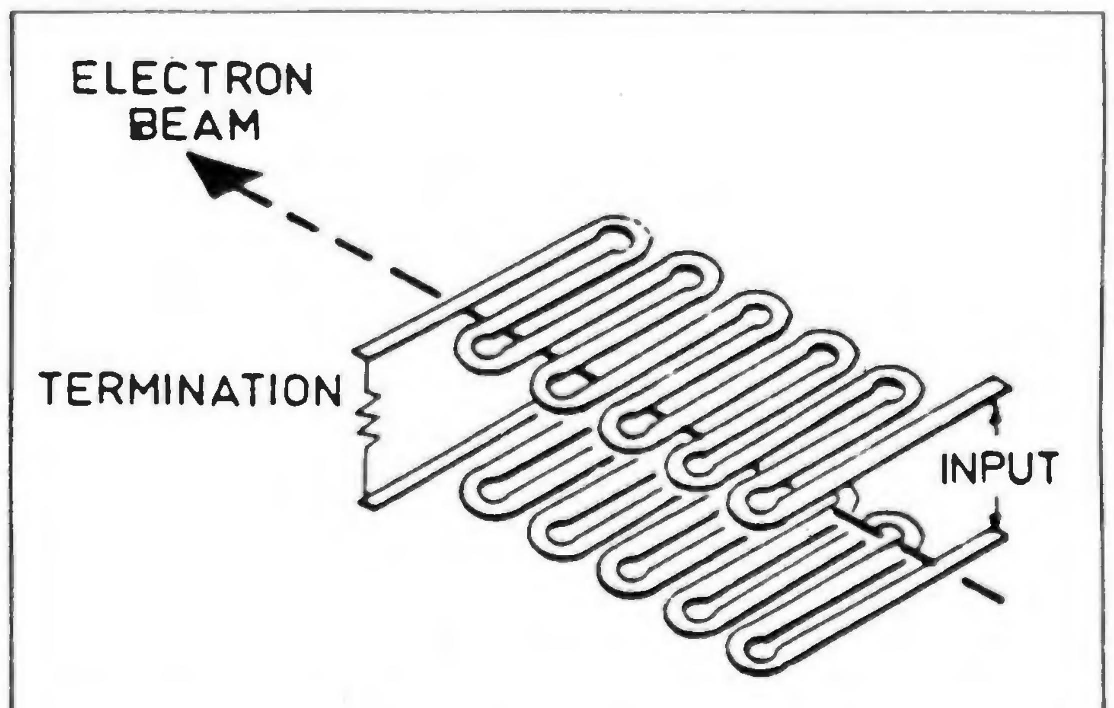


Fig. 3 Diagram of a balanced helix system showing the zero plane.

post-deflection acceleration design with a domed mesh. This is effectively an accelerating negative lens with rotational symmetry providing post acceleration and scan magnification horizontally and vertically at the same time.

Dr. H. Virani is a freelance writer from Mississauga, Ontario.

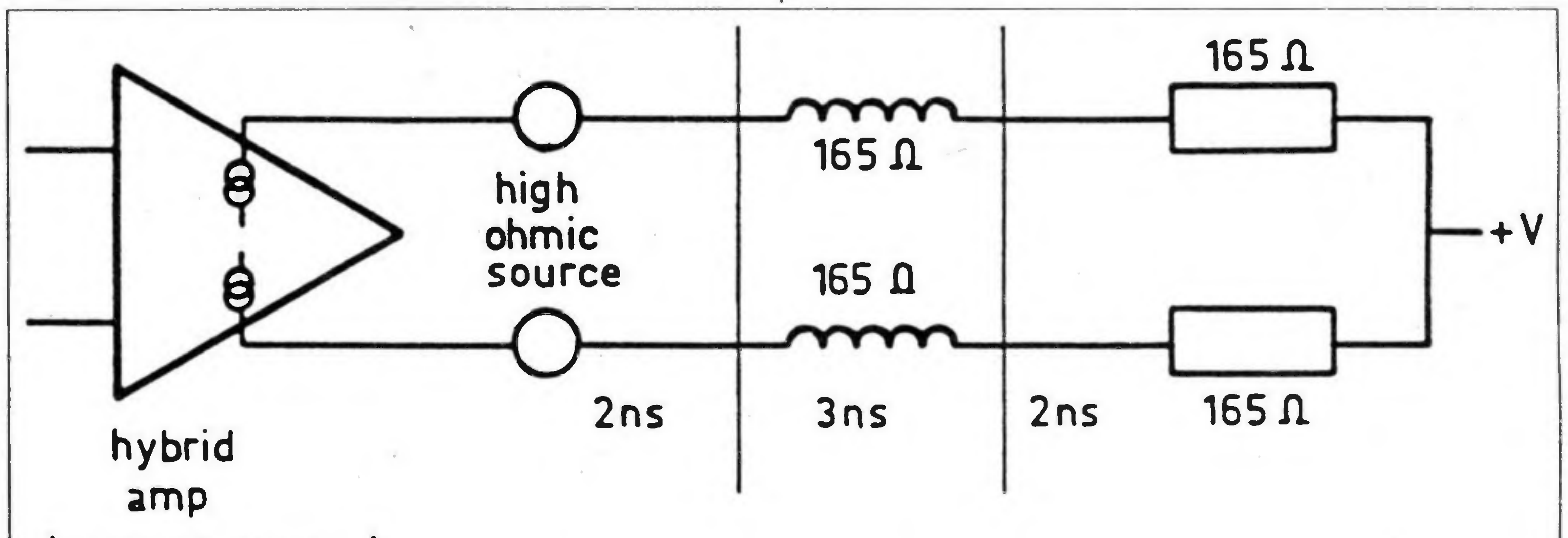
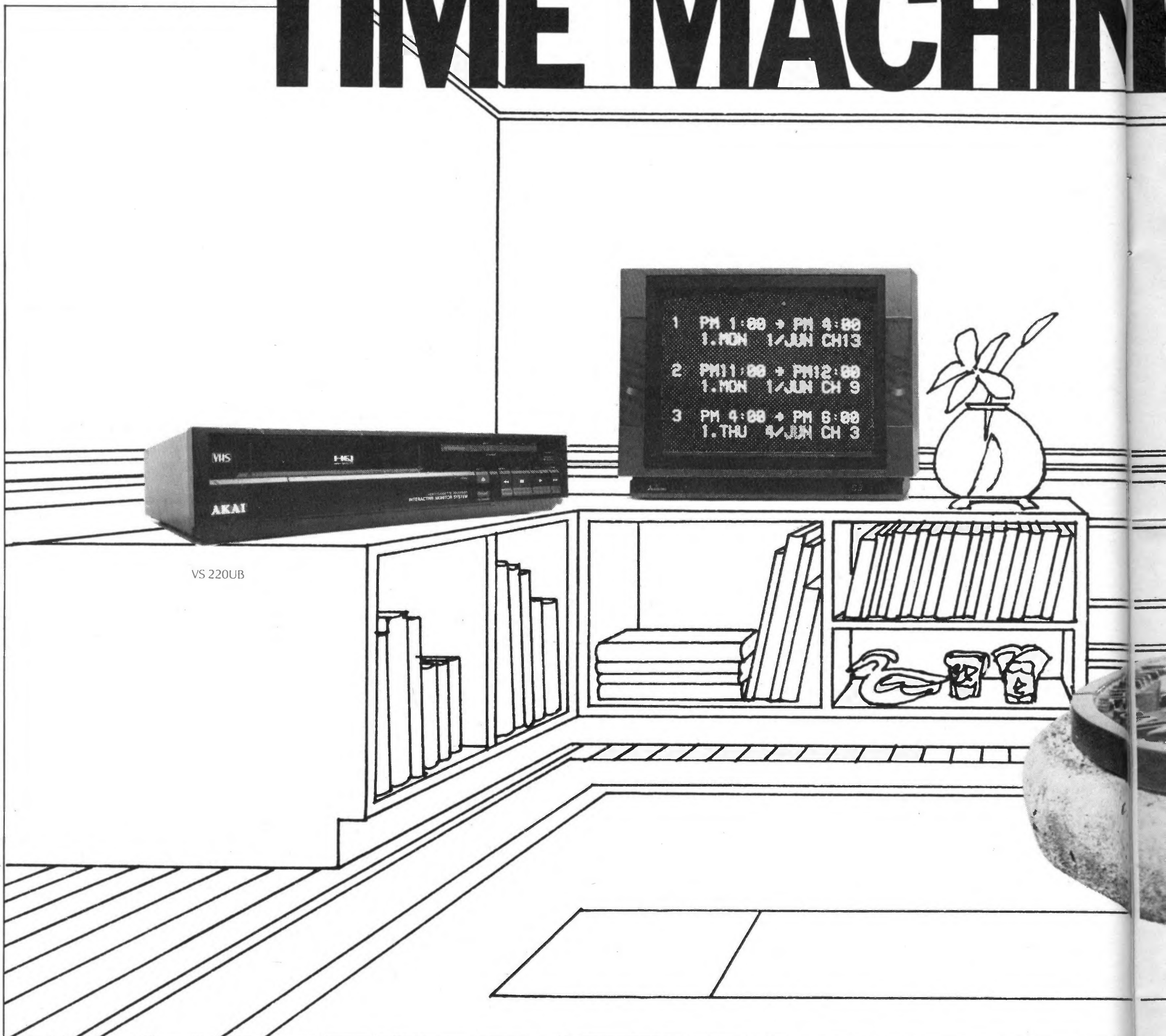


Fig. 4 Shematic diagram of deflection system/driving circuit.

TIME MACHIN



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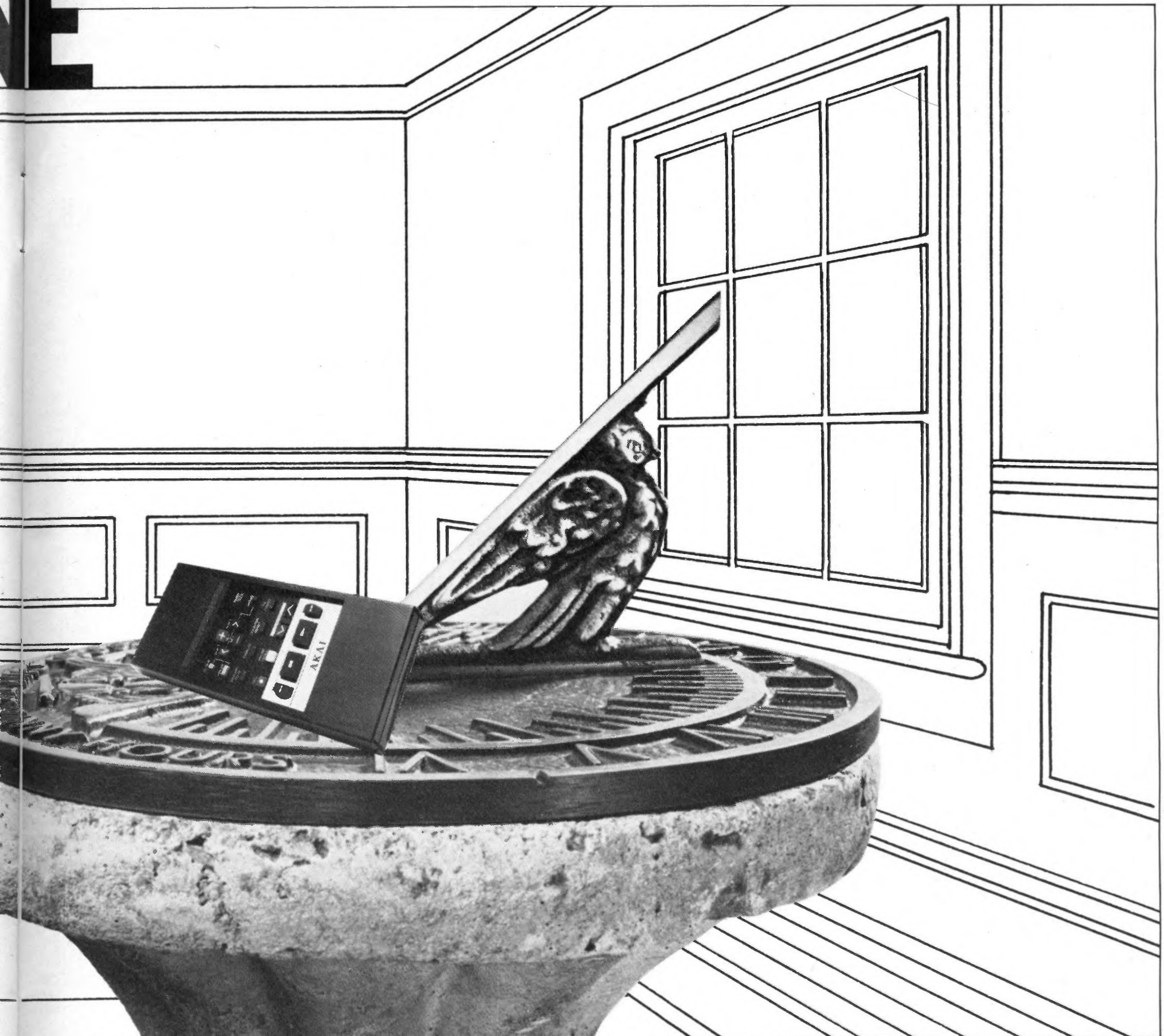

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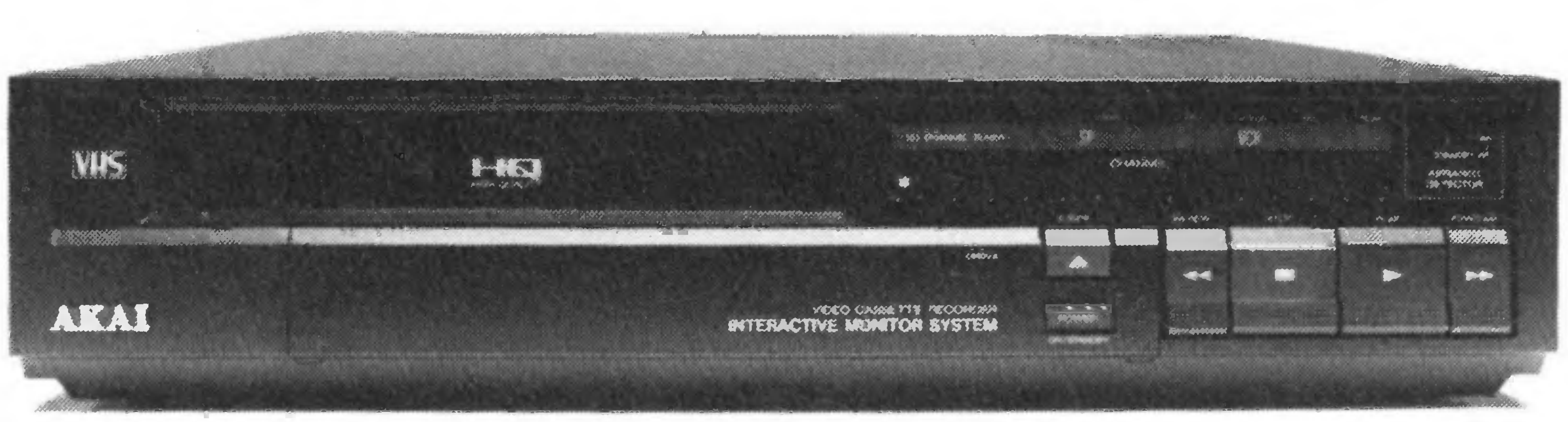

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The Magic of Magnetic Resonance Imaging

Magnetic body scans and how they work

By Carol Thomas

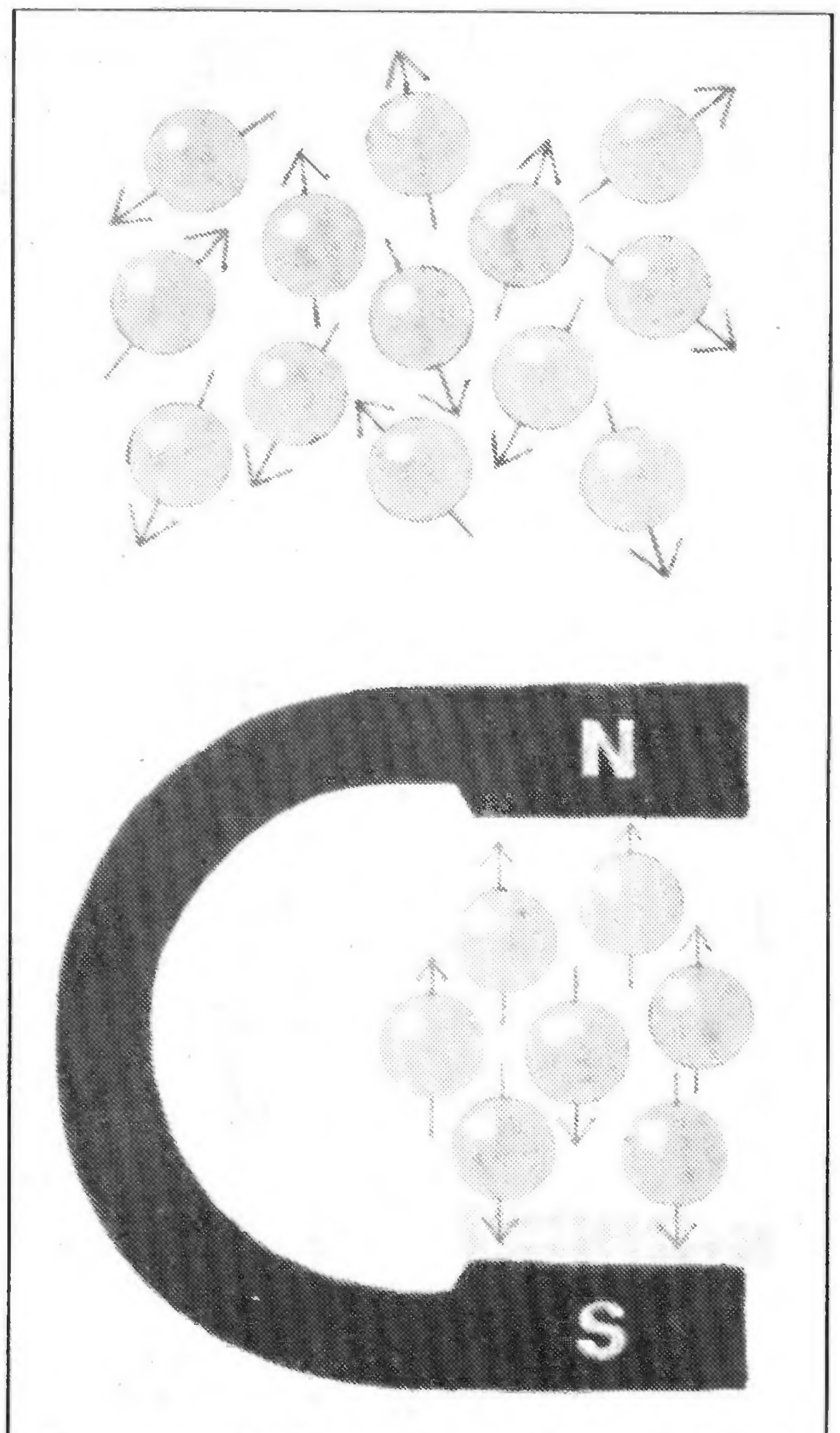
It used to be that when your doctor wanted to find out what was going wrong inside you, he found out the hard way -- with a scalpel. But in the past hundred years, with the advent of X-rays and, more recently, ultrasound and CT scanners, doctors have been looking inside the human body without so much as touching the skin. The latest newcomer to this group of high-tech systems is Magnetic Resonance Imaging, or MRI, a tool which has many of the advantages of the other three methods and few of their drawbacks.

MRI has its roots in NMR (nuclear magnetic resonance) spectroscopy, an analytical tool which can be used to determine the structure of organic molecules. The magnetic resonance phenomenon was first described in 1939, when it was noticed that a beam of hydrogen molecules, passing through a magnetic field, could be deflected by radio frequency energy. In the mid-1940s, it was found that a continuous wave of radio frequency energy radiation applied while changing the magnetic field produced radio frequency absorption in paraffin wax or water. Then, in the early '50s, it all came together when several groups showed that protons in different chemical environments absorbed different radio frequencies, hence, the birth of NMR spectroscopy.

It took until 1980 for NMR imaging methods to develop to the stage where MRI could be used clinically. The first pictures produced were crude, since the magnets used in the units were much weaker than those used now, although they still showed information that could not be gathered by any other method. However, in the past seven years, the field has grown quickly, and there are now 13 MRI systems installed or soon to be installed in Canadian hospitals.

Why MRI?

It might be questioned why a new imaging method is necessary when we have X-rays, ultrasound and CT scanning already on hand. However, X-rays and ultrasound are limited because the waves or particles used have to interact with body tissue and possess sufficient penetration depth. These conditions are satisfied by X-rays and gamma rays, but they use ionizing radiation, which carries risks of radiation damage, cancer and so on. As well, to show soft tissue, contrast agents (dyes) or tracer injections have to be used. These are not always pleasant for the patient, as anyone who has had a barium X-ray will attest to.



A representation of atomic nuclei in free space (above) and in a magnetic field. Courtesy Siemens Electric Ltd.

Ultrasound, although it doesn't involve radiation risks or tracers, is limited in penetration depth by strong reflections from bone and air, so the range of applications is not as wide as that of other techniques. MRI, however, uses no tracers or radiation yet produces high contrast cross sectional images of any plane desired, and has high sensitivity to physiological alterations.

How It Works

The principle on which MRI works is the phenomenon of atomic nuclei emitting measurable radio signals when placed in a magnetic field and stimulated by a specific radio frequency. This applies to all stable nuclei which contain an odd number of protons, neutrons, or both, because these nuclei have two vital properties, *spin*, and *magnetic moment*, properties which make them behave like a spinning magnetic gyroscope. About two thirds of all stable nuclei have these characteristics.

Since the adult human body is about 56 per cent water, hydrogen is the most common element in humans, and hydrogen, with its one proton, is an ideal element for NMR analysis. When protons are in a magnetic field, they align themselves with or against the field, more commonly with it, because this is energetically favorable. Because more protons are aligned with the field than against it, a magnetization exists in the direction of the magnetic field. This magnetization spins about its axis, because of the angular momentum of all the nuclei involved.

In a state of equilibrium, the magnetization lines up with the magnetic field like a compass needle. However, if this magnetization is deflected, it will not return directly to its equilibrium state, but instead will rotate in ever-decreasing circles around the direction of the field, which is where the gyroscope analogy comes in. The angular velocity of the rotating magnetization is proportional to the strength of the magnetic field. To measure the precession, or movement with angular momentum, of the nuclear magnetization, the sample being examined is surrounded by a coil in which an alternating voltage of the frequency of the angular momentum is induced.

A radio frequency field is used to deflect the nuclear magnetization away from the magnetic field and thereby induce precession. This field is generated by a radio frequency current pulse in the coil around the sample. If the frequency of the field is equal to the precession frequency of the magnetization, then the energy will be transferred and the magnetization will be deflected.

After the radio frequency pulse is switched off, the NMR signal induced in the coil is recorded. The frequency of the signal corresponds to the precession frequency and its initial amplitude to the number of stimulated nuclei in the sample. Since atomic nuclei in different chemical environments possess different resonant frequencies, it is possible to determine how much of a given element is in which organic or inorganic form.

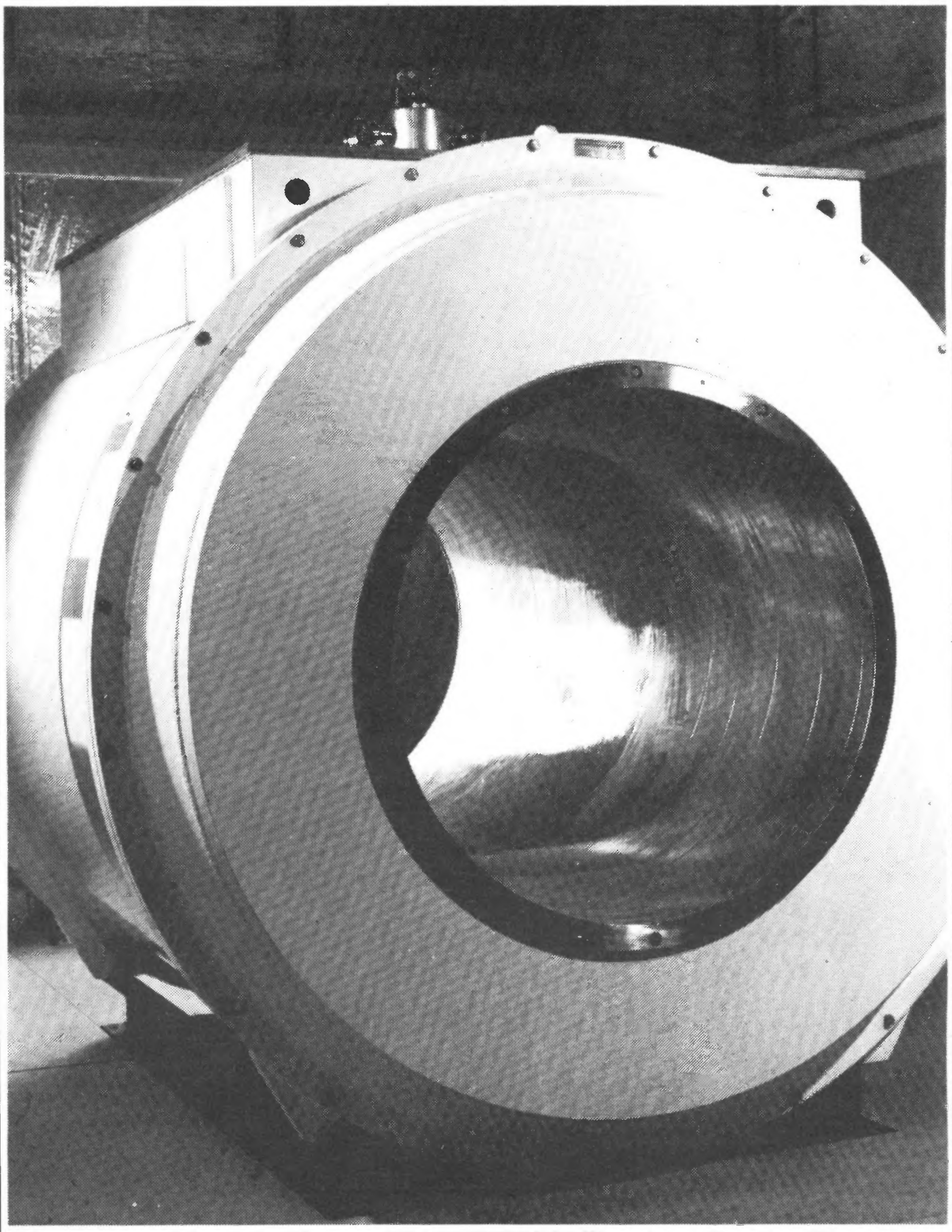
Using this on people is somewhat more complicated, because this sort of measurement on large biological objects produces values which are often meaningless. So, a method was developed to produce an NMR spectrum just from a specific part of the object (or person) by tuning the NMR receiver to the frequency of only one homogeneous volume being investigated. This volume can be further spatially limited by the shape of the receiving coil used.

How An Image Is Made

For NMR imaging, the contributions to the NMR signal from the various regions of the body have to be differentiated. This is done by making the strength of the static magnetic field dependent on its location. Because the resonance frequency and the magnetic field strength are proportional to each other, the various contributions to the signal can be allocated to their sites of origin by examining the frequency. Only the signal from a limited volume element, or "voxel", is detected. By measuring a series of voxels in the human body, the image of a slice can be built up.

To vary the strength of the magnetic field, auxiliary magnetic fields whose strength varies locally are superimposed on the base field. These auxiliaries produce a linear dependence of the magnetic field strength in the x, y or z-directions. To select a particular slice to be examined, a field gradient perpendicular to the slice plane is switched on before the radio frequency pulse is applied. Only the magnetization in that slice is excited out of equilibrium by the pulse, while all other regions of the body are uninfluenced.

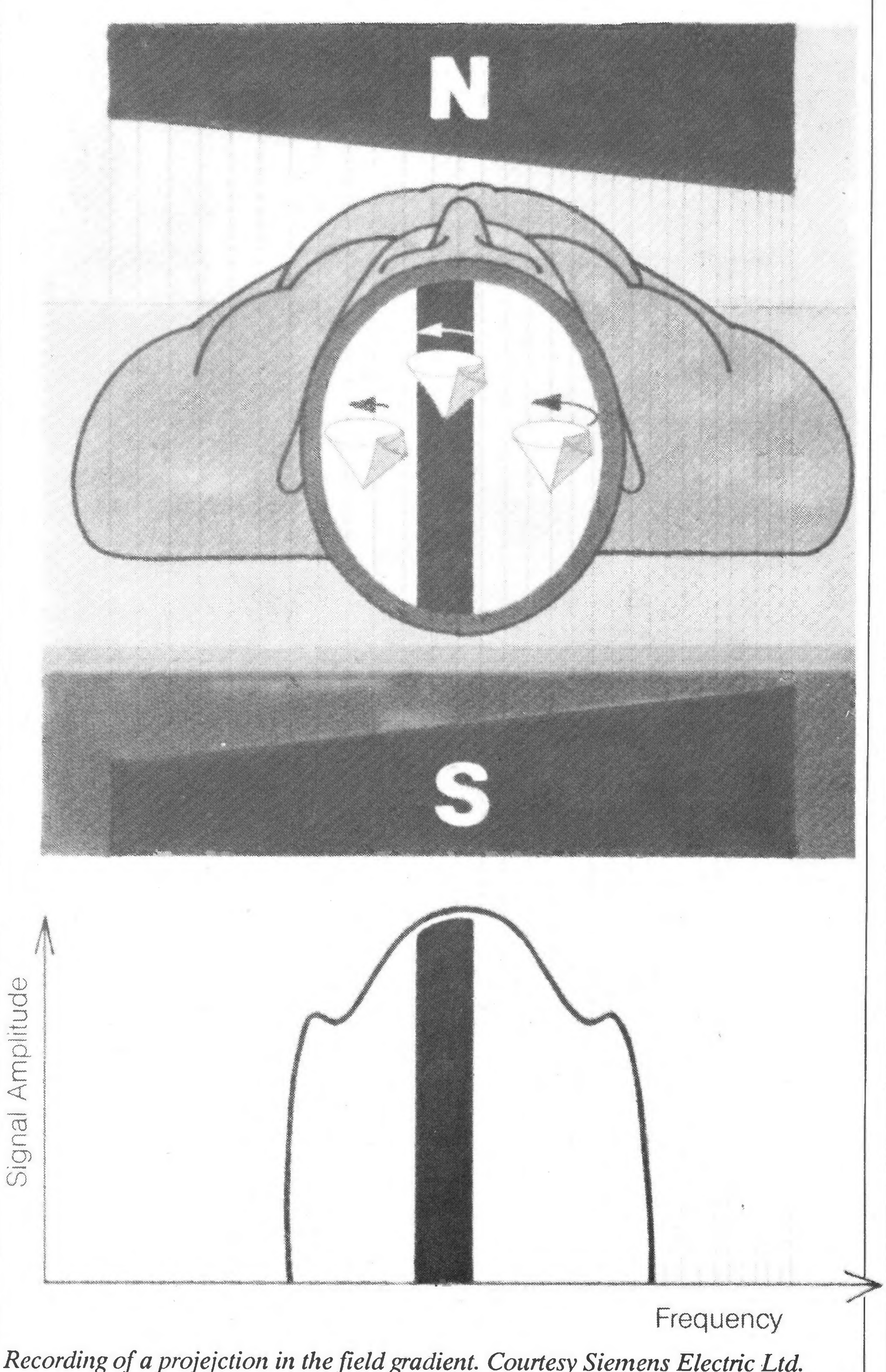
To record the measurement signal and thereby produce an image of the selected slice, the first gradient field is switched off, and in its place, a field gradient whose direction lies in the plane of the slice is switched on. A mixed frequency is received at the coil, which contains all the NMR frequencies which arise from that slice. This is repeated with different field gradients until enough information has been ac-



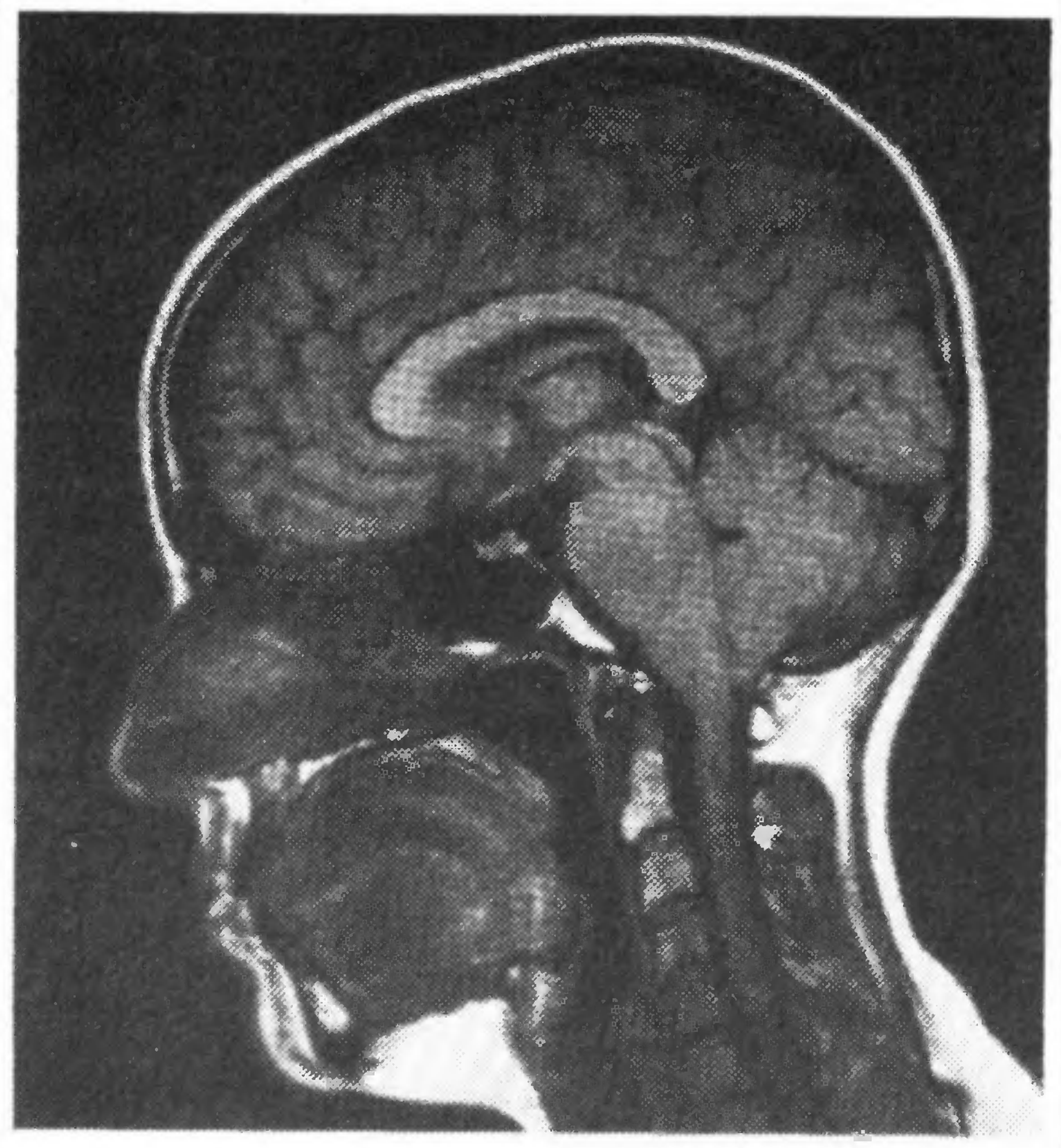
Magnet assembly of the Siemens MAGNETOM MR system. Courtesy Siemens Electric Ltd.

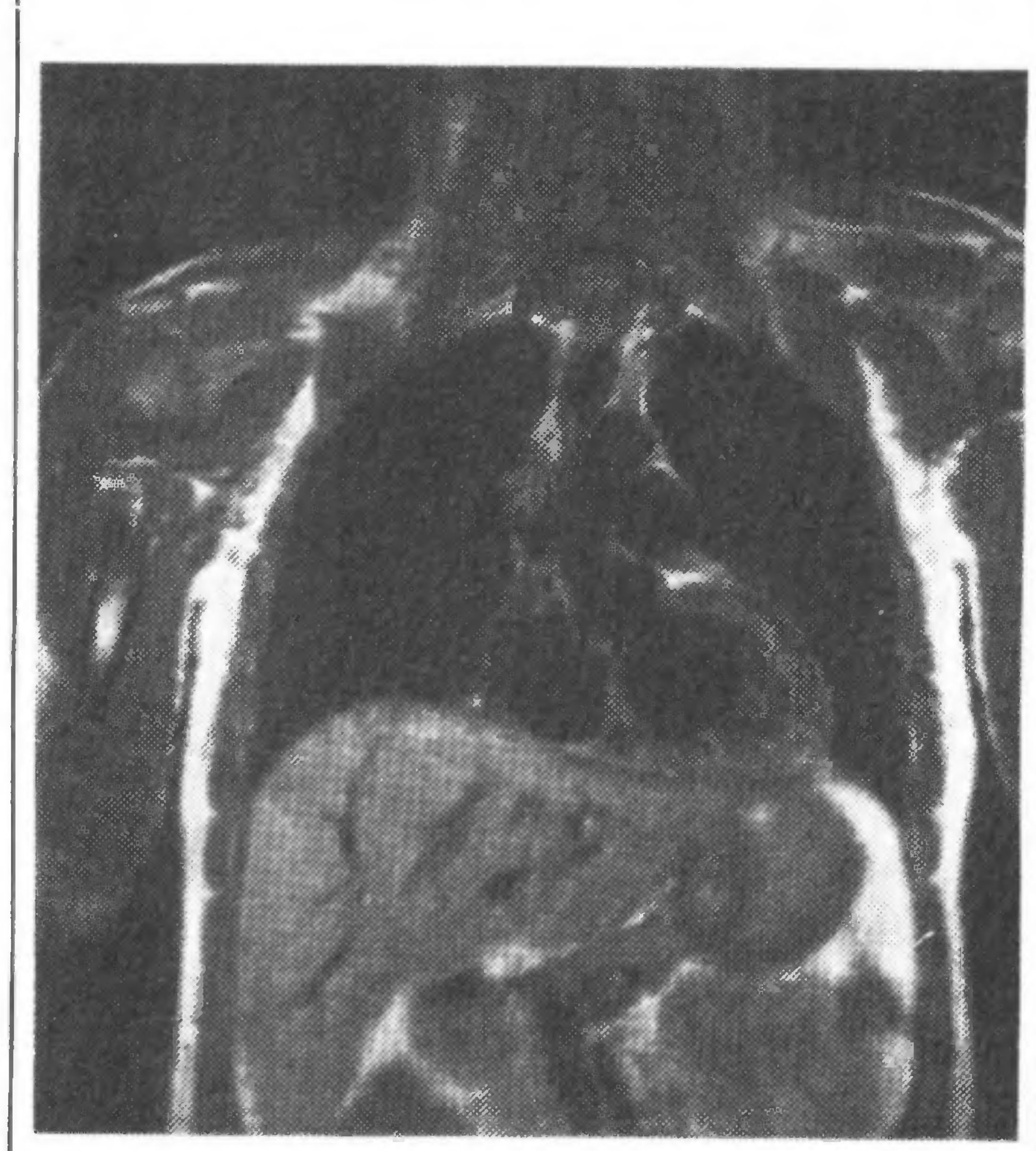
cumulated to reconstruct an image of the slice using a Fourier transform.

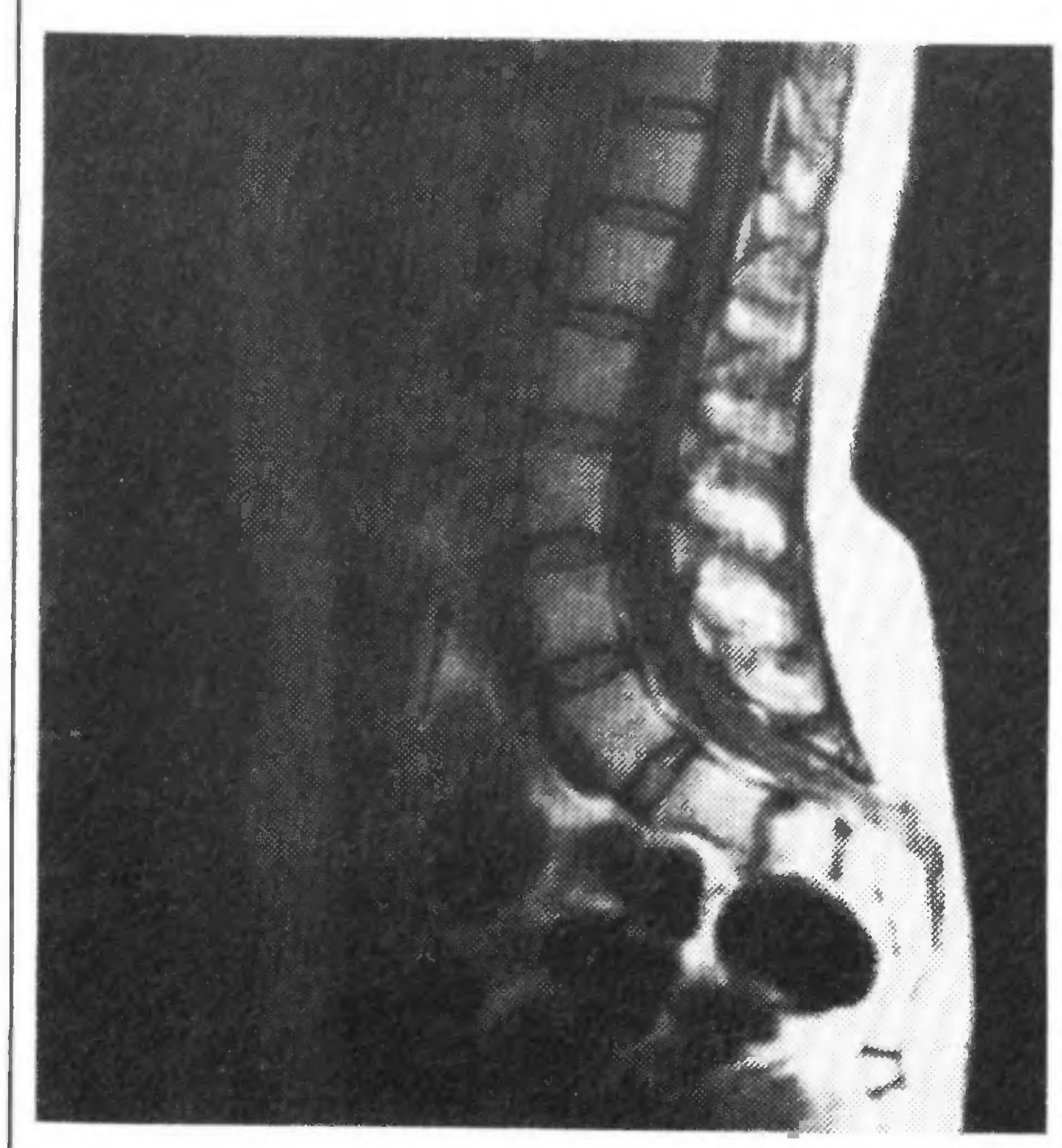
The information gathered from the NMR signal includes the concentration of the nuclei being examined and also their relaxation times. Relaxation refers to the decay of the magnetization's precession over time as it returns to equilibrium after excitation. Because of interaction between spins of neighbouring magnetic moments, some components of the magnetization rotate more rapidly than others, and the moments become increasingly distributed. This is called transverse or spin-spin relaxation and its time constant is called T_2. Then, due to interaction with the environment, the nuclear magnetic moments move towards equilibrium again and become parallel to the magnetic field. This is called longitudinal or spin-lat-



Recording of a projejction in the field gradient. Courtesy Siemens Electric Ltd.







Various MRI images displaying a normal brain (top); normal thorax and upper abdomen (middle); and spine with a tethered cord (bottom). Courtesy of Siemens Electric Ltd.

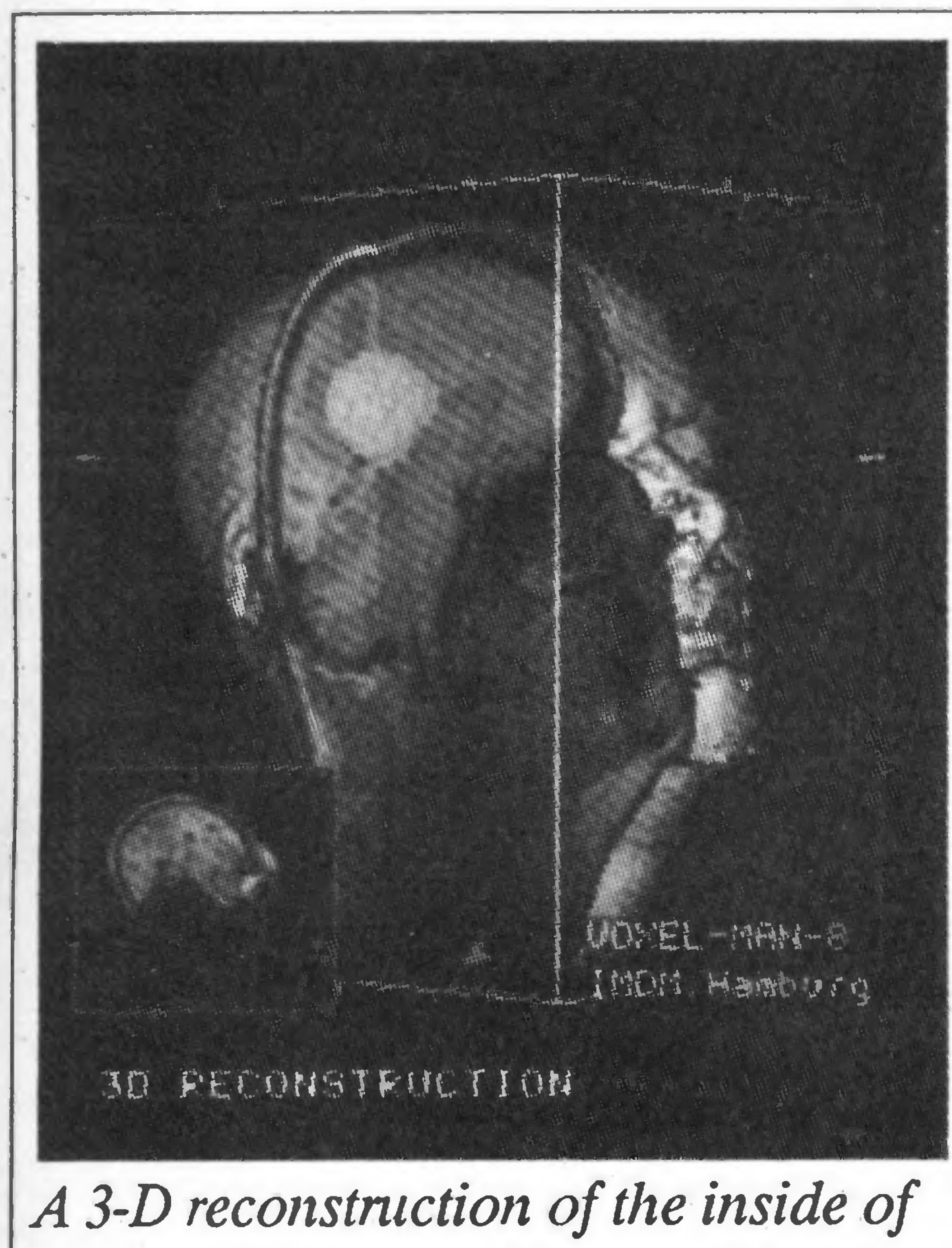
tice relaxation, and its time constant is T_1.

T_2 is always shorter than T_1; that is, it takes less time to disperse the magnetic moments than to realign them with the magnetic field. Both relaxation processes occur because of the interaction of nuclear spins with the tissue environment: T_1 to thermal interaction, and T_2 to differences in the intermolecular magnetic fields. Therefore, these times can be used to derive useful biochemical information which can be applied clinically.

By adjusting the timing of the radio pulses and the recovery mode, the soft tissue of the body can be displayed in many different ways, emphasizing different characteristics of the tissue. The image appears on a video screen, and a hard copy is made by a camera.

Uses

Because NMR imaging displays soft tissue, but not bone, one of its most important uses is in neurology; looking at the brain and the spinal cord. It is generally conceded that MRI has a distinct advantage over X-ray and CT scanning in this area, since it can show the environment that tissues are in, and can also measure and produce images of slices in any desired orientation without moving the patient. CT scanning can only be done in the axial (transverse) plane, while MRI can record in all planes, including oblique ones. It is not an uncommon experience for one brain scan to show nothing abnormal, while the next, in a different plane, suddenly shows a clear brain tumour.



A 3-D reconstruction of the inside of the head. Courtesy Siemens Electric Ltd.

A spinal cord compression can be very easily seen with MRI, while to examine it with X-rays is an invasive procedure, requiring tracer injection. Multiple sclerosis patients also have their disease processes monitored with MRI, since CT scanning requires a double dose of tracer injection.

There are certain areas of the body where MRI may not be as good an imaging method as other modalities. MRI images taken from the chest and abdomen can be of poor quality because the patient's respiratory motion wipes out the clarity of the image. Currently, the imaging time is four to five minutes, but with new techniques, this has been reduced to five to ten seconds. The patient then holds his breath while the measurements are taken, and the picture remains clear.

What The Patient Does

It takes about an hour for a patient to be examined by MRI. Advances in MRI technology have reduced the time for each series of images to be produced, but since new techniques and options have also been introduced, the patient time in the unit remains about the same. No preparation for the procedure on the part of the patient is necessary. After the patient has been positioned comfortably within the unit, a strap is placed across the head to provide awareness of motion. The patient must remain still while the images are taken (for between 15 and 45 minutes), since any movement will ruin the pictures.

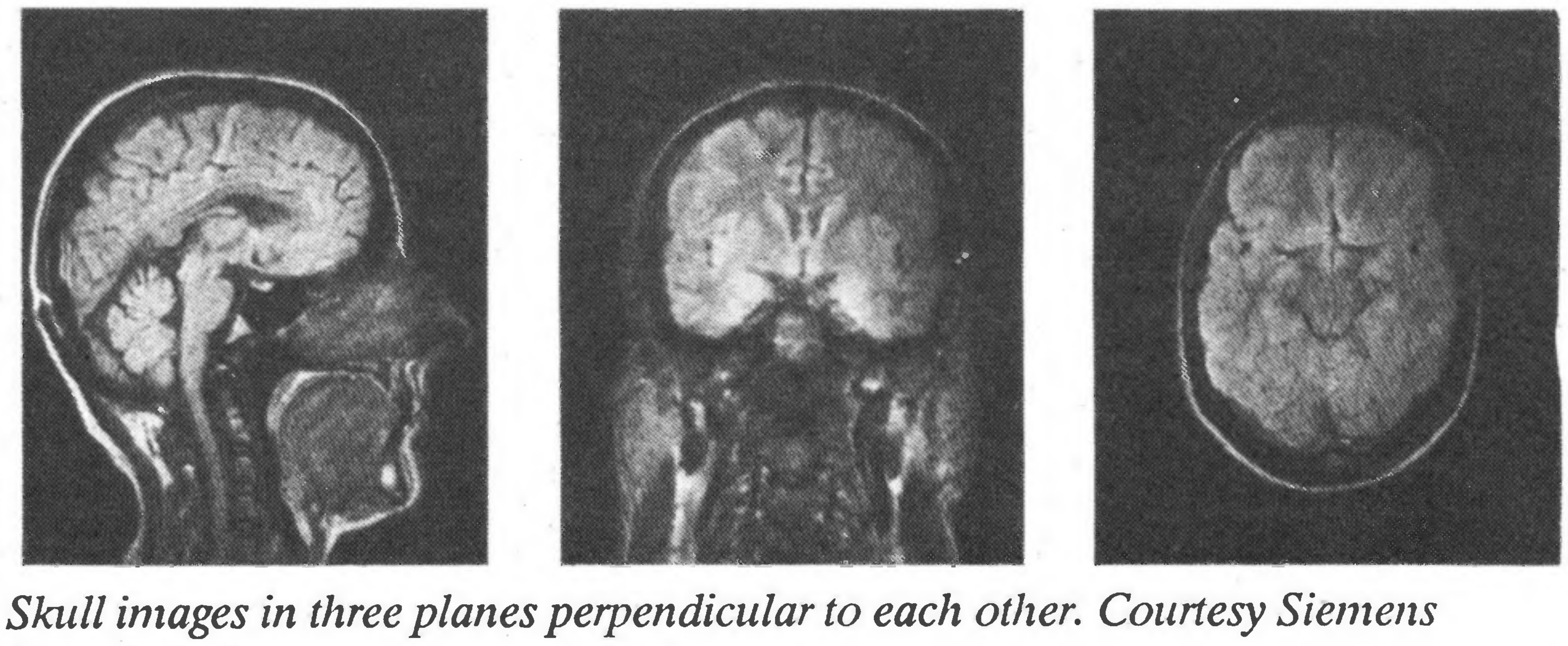
Not every patient is a candidate for MRI. The technicians in the hospital MRI units screen out anyone who has a pacemaker, which might be affected by the magnetic field, or who has had brain surgery for an aneurysm, since the metal clips implanted during surgery might twist under the effects of the magnet. MRI can also be inappropriate for metal workers, because if they have metal chips in their eyes acquired in the course of the job, the chips can twist during the procedure and damage the eye. However, if an X-ray is done first to ascertain that there are no metal chips, MRI can be performed.

Patients with metal implants, such as an artificial hip or knee joint, are not at risk as long as the implant material is non- ferromagnetic, but if the surgery has been performed within the previous month, the MRI procedure may be delayed. Likewise, patients who have had recent heart surgery (less than three months ago) may be put off, since certain types of heart valves have to be tested before the patient can undergo MRI.

For patients who do not fit into any of the above categories, MRI is practically risk-free. Studies have shown that there are no adverse biological effects from the static or time-varying magnetic fields, or from the radio frequency electromagnetic field when used at the levels necessary for MRI.

Installation

For a hospital buying an MRI unit, there are several factors to consider to decide on a model, including cost, which ranges from \$2.3 to 3 million (Cdn). Magnetic field strengths are available in 0.5 Tesla, 1.0T, 1.5T and 2.0T, each of which has different clinical applications. To gain high resolution images of very thin slices of tissue, the signal-to-noise ratio in the NMR signal must be high, which requires a higher (1.0 to 1.5T) field strength, and therefore a larger magnet. The magnets used are superconductive magnets, cooled by liquid helium. Connec-



Skull images in three planes perpendicular to each other. Courtesy Siemens Electric Ltd.

tion to a current supply is only necessary for energizing up the required field strength. After this, the field is temporally stable and requires no further electrical energy. The magnet has to be shielded to avoid both interference with machines in other rooms, and contamination of the images.

The technicians working with the system require at least three weeks of training before they can operate it, but for a full understanding of the principles behind the technique, one technician said it would take about five to six months on the job.

In The Future

The uses of MRI are continuing to increase. The latest technological breakthrough is MRI angiography; showing the blood vessels alone without the injection of a dye. It is not being used clinically yet, but research hospitals are investigating it, and it could be available to patients within a couple of years. Advantages over current angiography methods include less blurring due to motion of the blood, and the option of visualizing vessel trees acquired with 3-D techniques. Arteries and veins can be selectively enhanced, and the vessels can be examined from different angles of view.

Another area opening is imaging with different elements than hydrogen. Sodium imaging has the potential to detect and localize tissue cells which are damaged due to cancer, stroke or epilepsy. Phosphorus imaging has also been introduced, since phosphorous plays a key role in human metabolism.

Patient throughput, or the rate at which patients can be put through the system, has been improving rapidly. Fast scan techniques, which can reduce the scanning time to 3 seconds, allow 3-D imaging and better chest and abdomen images. It can also reduce the blurring due to motion of the blood.

MRI is not available everywhere in Canada yet; there are three machines in British Columbia, six in Ontario, one in Alberta and three in Quebec, but none in the Maritimes, Saskatchewan or Manitoba. However, as techniques continue to improve and more uses are found for the method, who knows? MRI may be the diagnostic wave of the future.

We would like to thank Siemens Electric Limited for their assistance with this article.

Carol Thomas is a freelance science writer from Toronto, Ontario. ■

Brain with pituitary enlargement (top); fast imaging of the kidneys (middle); and a normal joint of the foot (bottom). Courtesy Siemens Electric Ltd.

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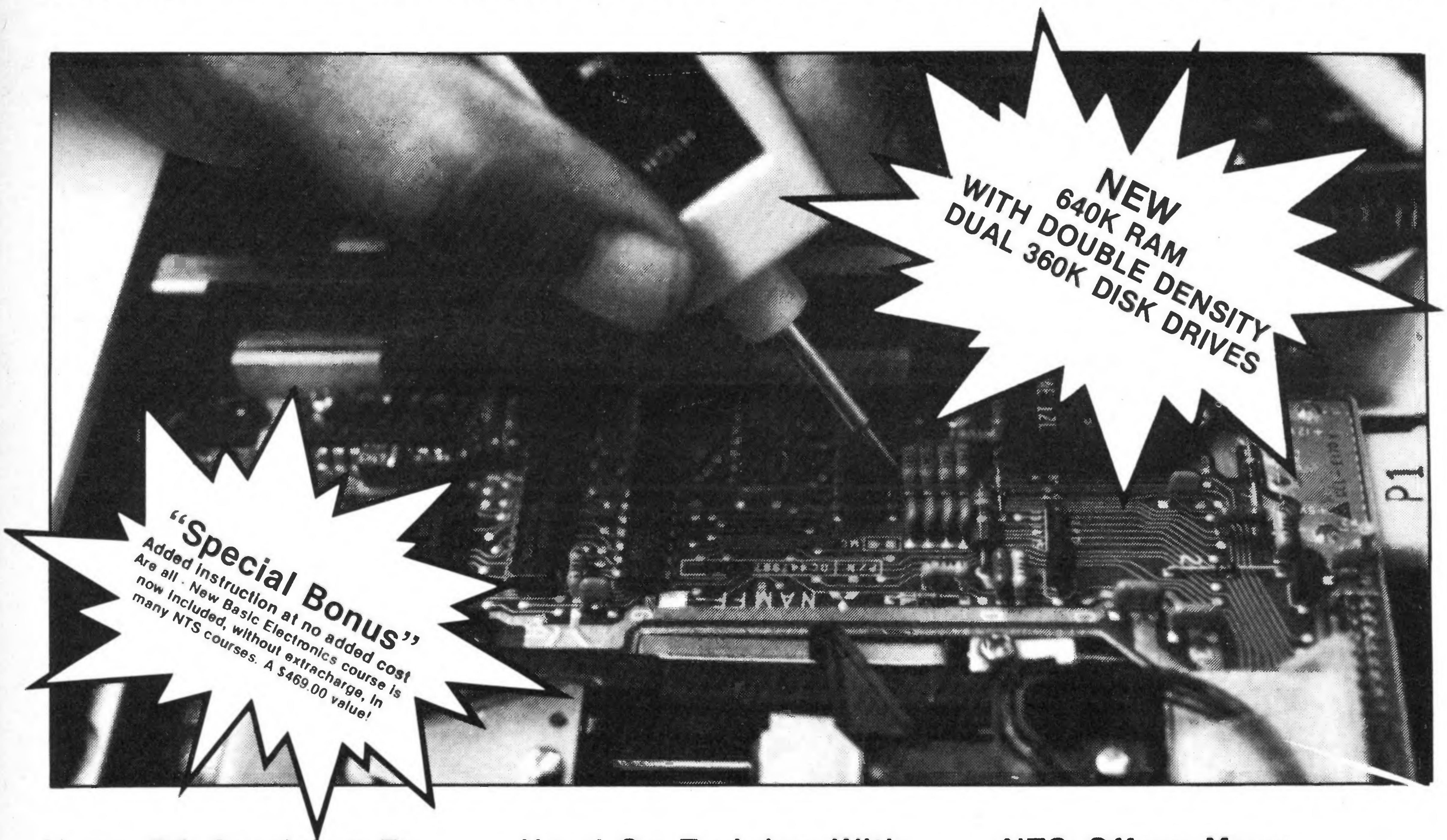

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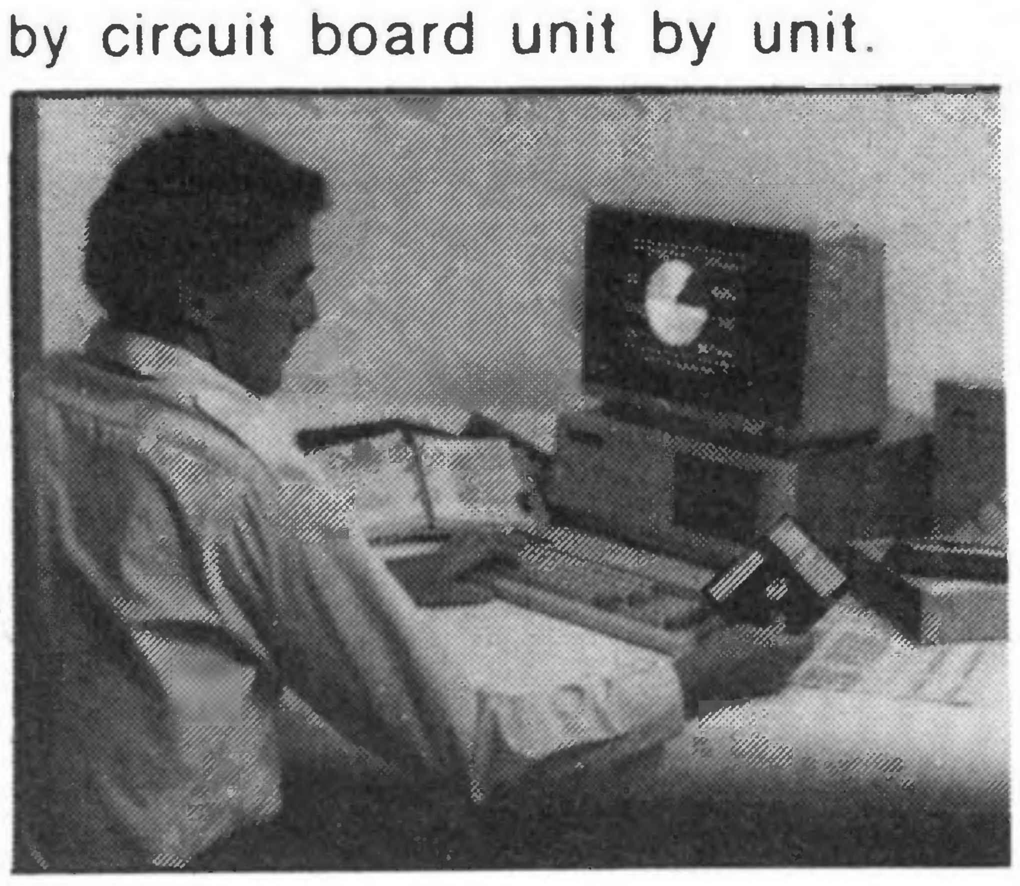

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Using A Multimeter

What to look for, it's limitations and how to use one of the most versatile of test instruments

By Mark Stuart

Like most electronics enthusiasts my toolkit started with a screwdriver, a pair of pliers and a soldering iron. The first measurements that I need to make were simple and crude. There were three very common questions to answer:

Is the battery flat?
Has the fuse blown?
Is the "power" getting through?

Without knowing it I was asking about the three basic electrical units: voltage, resistance and current. With the aid of a battery and a bulb I was able to get some indication of all three, using the methods shown in Fig. 1.

With experience I was able to judge voltage and current by the brightness of the bulb, and by using the fuse checking arrangement I was able to test some low value resistors as well as fuses. I got by using these methods for quite some time until the great day arrived and I carefully unpacked my first multimeter. With this prized possession I was able to measure voltage, resistance and current accurately over wide ranges. The real beauty of it though, was that I could use it in exactly the same way as my battery and bulb. The principles were exactly the same, only the quality of the equipment had changed.

As my electronics knowledge advanced I learned that my multimeter also had some shortcomings. Just as the battery and bulb method had its limitations, so too did the multimeter. The multimeter of course got much nearer to telling me exactly what was happening, but it wasn't always telling me everything, and sometimes it could be quite a long way from the truth. In fact, I had a good deal more to learn about electrical and electronic measurements as the rest of this article shows.

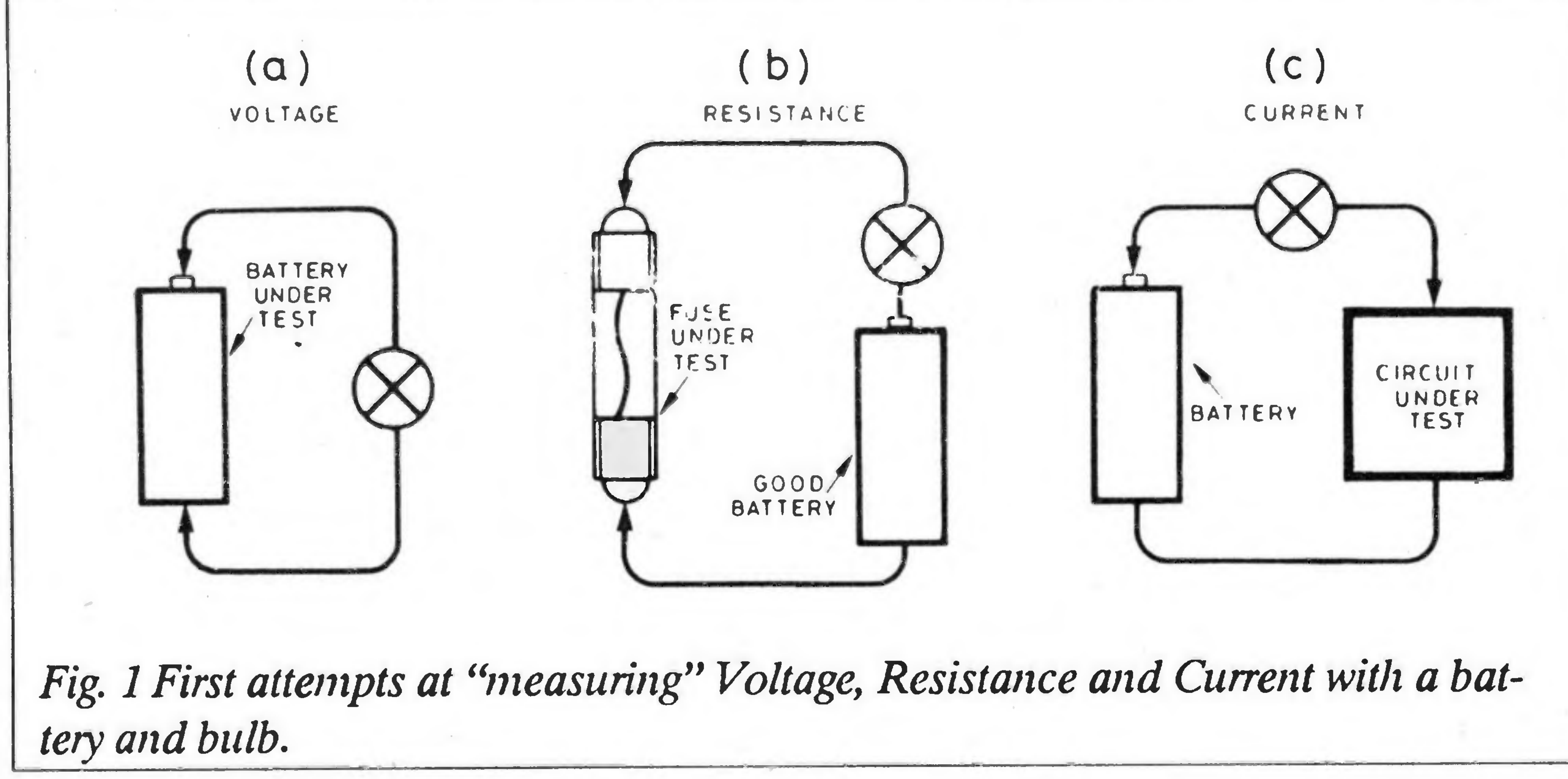


Fig. 1 First attempts at "measuring" Voltage, Resistance and Current with a battery and bulb.

Voltage Measurements

In Fig. 1a the basic principle of voltage measurement is shown. Voltage appears *across* components in a circuit and is measured by putting the meter leads, one at each end of the component, that is, in parallel. Fig. 2 shows some typical measurements and the points from where they are taken using the circuit of an infrared burglar alarm as an example.

The most common measurement made in circuits of this kind are voltage measurements. The reason for this is that unlike currents, voltages can be read without breaking the circuit. For example, the first sensible check on a circuit is to measure the supply voltage. A simple multimeter set to the 25 volt DC range could be used with the negative probe (usually black) connected to point a and the positive probe (red) to point b.

The next check would be to move the positive probe to point n to read the Zener stabilized supply voltage across D2. To measure the collector voltage of TR1, the positive probe is moved on to point d still keeping the negative probe connected to point a. A great deal can be learned about a circuit by voltage measurements made in this way.

With most circuits all of the voltage measurements are made from a common point (in this case point a) usually the negative supply point. The voltage at points b, n, and e are said to be measured "with respect to negative". Voltages may be measured with respect to any suitable point in a circuit or across individual components. For example the voltage across R11 is measured by putting the negative probe on point r and the positive probe on point p.

OHMs per Volt

So far the voltages measured have all been from "low impedance" points in the circuit and will read accurately. If the meter is connected to read the voltages at points c and g (with respect to negative) the readings will be low. The reason for this, is best explained by reference to Fig. 3 which shows the internal circuit of a multimeter when set to its voltage ranges. The meter movement is essentially a current measuring device, the construction and operation of which has been described elsewhere.

To convert a basic 50 microamps meter movement into a voltmeter, a series resistor is used. The value of a resistor is calculated from Ohms law so that it passes 50 microamps at the required full scale voltage. For example a 10 volt range needs a resistor of 10 volts divided by 50 microamps that is 10/0.00005 ohms = 200,000 or 200k. The other ranges are calculated in a similar way, giving 500k for 25V and 2M for 100V. A value of 50 microamps has been chosen as this is an extremely common value for standard multimeters.

The expression "ohms per volt" which appears in multimeter specifications is derived by working out the series resistor that would be required to give a full scale voltage of one volt. For a 50 microamp meter, it is 1/0.00005 = 20k. A multimeter with a 50 microamp meter is therefore a "20 kilohms per volt" type. The best (most sensitive) analogue multimeters are based on a 10uA movement and so have a sensitivity of 1/.00001 or 100k per volt.

How this affects the circuit under test depends upon how easily the circuit can supply the 10 or 50 microamps that the meter requires. Power supply points such as b and n can supply an extra 50 microamps without any difficulty, but to sensitive parts of the circuit such as points c and g 50 microamps represents a heavy current drain that substantially affects circuit operation.

In the case of point c the actual voltage in the circuit is 0.6 volts and the current flow through R6 and into the base of TR1 is two microamps. If the multimeter is set to the 10 volt range its resistance is 200k. At 0.6 volts 200k draws a current of 0.6/200,000 or three microamps. Since this is more than the current already flowing in the circuit there is not enough current to drive the meter properly and so the meter reads low.

Similarly when the voltage at point g is measured the current required by the meter is drawn from point f via R15. As the voltage here is approximately one volt the meter requires five microamps on the 10 volt range which must be drawn through R15. Now to get 5 microamps through one megohm takes five volts (Ohms law again). As there is only one volt available it is obvious that the meter will read very low. In fact the meter will read 0.2 volts which is miles away from the true voltage.

If all the math here is a bit too much, don't worry, the principle is simply that at points in the circuit where there are high value resistors, voltages will read lower than they really are.

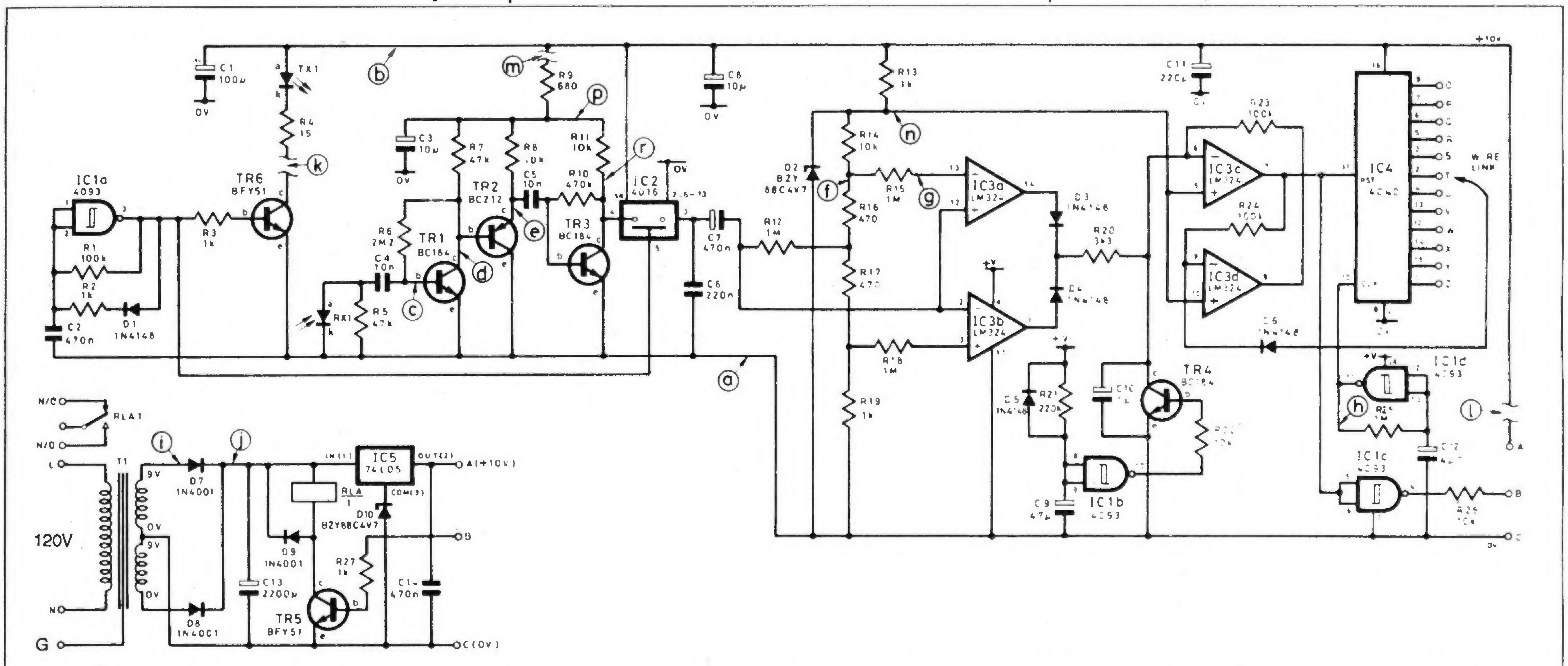


Fig 2 Some typical measurement "test points" in a working circuit of an infra red burglar alarm. Points k, l, and m indicate where current measurements are made.

Average Reading

Another situation where a multimeter doesn't tell the whole truth is when the voltage at point j is measured (with respect to negative). At point j there is not a steady voltage, but one which varies one hundred times a second from approximately 14 volts to 16 volts. The meter will try to follow the voltage, but fail, because it can't move quickly enough. The result is an average reading of 15 volts. For most purposes an average reading is adequate, but it gives no indication of the ripple voltage. This is simply a job that a multimeter can't do. The best instrument for this is an oscilloscope.

Other points in the circuit will also give misleading readings. For example, point h oscillates between 0V and +10V, spending half of its time in each state. The meter will read the average voltage which is five volts, but give no indication of the oscillation.

The voltage at points d, e and r will give one reading when the infrared beam is being received, and another reading when it is not. In many circuits, voltage differences such as this do occur and sometimes service sheets or manuals give two sets of voltage readings. The "quiescent" voltages are usually those found when the circuit is operating normally but without an input signal and are the most commonly quoted ones.

Despite these imperfections, voltages measured with a multimeter are still the simplest and most effective "first approach" to circuit testing. The number of voltage measurements made using multimeters each day must exceed the numbers of all other electrical measurements put together.

Resistance Measurements

The measurement of resistance is much more straightforward than voltage measurement but the meter circuit is slightly more complicated. Fig. 4 shows a simplified standard multimeter circuit for resistance measurement. Resistors R1, VR1, and R2 are simply to make the 50uA meter movement into a voltmeter reading 0 to 3 volts. The variable resistor (VR1) allows the sensitivity to be varied slightly so that full scale deflection can still be achieved when the battery voltage falls to 2.5V. The three range resistors R3, R4 and R5 are selected individually by the range switch S1.

When the probes are touched together the full battery voltage is connected across whichever range resistor is in circuit and the meter reads full scale. If necessary, adjustment of VR1 can be made for exactly full scale. When the probes are separated the battery negative terminal is no longer connected anywhere and there is no deflection of the meter. These two extremes represent zero resistance (or short-circuit) and infinite resistance (or open-circuit) respectively. The scale of the meter reads backwards because zero resistance corresponds to full scale deflection and infinite resistance to no deflection.

When an unknown resistance is connected across the meter terminals, the battery is no longer connected directly across the range resistor via the unknown resistor. If the unknown resistor is equal to the range resistor, half of the battery voltage will appear across each, and the meter will read centre scale deflection. So with the three range resistors given, centre scale is

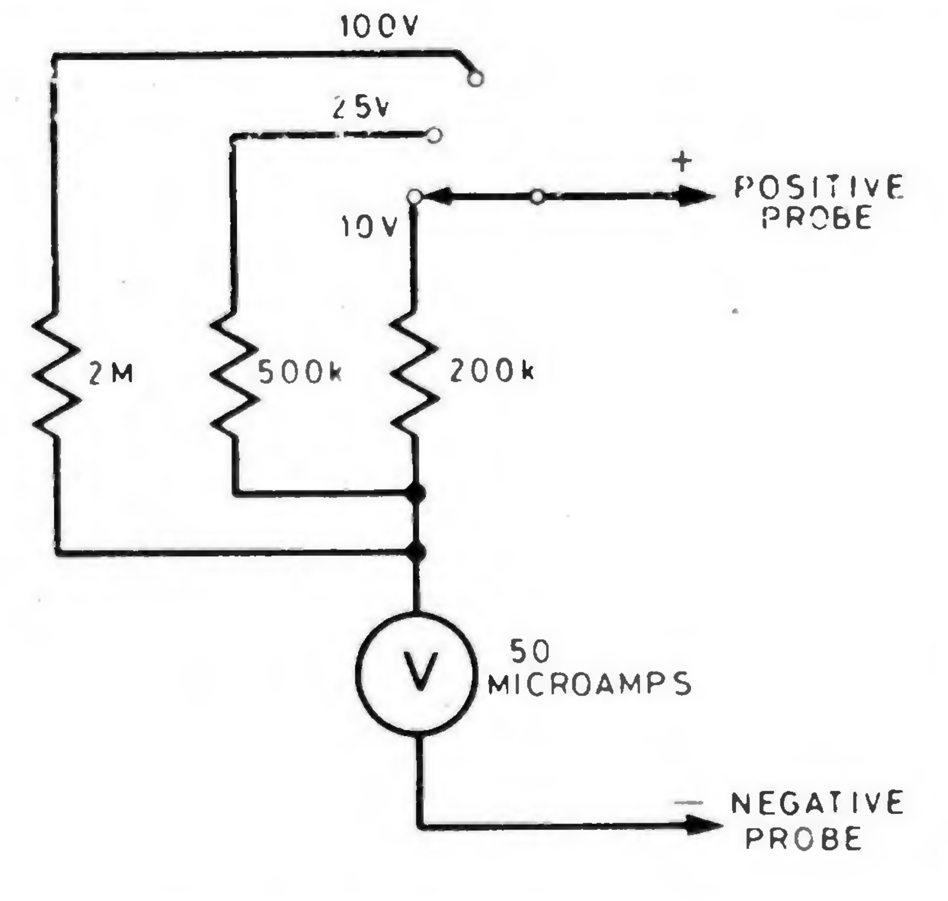


Fig. 3 Circuit diagram of multimeter voltage ranges: 10V; 25V and 100V.

obtained by measuring resistors of 20ohms, 200ohms and 2k. For those who want to do the arithmetic the deflection for other values of resistance is given by dividing *R* (Range) by (Range) plus *R*x where *R*x is the unknown resistor.

For the 20ohm range this gives a deflections on the 50 microamp meter corresponding to nine microamps for 200ohms, 33 microamps for 10ohms, 25 microamps (centre scale) for 20ohms and a tiny deflection of one microamp for 2k ohms. A glance at any multimeter resistance scale will show that this is nonlinear, and is especially cramped at the high resistance end.

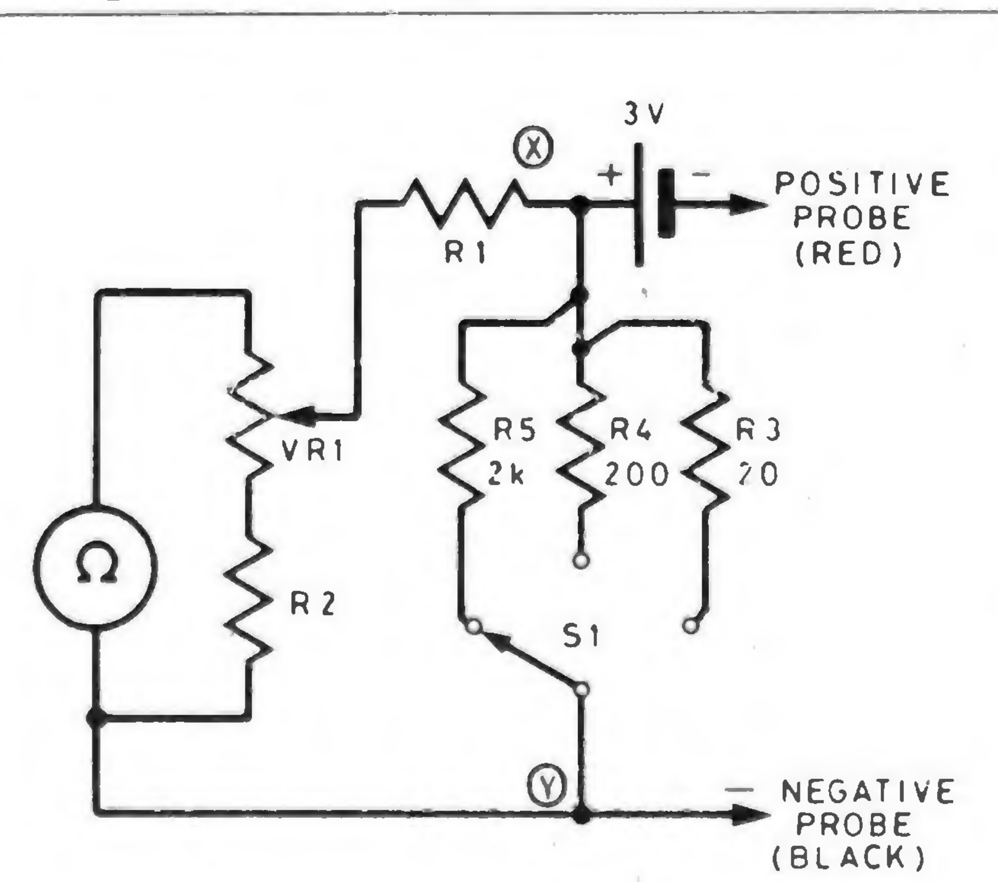


Fig. 4 Circuit diagram of multimeter Ohms ranges: 20 ohms; 200 ohms and 2 kilohms (2k).

If there are sufficient ranges (usually four or five) however, it is possible to get satisfactory readings from one ohm to one megohm. Higher resistance readings can also be obtained but it is necessary to have a higher voltage battery. Some multimeters have provision for two batteries, the higher one being switched into circuit when the highest resistance range is selected.

Apart from measuring resistance one of the other uses of the k ohms ranges is to make simple checks for continuity, and to test diodes.

Diodes

When testing diodes it is essential to bear in mind this very important fact: The RED Probe is NEGATIVE and the BLACK Probe is POSITIVE.

This comes about because of the need to keep the negative terminal of the meter movement permanently connected to the negative probe. The construction of the meter and the switching arrangements are made much simpler by this means. Referring to Fig. 4 should help to make it clear. Over the years this polarity reversal has been accepted as "standard" and all conventional analogue multimeters are the same. Digital meters and electronic meters, however, have more complicated switching arrangements and, as if to add to the confusion, have their positive output on the red probe for ohms measurement. If in doubt the best way is to keep a known diode handy. Usually resistor values are measured by first removing the resistor from circuit.

In-circuit measurements can be made but often the readings will be low because of other components forming parallel paths. This is particularly so in circuits with transistors and ICs. For example the value of R7 in Fig. 2 could be measured in theory by connecting the probe between points p and d.

With the black probe on d and the red probe on p a correct reading could be obtained, but with the probes reversed a parallel path via R8 and the base-emitter junction of TR2 is introduced leading to a reading nearer to 15k.

In a situation like this where one way the resistance is lower than the other way, it is always true that the higher value is nearer to the correct reading.

If the resistance reads the same in both directions it is probable that the value is correct, but by no means certain, because there could be purely resistive parallel paths in existence.

A final note on resistance ranges: make sure that the circuit is switched off whenever resistance measurements are made. A glance at Fig. 4 shows that on the resistance ranges all that exists between the probes is a battery and the range resistor.

Connecting a power supply across this unlucky combination is a frequent source of smoke as the range resistor is destroyed. Luckily the meter movement itself is usually adequately protected by R1, but it's better not to put it to the test.

Current Measurements

Current measurements are made by breaking the circuit and inserting the meter. While voltage is measured *across* components, current passes *through* them.

The multimeter current ranges circuits are shown in Fig. 5. As with the voltage circuit the current circuit is very straightforward. The three resistors are known as shunts because that is their function.

For example on the 1mA range 950 microamps flow through the shunt resistor while 50 microamps flow through the meter. On the one amp and 100mA ranges the same principle applies, with all but 50 microamps flowing in the shunt resistors. To calculate the value of the shunt resistors the meter movement resistance needs to be known. In the case of most standard 50 microamps meters this is 2k. The value of the current that must flow in the shunt is first calculated: e.g. for 1mA the shunt current is 1mA minus 50 microamps which equals 950 microamps. The shunt value can then be worked out as follows: shunt value = meter movement current times meter resistance divided by shunt current.

For 1mA this gives: 0.00005 times 2000 divided by 0.000950 which gives 105 ohms. The other shunt values are one ohm and 0.1 ohm for the 100mA and 1A range respectively.

The measurement of the power supply current of the main circuit board of Fig. 2 is taken by breaking the circuit at point l and inserting the meter. When measuring an unknown current it is wise to start with the highest range (in this case one amp) so that the meter is not overloaded. The range switch can then be advanced until the best range is reached. The alarm circuit takes approximately 20mA so is best measured on the 100mA range.

Series Resistance

When the meter is put into the circuit it adds another series resistance which has some effect on the current being measured. In this instance when set to the 100mA range the meter shunt resistance one ohm is added to the circuit. With 20mA flowing a resistance of one ohm produces a voltage drop of 20 millivolts. This is not significant in 10 volts, but there are situations where the extra voltage drop of a meter can have a significant effect. An example of where meter resistance begins to cause problems is given when measuring the current in the Infra-Red emitter circuit (point k). The current is not continuous but instead is a series of pulses of approximately 0.5 amps with a mark-space ration of 100 to 1. The average current is therefore 0.5 divided by 100 or 5mA.

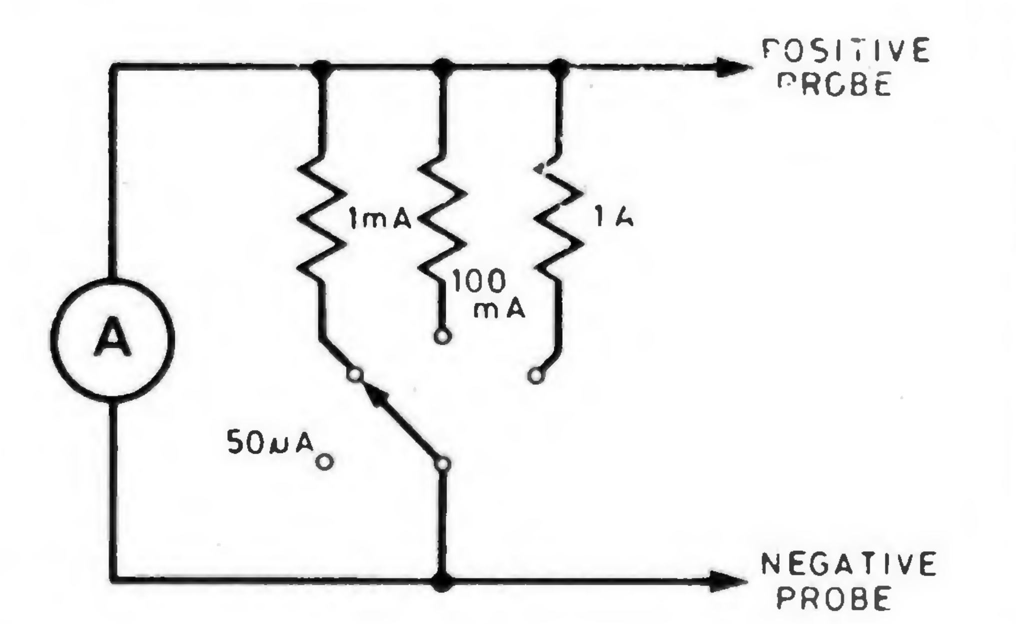


Fig. 5 Circuit diagram of multimeter Current ranges: 1A; 100mA and 1mA.

Connecting the meter into circuit adds an extra one ohm to the 15ohms already present (R4) and so the pulse current is reduced. The average current reading will be lowered from 5mA and will read one part in 15 lower than the true value.

Another problem encountered when inserting a multimeter into power supply circuits is that sometimes even a small extra resistance can cause severe instability and violent circuit oscillation. In these conditions the meter reading will be quite different from the true circuit current. In general, current measurements are relatively trouble-free and accurate, without the huge errors that can occur when making voltage measurements.

A.C. Measurements

So far the voltage and current measurements made have all been in DC circuits. Another essential requirement is to be able to measure alternating currents and voltages, particularly at the main supply frequency. The usual way to achieve AC measurements is simply to put a diode in series with the meter. The meter is thus fed with a half wave rectified signal which it averages to produce a constant reading. A separate set of series resistors and current shunts are required so that the meter reads correctly.

In most meters it is assumed that the AC signals being measured will be sine waves and that the frequency is in between 10Hz and 5kHz. Some better meters give a wider frequency range. In general the meter manufacturers take some liberties with AC measurements, particularly AC current, based on the fact that the main use of such range is to measure power supply voltages and currents where an error of up to ten per cent can be acceptable. High quality expensive multimeters have elaborate AC ranges often using special transformers to step up the voltage so that the rectifier circuits can work to their very best.

The main problem encountered when taking AC measurements is that any departure from a sine wave signal will produce inaccurate readings. A square wave and a pulse waveform will both give strange readings, and as the waveform is not usually known to the meter user it is very hard indeed to get meaningful results. It is safest to stick to reading mains frequency sinewave signals, and leave the rest until an oscilloscope is available.

Conclusion

Having spent most of this article discussing the drawbacks and limitations of multimeters I think I should say that I find my multimeter to be indispensable. There are very few circuits that can't be examined or repaired with its aid. My toolkit is now much more extensive than 25 years ago when that first multimeter arrived, and in those years the changes in electronics have been incredible. Sadly I no longer have the original meter — I dropped it downstairs some time ago, and before that I blew the 20 ohm range resistor by trying to measure a power supply voltage with the meter set to kohms. ■

The EduKit 3EC Automotive Trainer

Automotive electrics and electronics in an easy to understand, hands-on format

By Edward Zapletal

Anyone who has ever encountered automobile electrical problems knows that they are the most frustrating thing of all. They are often hard to diagnose; appearing to be more like electrical "mysteries" than problems. And given the growing complexities of today's newer cars, with all their computer gadgetry, the mysteries deepen ever further. With this in mind, teacher and author Frank Kurucz has developed a hands-on approach to help novices, and particularly students, to untangle those automotive electrical mysteries.

As with all the other books in the EduKit 3EC series, the aim of this one is, according to Mr. Kurucz: "to promote 'electrical thinking', the single, most valuable tool of all to those studying or working with automotive electricity." The 90- plus page book is divided into four sections: electrical knowledge for automotive technology, electrical components, circuits, and systems.

In addition, there is an appendix which deals briefly with the use of multimeters for circuit analysis and troubleshooting. The package also includes a built-in testing method where the participant answers questions during each section as well as at the end of each section. An answer book is also supplied for teachers, parents, or those who just want to go it alone.

What is important here is that someone with little or no knowledge of electric theory should be able to work through each section and get a basic feel for electric circuits and their applications in the automotive environment.

As its name would imply, the EduKit 3EC trainer is more than just a book - it also provides the means to get some basic hands-on experience with electronics. A small solderless circuit board (breadboard) is provided along with a number of components, four batteries, lamps, switches etc. These are used in conjunction with the book to teach simple electrical principles and circuit building techniques.

Section one, electrical knowledge for

automotive technology, lays some quick groundwork for the participant in such areas as voltage, current, resistance, circuits, power, and switching. Each of these is explained in a concise, simple fashion with equivalent automotive applications given as examples. Simple circuits can be constructed to give practical experience in component identification and wiring methods.

The second section deals with electrical component types such as resistors, capacitors, inductors, and semiconductors, and their particular functions in automotive electronics. Foremost of these functions is the ignition system.

Ignition-related devices such as Hall-Effect switches, reluctor coil systems, and transformers are discussed, as are transistors, generators, and batteries.

This section is capped-off with an introduction to integrated circuits, both analog and digital, and some guidance is given towards the correct procedure for wiring ICs.

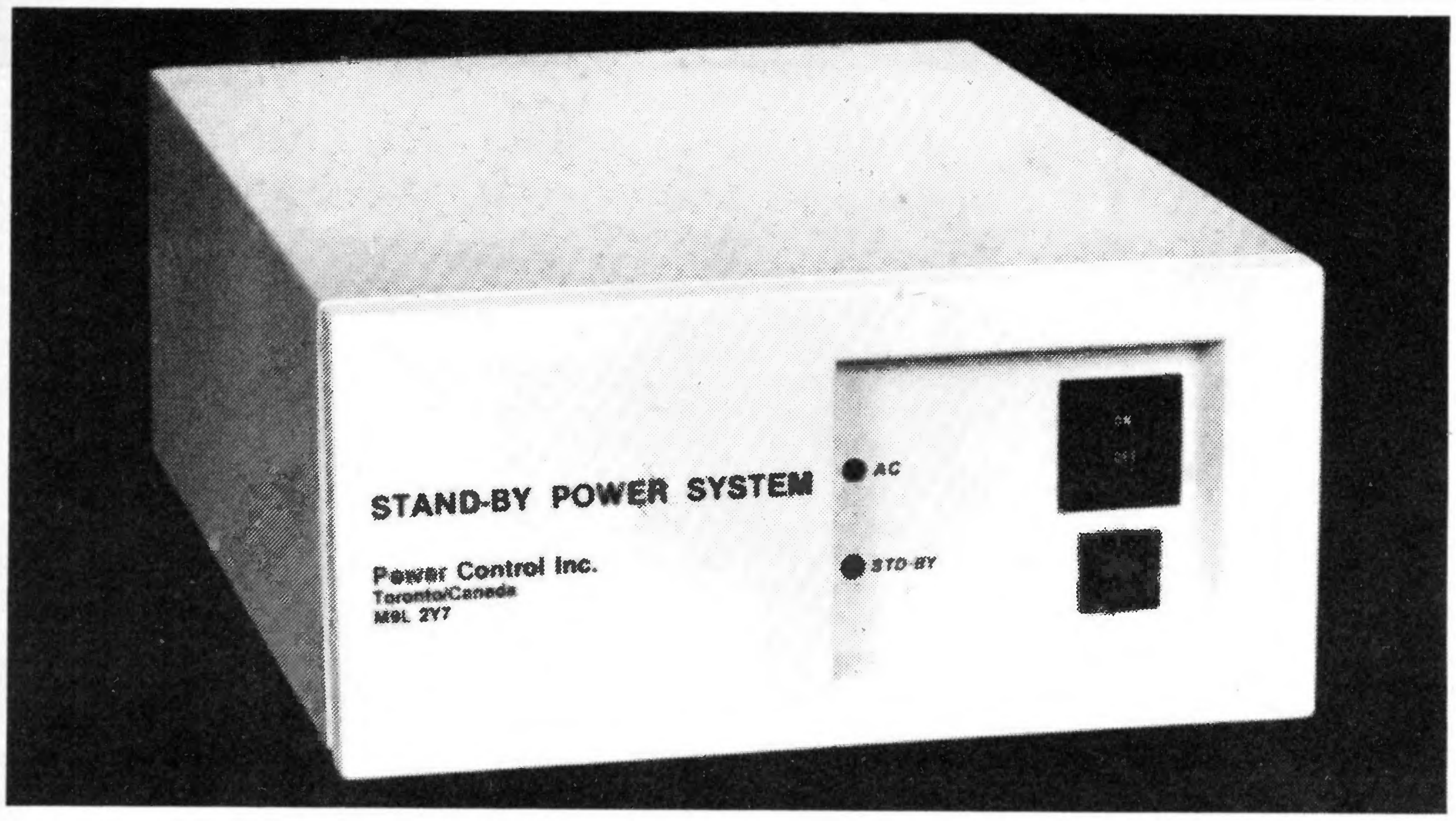
Section three deals strictly with circuits and circuit analysis, with heavy emphasis on the concept of "electrical thinking". Examples of common automotive circuits such as starting, charging, and windshield wipers, washers etc. are analyzed using the basic laws given in the earlier sections. In addition to these, more complex logic circuits and logic fundamentals are also covered.

A special note: during the review we uncovered a small error in one of the logic circuit diagrams. The publisher has been notified and an addendum is in the works to rectify this.

An overview of computers makes up the fourth section of the 3EC trainer. This section was not intended to teach computing, rather to give the novice some insight into the uses of computers in the home, automobile and in industry to some extent.

Overall, the 3EC Automotive offers practical, hands-on experience in understanding the fundamentals of electricity and electronics in the automobile. The cost of the package is $49.95 and there's special pricing available for schools.

For information contact: EduKit, P.O. Box 38, Station N, Toronto, Ontario M8V 3S4 or phone (416) 897-1217. ■



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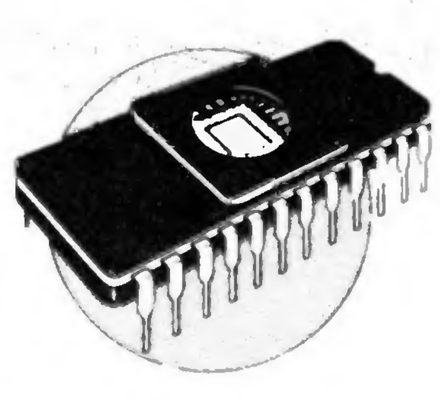

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Noise Gate

An ideal project for the muscian who wants to create the right sounds, without the noise

By Ian Coughlan

Over the last few years the popularity of electronics effects units for musicians has grown dramatically, particularly those using time-delay techniques. These include flangers, choruses, echo, reverbs, and so on. While these effects offer the musician new and interesting sounds, they often suffer from a poor signal-to-noise ratio; that is, the amount of noise produced relative to the maximum signal level that the system can handle. This noise is normally masked by the music, but stop playing and the same noise becomes quite objectionable, manifesting itself in the form of hisses, whistles, crackles, whoops, etc.

Using more than one effect-box simply makes matters worse, as do noisy leads and jack-connectors. One solution would be to turn the amplifier's volume control down whenever playing stops, but that is obviously impractical. The Noise-Gate offers a neat and simple answer to the problem. Connected immediately before the input to the amplifier, and therefore after any effect- boxes in use, it constantly monitors the signal level. If the signal is below a certain level, then the Noise-Gate will "close" and prevent the signal from reaching the amplifier. Start playing and the signal rises, causing the Noise-Gate to "open", allowing the signal to get through to the amplifier. So when there is music, the signal gets through; when there is only noise, it doesn't.

The signal level at which the Noise-Gate will open is called the "threshold", and a control is provided so that it may be adjusted. The threshold should be set just above the level of the noise (the so-called "noise floor"), so that any signal above the threshold, and therefore above the noise floor, will open the Noise-Gate. Note the terminology used: *open* means the signal is allowed to pass through, *closed* means it is not. Don't think in terms of a switch: think in terms of gate (hence the name "noise-gate").

The Noise-Gate should open as quickly as possible in response to an increase in the input level, so that little of the music is lost. In this design, the response time is around a couple of milliseconds. Obviously, the same does not hold true when the input level falls below the threshold, otherwise the Noise-Gate would close with every gap in the music of more than a millisecond or two. This design will remain open for about half a second after the music stops. These times are not externally adjustable, but the experimenter may wish to try altering the values of the relative components, to lengthen or shorten either or both times.

There is also a control for adjusting the gain of the Noise-Gate. Normally this would be set to unity (output = input), but can be set anywhere between 0.02 and 5 (or -34dB to + 14dB gain). A switch on the rear allows the user to open the Noise-Gate regardless of the signal level, this is handy for tuning-up instruments; an LED on the front panel displays the status of the Noise-Gate.

Circuit Description

Integrated circuit IC3 (Fig. 1) is a quad CMOS switch, and IC3a, is the "gate". For the input signal to reach the output, it must first pass through IC3a, and the state of this switch is controlled by the voltage on IC3 pin 13. When this voltage is high, the switch allows the signal to pass; when it is low, the signal is blocked. IC1b, wired as a variable gain stage, boosts or attenuates the gated signal, and provides a low output impedance suitable for driving virtually any amplifier or tape- recorder input stage.

For the Noise-Gate to open, about six volts peak-peak is required at IC2a pin three. This is much larger than can be provided by musical instruments, so the input signal is boosted considerably by IC1a, another variable gain stage, whose gain is adjustable between 23 and 73, giving a threshold that can be set from about 85mV peak-peak, to 250mV peak-peak. IC2a pin two is biased by R10 and R12 to about 9V. With no input signal present, IC2a pin three is at 6V. Therefore, for IC2a, which is the threshold detector, to operate IC2a pin three must exceed 3V peak (or 6V peak-peak). When the threshold is reached, IC2a pin one will go high, charging C9 determine the

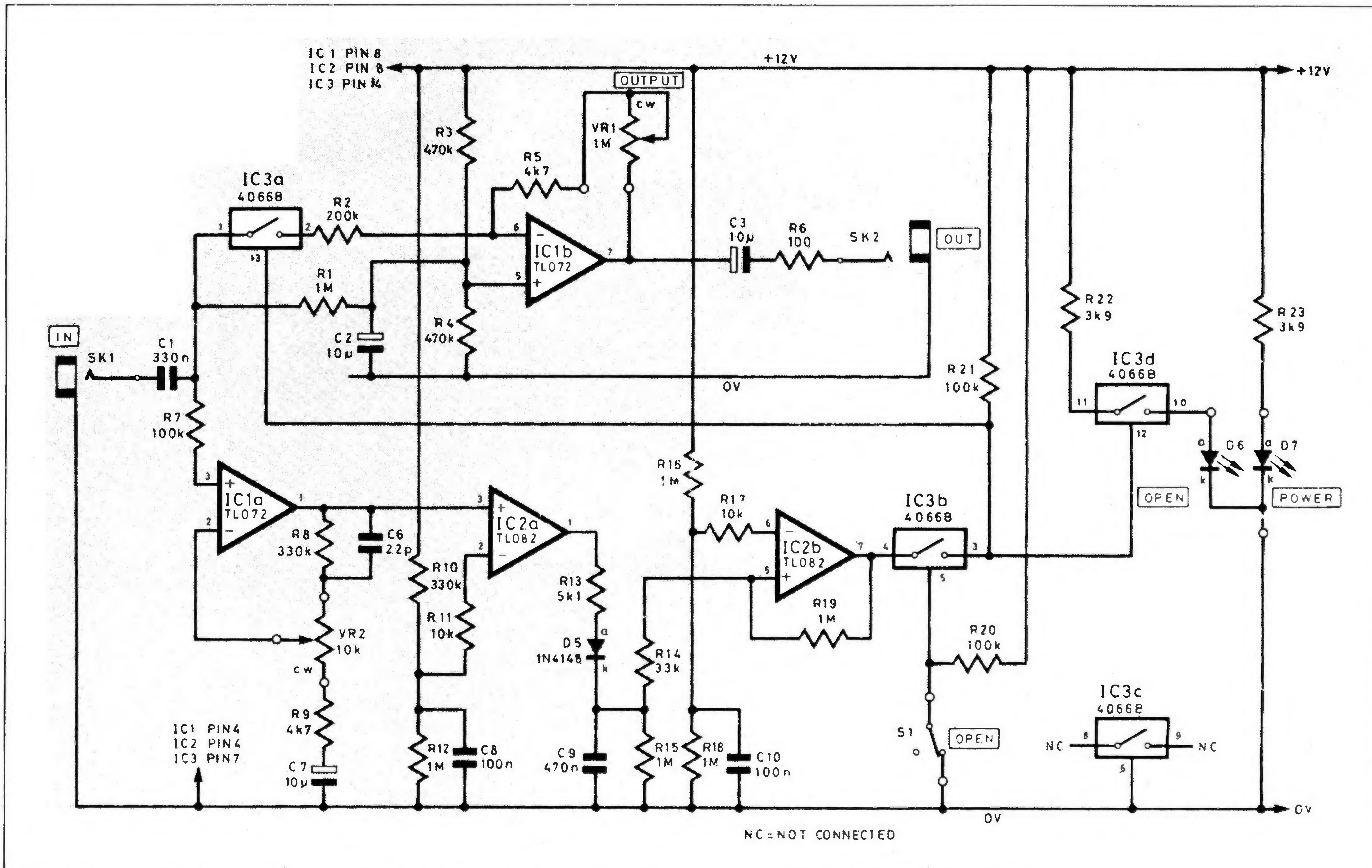


Fig. 1 Complete circuit diagram for the Noise-Gate. The 12V power supply section is shown below.

time taken for the Noise-Gate to open. When the voltage on C9 exceeds about 6.2V, the voltage on IC2b pin five will exceed that on pin six (6V), and will cause IC2b pin seven to go high. Without R19, IC2b would tend to oscillate as the voltages on pins five and six approached each other.

When the input level drops below the threshold, C9 will no longer be getting charged from IC2a pin one, and will discharge through R15. R15 sets the time taken for the Noise-Gate to close. This resistor may be decreased for shorter hold times, but must not be increased, otherwise the Noise-Gate will not function.

Switch S1, when closed pulls IC3b pin five to 0V, causing IC3b to open, allowing IC3 pins 12 and 13 to open, and allowing IC3 pins 12 and 13 to be pulled high via R21. IC3a will therefore close, allowing the input signal to reach the amplifier stage, as described above, and IC3d will close, causing D6, an LED to light, indicating that the Noise-Gate is open. Since IC3b is open, the voltage on IC2b will have no effect on the status of the Noise-Gate: i.e., the gate will be open regardless of the input signal. When S1 is open, IC3b will then be closed, and the state of IC3a and IC3d, and therefore the status of the Noise- Gate, will depend on the voltage on IC2b pin seven, this in turn depends on the input signal level.

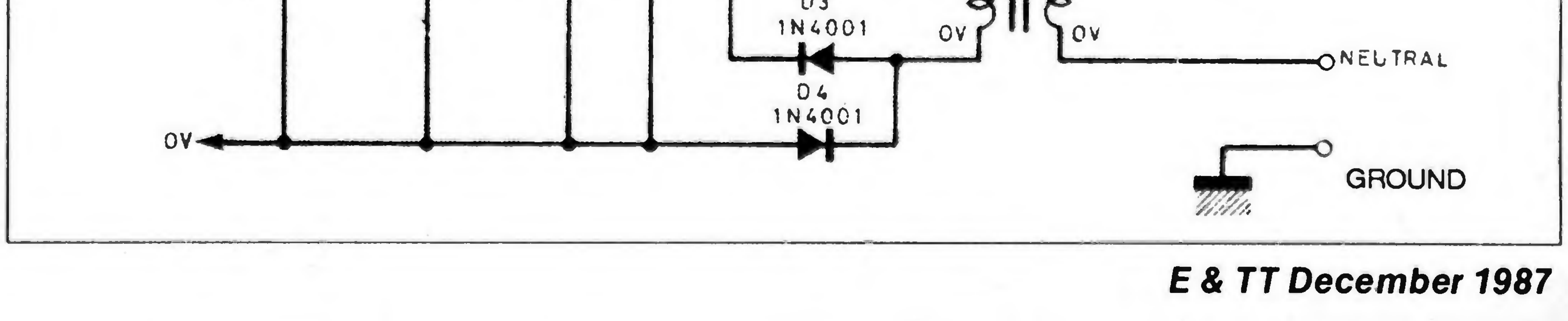
Power is supplied by transformer T1, and regulated by IC4, a 78L12 voltage regulator, see Fig. 1.

Construction

Construction of the Noise-Gate is fairly straightforward and is built on a single printed circuit board. Because the power transformer is also mounted on the board *extreme care should be taken when testing.*

The component layout and printed circuit board foil master pattern is shown in Fig. 2.

Begin by checking the bare printed-circuit board for shorts. Veropins should be inserted into the PCB from the foil side. These can be gently tapped into place with a hammer, and then soldered. Fix the resistors to the PCB, followed by the capacitors and the link-wire. If using DIL sockets for the ICs, fit these next, then the fuse-clips, IC4, and the diodes. Turn the PCB over, and connect insulated wire



between the points shown in Fig. 2. Lastly, fix the transformer to the board, and fit the ICs in their sockets.

After selecting a suitable case, drill the holes, and deburr the surfaces to be painted (the front and the rear), prime them, and paint them. When the paint is dry, lettering can be applied, using Letraset dry-transfers, which should then be protected with a light coat of varnish. Fix the grounding-point and the PCB mounting pillars to the base of the box. As a safety measure, apply a few lengths of PVC adhesive insulating tape to the inside of

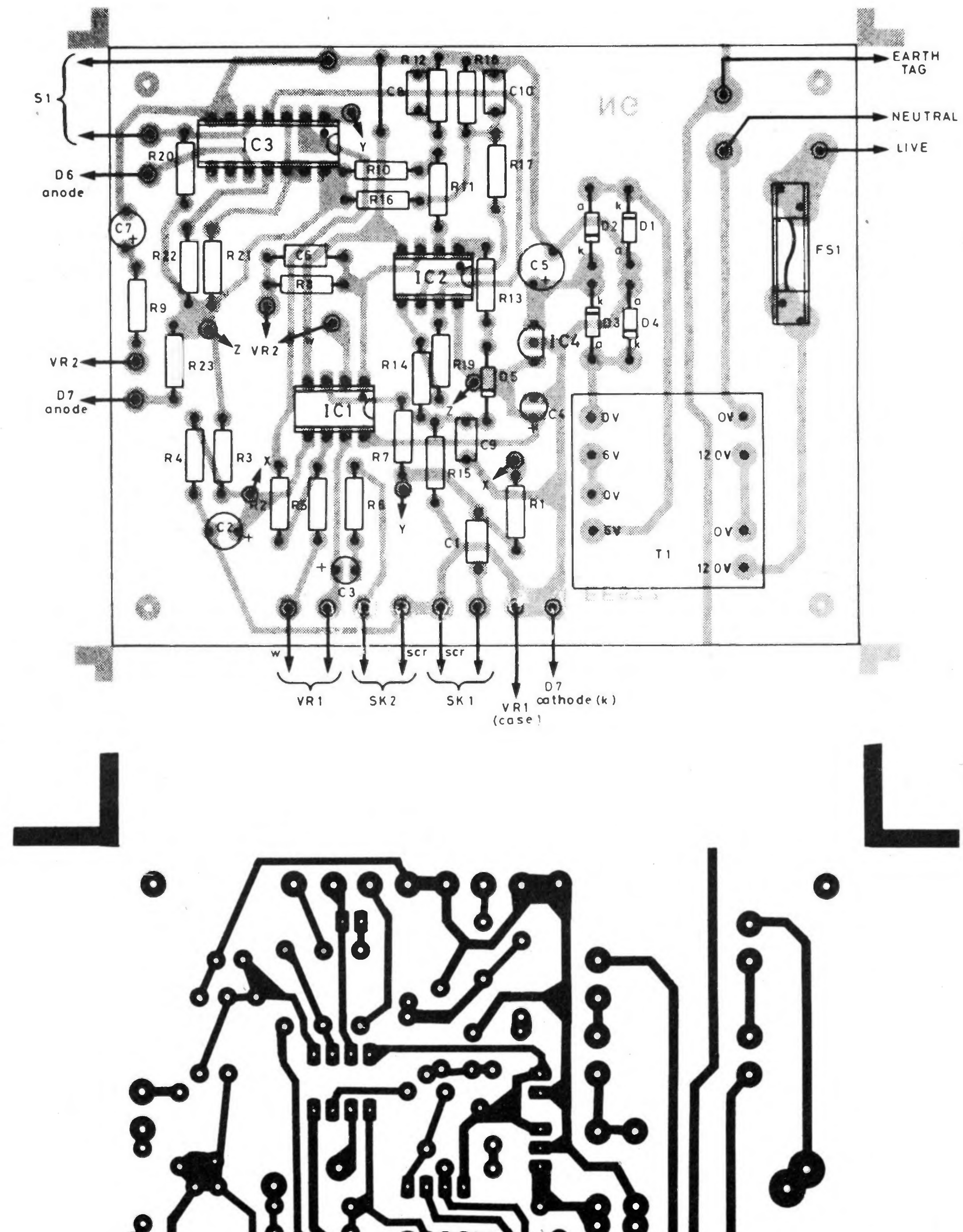


Fig 2 Component layout and full size printed circuit foil master pattern for the Noise-Gate. Note that the wires terminated with single letters should be a single-sleeved link, i.e x to x, y to y etc, and should be soldered on the underside.

the box, underneath those areas of the PCB that carry the 120VAC. Fix the PCB to the four mounting pillars.

Interwiring

Connect the power cord (not forgetting the grommet and a cable clamp) to the PCB, and the ground conductor to the ground tag, which should be connected to the grounding point on the box. At this point it may be worth checking that the power supply is operating.

Fit a 500mA fuse, and check the resistance between the live and neutral conductors of the power cord (this should be a few tens of ohms). Next, check that the ground conductor is connected to the case, and that the resistance between the ground conductor and the live and neutral conductors is very high (it ought to be immeasurably high on a normal multimeter; in other words, check for an open circuit). Next, check for a similarly high resistance between the live and neutral conductors and the 6V power can be applied. Take extreme care as high AC voltages are potentially lethal. Check across pins seven and 14 of IC3 for 12 volts.

If the 12 volts is not present, then disconnect the power before attempting to find out why. If the 12 volt supply is correct, disconnect the power before continuing the construction.

Fix the two sockets, the switch, the two potentiometers, and the two LEDs to the box. Connect these components as shown in Fig. 3, using 7/02 connecting wire and miniature screened cable. Make a quick visual check over the PCB to ensure nothing has been missed out or fitted the wrong way around. Fix the lid on the box, and connect the power supply. The Power LED should light. The Open LED may also be lit, depending on the position of the switch on the rear of the noise-gate: position the switch so that the LED goes out.

Testing

Connect the noise-gate between an instrument and the amplifier. If using effects boxes, the noise-gate should be connected between the last of these and the amplifier. As the instrument is played, the Open LED should light, and the signal from the instrument should reach the amplifier. The Open LED should go out as playing stops: if it does not, then rotate the threshold control until it does. The Output control should be set to provide an output level suitable for whatever amplifier or tape- recorder is being used.

Flangers and choruses are among the worst producers of noise, so, if using one or both of these effects, switch them on, and adjust them for their worst output (that is, for maximum noise). Adjust the threshold control until the Open LED just lights, and then rotate it in the opposite direction until it goes back out. Playing the instrument should now open the gate, and the gate should close about half a second or so after playing stops. Construction and testing is now complete. ■

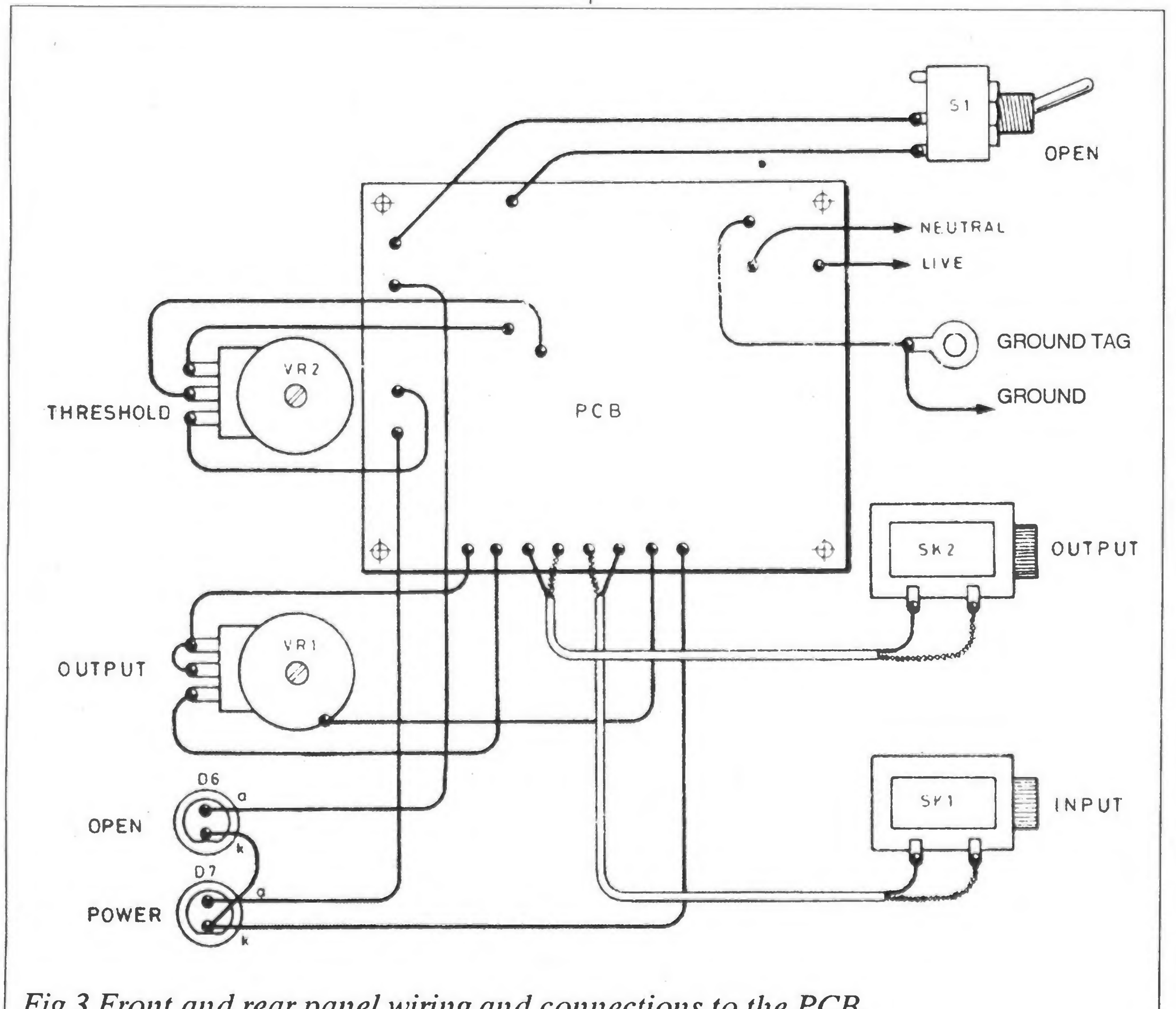


Fig 3 Front and rear panel wiring and connections to the PCB.

Parts List

Resistors

All 0.25W 5% carbon

R1,12,15,16,18,19	1M
R2	200k
R3,4	470k
R5,9	4k7
R6	100R
R7,20,21	100k
R8,10	330k
R11,17	10k
R13	5k1
R14	33k
R22,23	3k9

Potentiometers

VR1	1M log. carbon
VR2	10k log. carbon

Capacitors

C1	330n min. layer polyester 100V
C2,3,4,7	10u min. rad. elect. 16V
C5	100u min. rad. elect. 16V
C6	22p polystyrene 160V
C8,10	100n min. layer polyester 100V
C9	470n min. layer polyester 100V

Semiconductors

IC1	TL072 dual low-noise op-amp
IC2	TL082 dual op-amp
IC3	4066B quad switch
IC4	78L12 +12V reg.
D1,2,3,4	1N4001 1A 50V rectifier diode
D5	1N4148 small signal diode
D6,7	3mm red LED

Miscellaneous

S1	SPST min. toggle
SK1,2	6.3mm jack sockets
FS1	500mA fuse
T1	1.2VA transformer w/12V secondary

PCB; case 154mm x 120mm x 45mm; PCB mounting pillars (4); LED mounting clips (2); miniature screened cable; suitable power cord, grommet and clamp; control knobs (2); soldertag; screws for PCB pillars; 1mm rubber sleeving; PVC insulating tape.

Hioki 3234 Printing Multimeter

Keep a list of measurements manually or automatically with the Hi Tester.

By Bill Markwick

WHEN you first unwrap the Hioki 3234 and hold it in your hand, you'll be impressed by the remarkable miniaturization and smooth operation, even by today's standards of tiny wizardry. Print out a list of volts, or ohms or or milliamps, each measurement identified with the appropriate symbol, on 1.5" roll paper.

Your next reaction might be "But what do I *need* one for?"

Aside from the convenience of having a record of tests you've made, the two most important uses of a recording meter are sequential troubleshooting procedures and monitoring some parameter at intervals. In the first case, good troubleshooting requires you to make a sequence of measurements as you make your way through the circuit. If it's a simple problem (such as no power supply voltages at all), you may only need a go/no-go indicator to trace from the supply to the fault, or vice versa. If it's a logic circuit, however, or a direct-coupled amplifier, a single fault can cause all sorts of voltage readings at various other components, and the way to troubleshoot is to use a consistent pattern of measuring.

This is where the recording meter comes into its own. You aren't likely to remember what reading you got ten measurements back, and writing down the readings is cumbersome. With a printout, though, you can instantly look up the readings you obtained before and compare them to new ones under a different set of conditions.

When it comes to monitoring a circuit over a lengthy period, a recording meter is unmatched for convenience if you can set it to automatically record a parameter at preset intervals.

The 3234

The multimeter section of the Hioki 3234 Hi Tester has a 3 1/2 digit LCD readout with auto or manual ranging. It measures DCV from 300mV to 500V full scale, ACV from 3V to 500V full scale, ohms from 300 to 30M, and AC/DC milliamps to 300mA. There's also a low-power ohms function; this keeps the probe voltage below 1/2V so that semiconductor junctions under test will not be activated. The Option position of the range switch is used for Hioki external optional equipment.

The multimeter and printer is powered by an internal NiCad rechargeable battery, giving about six hours of continuous use if the printer runs every ten seconds. The clock function is separately

```
00:03 87-10-28

000 DC 03.66 V
001     ***.* Ω
002     10.12KΩ
003     10.11KΩ
004     09.88KΩ
005     09.80KΩ
006     10.11KΩ


00:27 87-10-28

000 DC 06.29 V
001 DC 05.45 V
002 DC 05.36 V
003 DC 05.35 V

00:31 87-10-28
 TIME INT.=30S

000 DC 05.09 V
001 DC 05.00 V
002 DC 04.90 V
003 DC 04.82 V
004 DC 04.73 V
```

Left: the printout from the Hioki 3234 Hi Tester. At the top is a sequence of resistances as a resistor changes temperature. In the middle is a series of manual measurements, and a t the bottom is a list of voltages taken every 30 seconds as a large capacitor discharges.

powered by a standard LR-44 button cell. An AC adapter is provided to either run the unit or charge the battery.

The Printer

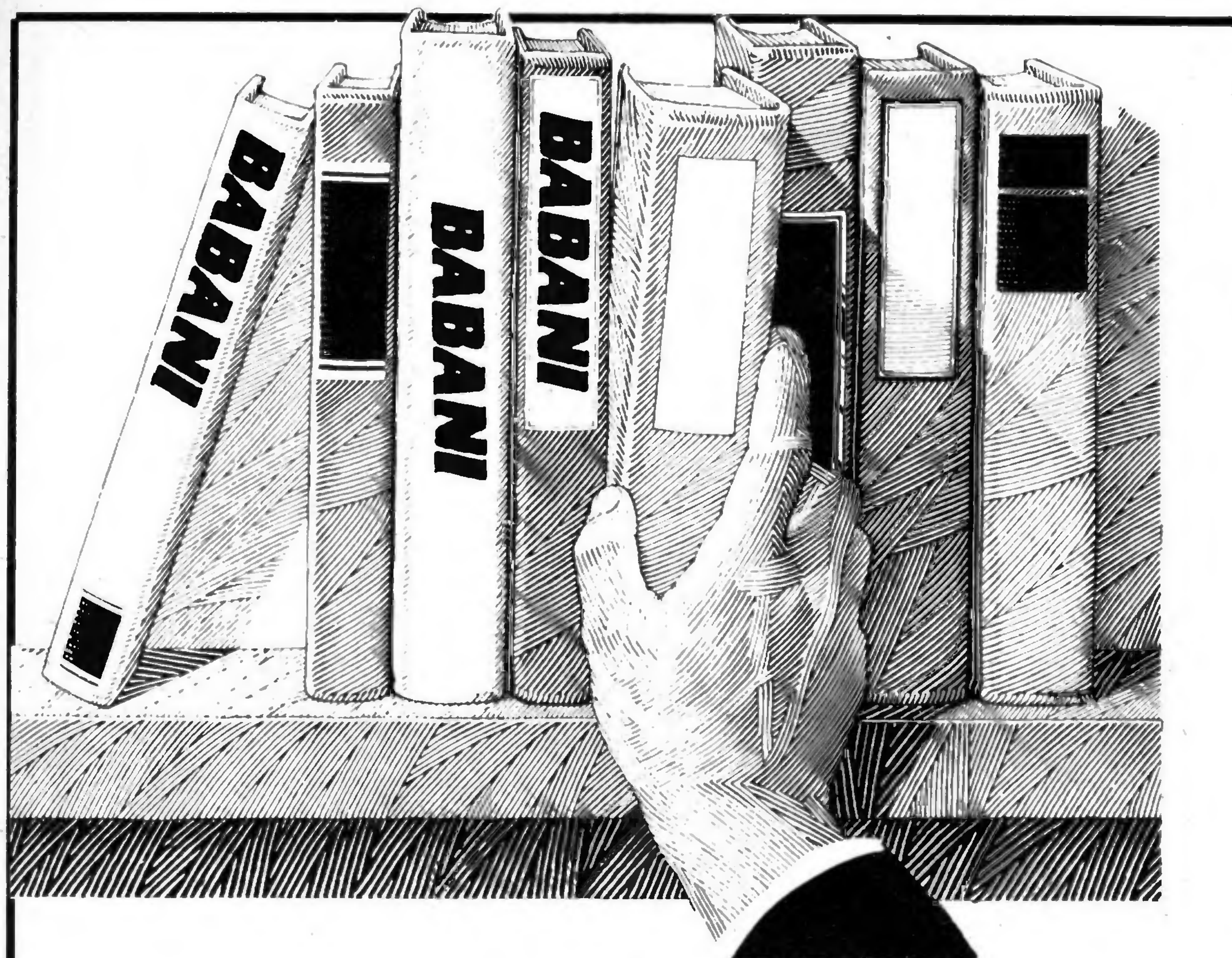
Each time that you press the Start/Stop button after a Clear, the printer records the hour, minute, year, month and day. Then it will record volts, ohms or milliamps, with each recording numbered. It's quite a convenience to be able to look up a reading and see whether it's changed from new readings.

The printing is on 38mm thermal paper, and enough is stored in the 3234 to print about 750 lines.

The time interval function can be selected from the numbers that appear above the DMM display; selectable intervals are 10 seconds, 30 seconds, 1,5,10 and 30 minutes, and 1 hour. Once the function and interval is set, the 3234 quietly records your parameter with a daily accuracy of plus or minus 3 seconds. You could set it to monitor the voltage or current variations of a power supply for an extended operating period, or monitor a resistance to see how much it changes during warmup.

The External Switch jack is used for remote triggering using a pushbutton. There's also a Sync input; this is used to synchronize two 3234s so that they operate at the same time during the time interval function.

At $1005 Canadian, the 3234 is something of a luxury for the average testbench, but it's a delight to use; I never realized how useful a printout could be until we had to send the review model back. For further information, contact RCC Electronics Ltd., 310 Judson St., Toronto, Ontario, M8Z 5T6, (416) 252-5094, FAX (416) 252-3031. ■



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R.A. Penfold
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CIRCUITS

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A wide circuits is given, from low noise microphone and tape head preamps to a 100W MOSFET type. There is also the circuit for 12V bridge amp giving 18W. Circuit board or stripboard layout are included. Most of the circuits are well within the capabilities for even those with limited experience.

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Field effect transistors (FETs), find application in a wide variety of circuits. The projects described here include radio frequency amplifiers and converters, test equipment and receiver aids, tuners, receivers, mixers and tone controls, as well as various miscellaneous devices which are useful in the home.

This book contains something of particular interest for every class of enthusiast - short wave listener, radio amateur, experimenter or audio devotee.

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E.A.PARR **$11.80**
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There is now a vast range of ICs available to the amateur market, the majority of which are not necessarily designed for use in a single application and can offer unlimited possibilities. All the projects contained in this book are simple to construct and are based on a single IC. A few projects employ one or two transistors in addition to an IC but in most cases the IC is the only active device used.

BP118: PRACTICAL ELECTRONIC BUILDING BLOCKS - BOOK 2 **$7.60**
R.A. PENFOLD
This sequel to BP117 is written to help the reader create and experiment with his own circuits by combining standard type circuit building blocks. Circuits concerned with generating signals were covered in Book 1, this one deals with processing signals. Amplifiers and filters account for most of the book but comparators, Schmitt triggers and other circuits are covered.

BP83: VMOS PROJECTS **$7.80**
R.A. PENFOLD
Although modern bipolar power transistors give excellent results in a wide range of applications, they are not without their drawbacks or limitations. This book will primarily be concerned with VMOS power FETs although power MOSFETs will be dealt with in the chapter on audio circuits. A number of varied and interesting projects are covered under the main headings of: Audio Circuits, sound Generator Circuits, DC Control Circuits and Signal Control Circuits.

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PC Weather Station Review

Start your own weather forecasting with this versatile weather station for the PC.

By E. Penn

Weather stations that I remember, at least the high school variety, were large and complicated and you had to be really faithful about writing down all the measurements daily. They weren't the sort of thing you had at home, not unless you were a real keener.

Now Technology Marketing of Oregon has come up with a weather station that's comprehensive, compact and best of all, uses an IBM PC or compatible to measure everything and keep extensive records of the findings. With a few keystrokes you can find out everything you wanted to know about past and present temperatures, rainfall, barometric pressure, windspeed and wind direction. And all from the comfort of your computer desk: no more slogging through the wet to see how water is in the rain gauge.

How It Works

The various parameters I mentioned above are measured by a collection of ingenious gadgets, and I'll discuss each of the various sensors in more detail later.

First, each sensor has a cable coming back to your PC. In one of the PC expansion slots lives a half-size printed circuit card; on this card is a panel full of jacks that faces out through your computer's card slot. Once connected up and powered by the included 9-volt AC adapter, the card is ready to start measuring everything and feeding the information to the software.

Secondly, the software is loaded into memory, either from the floppy disk as a regular program or from an AUTOEXEC file, or from your floppy disk. The program sits in memory doing its measurements until the computer is turned off; I didn't find any interference with the operation of other computer programs. It takes up about 35K of RAM.

Whenever you want to monitor anything, ALT-SHIFT-W brings up the data menu, with everything at a glance: the air pressure and its changes, daily and yearly rain, temperature with its high and low point, wind speed with gust speed and wind chill, and the wind direction.

An options menu lets you set the time, date, metric/imperial and so on. The various data are also saved to your choice of drive and directory for future reference. There's also a real-time clock on board which you can use if you don't have a clock card on your computer.

The Temperature Probes

There are two tiny probes, each smaller than a bean; one is for indoors and the other for outdoors. They live on the end of 11-foot cables, and each is individually calibrated for the printed circuit card that comes with your station. That is, the disk you receive is calibrated for your hardware alone, and should you do something as dim-witted erasing your disk, you'll have the embarrassing job of returning things to the factory for recalibration. The moral is: make backups and don't even think of using your master disk.

The readings from the outside probe are kept in registers on the printed circuit (which never powers down) and the inside readings are stored in the computer's RAM (and lost when you turn the computer off).

If the 11-foot cords are not adequate, you can purchase extenders from Technology Marketing, in 40-foot increments for a total of 200 feet. Homemade extenders are discouraged because they may affect calibration.

The Rain Gauge

From the outside, it just looks like a black plastic megaphone with a 40-foot cable. Rain funnels into the small end and the rainfall is measured by the computer in increments of 0.1 inch. It's self-emptying and needs no maintainence unless leaves fall into it.

A group of us junior scientists took it apart and had a guess or two at how it works. We poured water into the centre cylinder, it reached the level of the siphon tube and gurgled into the small cup and poured over a small glass tube, and then a sponge floated up and opened a drainhole to let the water out. Then you could repeat the cycle. Well, we decided that the little glass tube was a thermistor heated by the 5V supply, and that the water cooled it to toggle a counter.

Wrong. Technology Marketing told me that the "sponge" is actually a magnet embedded in foam, and when it rises, it closes the magnetic reed switch in the glass tube. Just the same as the windshield-washer warning light on my car. Clever, this.

We never did come up with a reliable way to check the accuracy of the rain gauge. Of course, it wouldn't rain when you wanted it to, and the lawn sprinkler was too random in action to give any kind of answer. We'll trust them, though, cause everything was so well made it inspired that kind of confidence.

Wind

The wind gauge consisted of an anemometer and a vane mounted on a shaft with 40-foot cables. The anemometer's rotation sends pulses to the PCB to measure windspeed, and the vane rotates with the wind direction, providing a readout in degrees as well as compass points.

This one is a little more tricky to install than the others, because it has to be clamped to an upright or screwed into a wooden post via the included adapter. The direction sensor is turned until the screen reads 0 degrees, and then the vane is fastened on pointing to the north, using either a compass or some known direction reference.

The instructions for installation are very good; they point out in their drawings, for instance, that the wind will eddy around the walls of a house, and so the wind sensors should really be mounted as high as you can manage.

Barometric Pressure

This one needs no installation; it's a tiny sensor mounted on the printed circuit, and it's set to your local pressure during installation. You might have to call a local airport or weather service if you want a proper value.

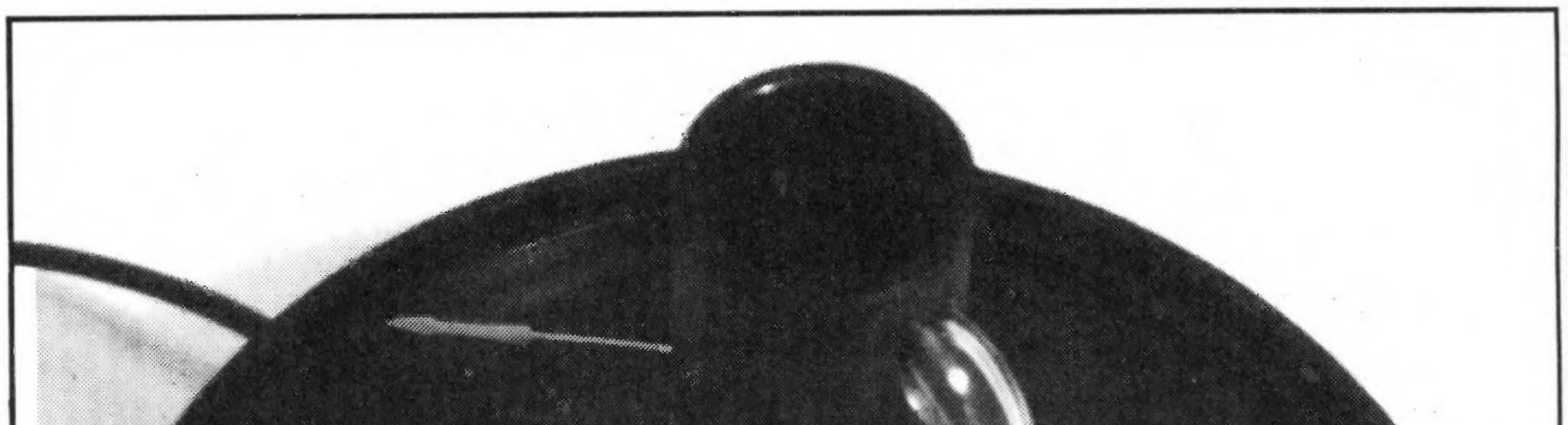
And that's it...

Once installed, the weather station will soon prove addictive to science fans. The comprehensive software is like a database: you can keep dibs on *everything*. It has menu after menu of features. For instance, you can set an alarm to sound the computer's squeaker on your setting of inside or outside temperature, wind speed or time. The rain readout is a little drawing of a tank that fills with water, and a tiny graphics faucet actually drains it out when you reset the counter. Any of the parameters can get a screen of its own for a much more expanded view.

You can also make graph plots of all data and print it out using the SHIFT-PrtSc function from DOS.

Almost...

In general, the quality and operation of the weather station hardware and software is beyond reproach. However, as an owner of a compatible, I had a bit of trouble with the computer side



The rain gauge, which can record any amount of rainfall in increments of 0.1 inch. The small cylinder on the right contains a float with an imbedded magnet, which trips the small reed switch and empties the gauge.

```
###############################**** WEATHER BULLETIN ****###############################
#                                  :                                                   #
#            11:13:30 AM           :           November  1,1987                        #
#----------------------------------+---------------------------------------------------#
#   Barometer        30.03 In. Hg. :         Daily  Rain      0.0 In.                  #
#----------------------------------+---------------------------------------------------#
#   Change            0.00 In./Hr. :         Yearly Rain      1.0 In.                  #
########################################################################################
#      Outside                  TEMPERATURE RECORD                     Inside          #
#      Temp A                            ^v                            Temp B          #
#      71.7  F     :----+----+----+----+----+----+----+----: <-  71.6  F               #
#  Hi  108.8 F     0    15   30   45   60   75   90   105  120    72.1  F     Hi       #
#  Lo    0.0 F ->  :----+----+----+----+----+----+----+----:      70.4  F     Lo       #
#                  ^                        ^           ^                              #
########################################################################################
#                                                           #                          #
#  0    5    10   15   20   25   30  Wind Speed    0 MPH    #          N               #
#  :----+----+----+----+----+----:                          #    NW    .      NE       #
#                           ^        Gust Speed   22 MPH    #          .               #
#-----------------------------------------------------------#  W<---- 248 . . .E       #
# 65   70   75   80   85   90   95   Wind Chill    71.7  F  #          .               #
#  :----+----+----+----+----+----:                          #    SW    .      SE       #
#      ^   ^                         Gust Chill    67.8  F  #          S               #
#                                                           #                          #
########################################################################################
```

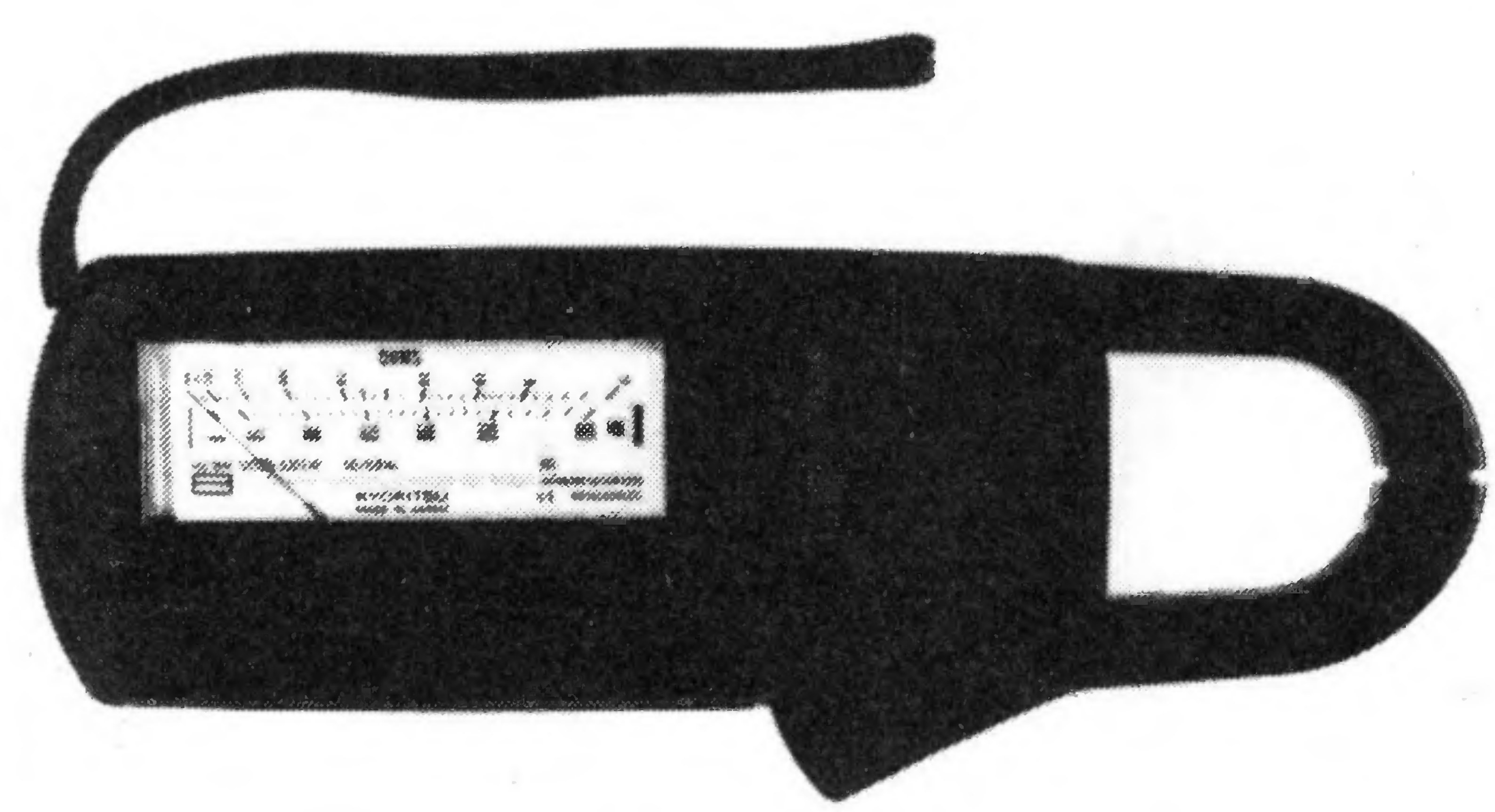
A printout of the weather data screen, which gives a summary of all the parameters.

of the installation. At first, I could get nothing but can't-find-card error messages, and I assumed that I had a duff unit. A call to Technology Marketing proved them very helpful, and I soon had a technical paper from them that solved the mystery. It turned out that both my real-time clock and the weather card were occupying the same port address (300 hex). It was a simple matter to solder a jumper onto the card to change the address to 340, but I really think that this information should be included for clone owners in the otherwise splendid documentation (for the record, I tried the card in three Bests: a Mark II, a Mark III and a Mark IV – same problem).

To sum up, though, I can't imagine a nicer piece of gear for individuals or schools interested in weather monitoring. The whole package is available for \$575US from Technology Marketing, Inc., 4000 Kruse Way Place, Bldg. 2, Suite 120, Lake Oswego, Oregon 97035, (503) 635-3966 ■

For Your Information

Continued from page 31



600 Amp Clamp Meter

A new 600 Amp Clamp-style meter has been introduced from Kyoritsu Electrical Instruments. The model 2804 is a rotary scale meter with AC current ranges of 6/30/100/300/600, AC voltage ranges of 150/300/600, resistance to 2Kohms and a maximum conductor size of 30mm. The unit can also be used in conjunction with the optional Kew Energizer model 8021 designed to split a two conductor line and also to measure low current. Comes complete with carrying case, ohms probe, test leads, and a two year parts and labour warranty.

Omnitronix Ltd., 2410 Dunwin Drive, #4, Mississauga, Ontario L5L 1J9 (416) 828–6221.

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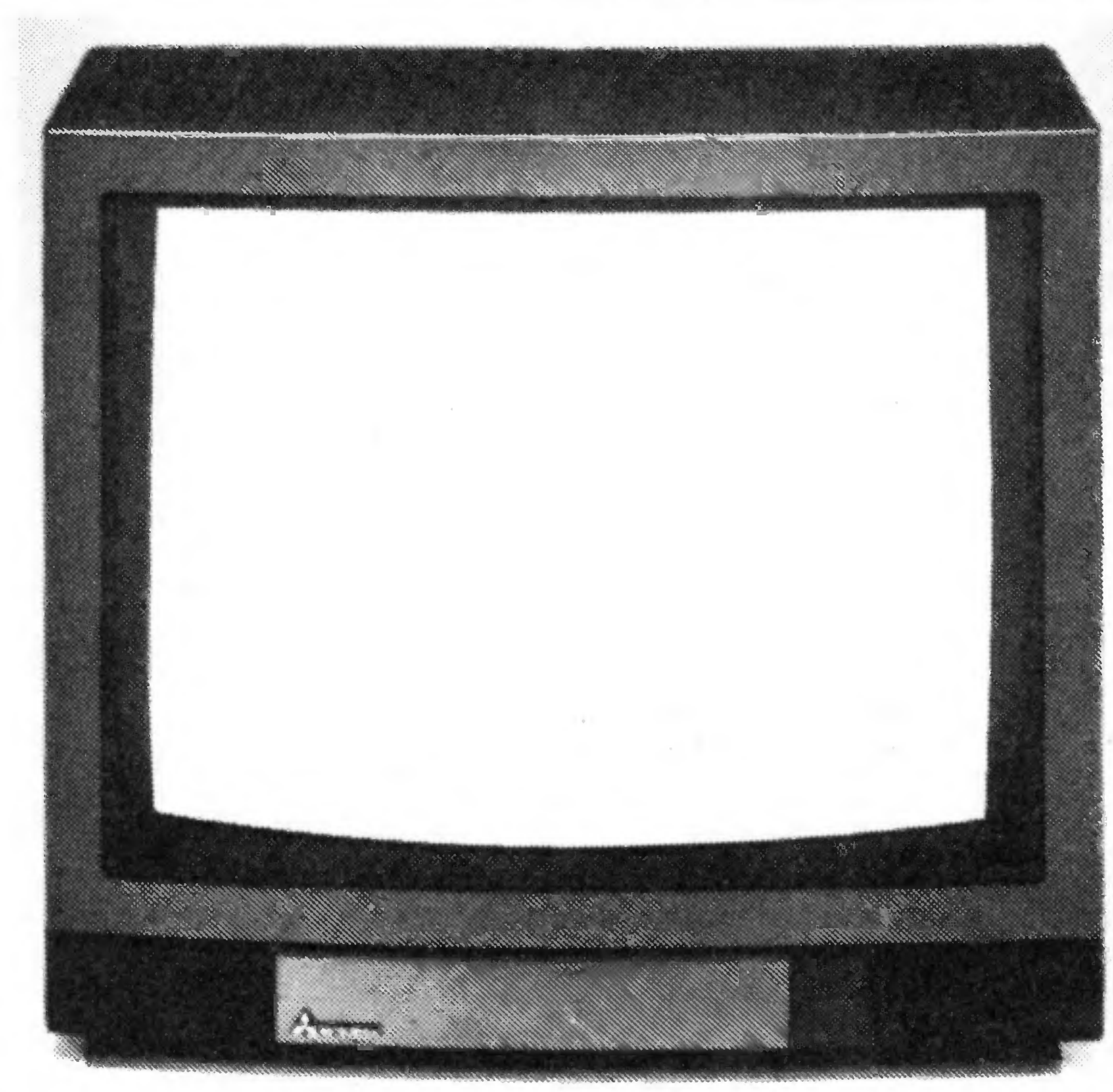

New Mitsubishi TV

Mitsubishi Electric Sales Canada Inc. has announced the availability of the CS-2654, High Tech 28-inch stereo Diamond Vision color TV.

Features include: 39-function integrated TV/VCR infrared remote control; MTS-SAP stereo broadcast reception; on- screen mode display with time of day and channel; 125 channel cable-ready tuner; automatic picture latitude circuitry; channel lock-out and program timer; separate bass and treble controls; stereo audio input and output; and video input.

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Basement Flood Alarm

A water level warning device with a difference.

By H. Wright

During a hydro power failure or the failure of the sump pump motor float switch, a sump can overflow, with disastrous consequences. If warned in time, the householder can get down there with a bucket. It will also double as a full sewage tank warning on a boat, and it could be used in rural or cottage areas where holding tanks are being more widely used.

How It Works

A dual 556 timer performs the noise making function. The schematic diagram is shown in Fig. 1. The left-hand half of IC1 generates a low (approximately 1.0 Hz) frequency square wave at its output pin 5, and this is attenuated to a suitable level by R5 and R6. The attenuated signal, which determines the frequency spacing between the high and low sound output, is applied to pin 11, the FM input for the right hand side of IC1. Output pin 9 drives a small speaker through R7 and C3.

IC1 gets its power through Q2 which is acting as a switch. When the water touches the probe tips, Q1 is biased on, draws current and produces a high at its emitter. This high turns on the alarm through Q2.

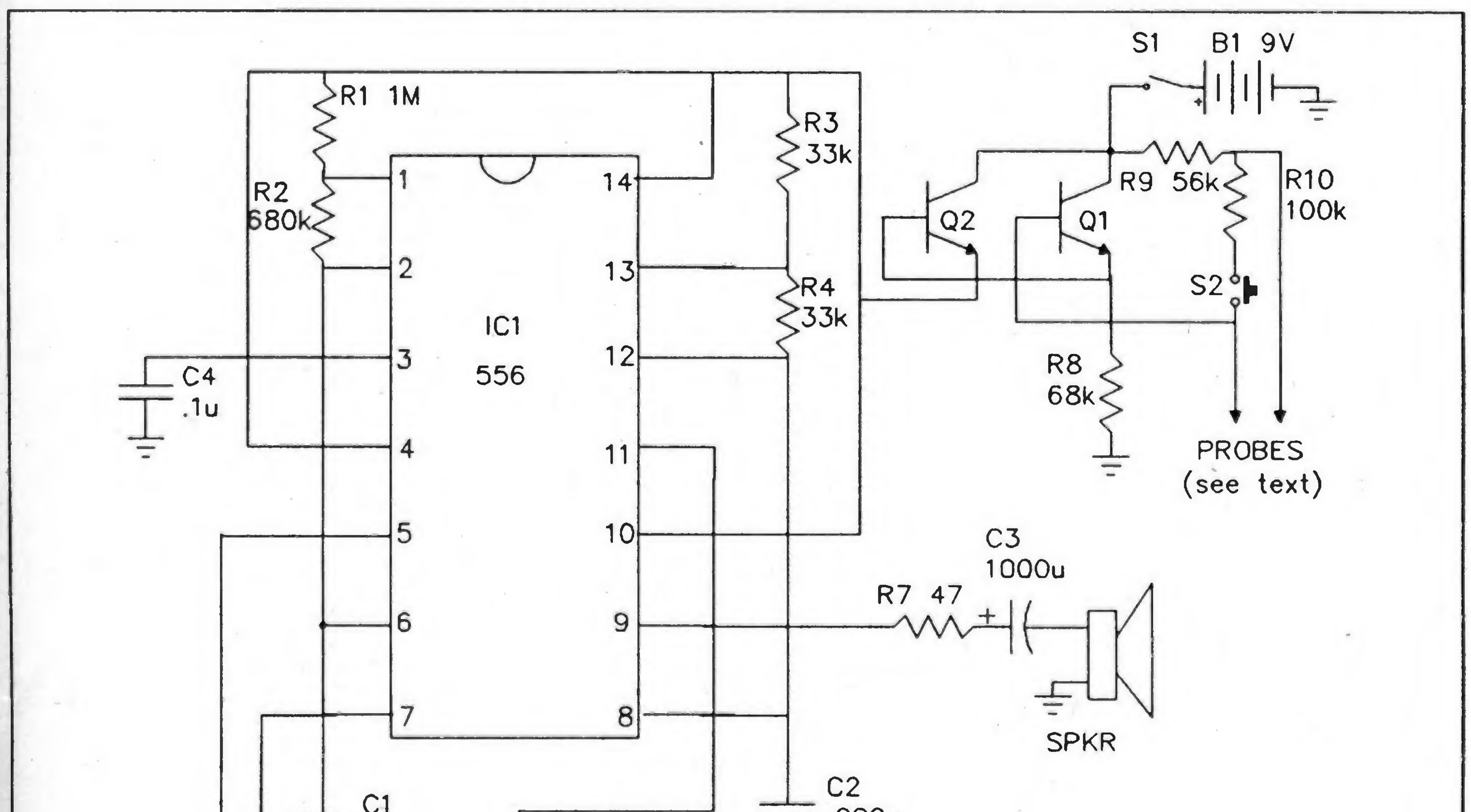


Fig. 1 The schematic diagram of the Basement Flood Alarm.

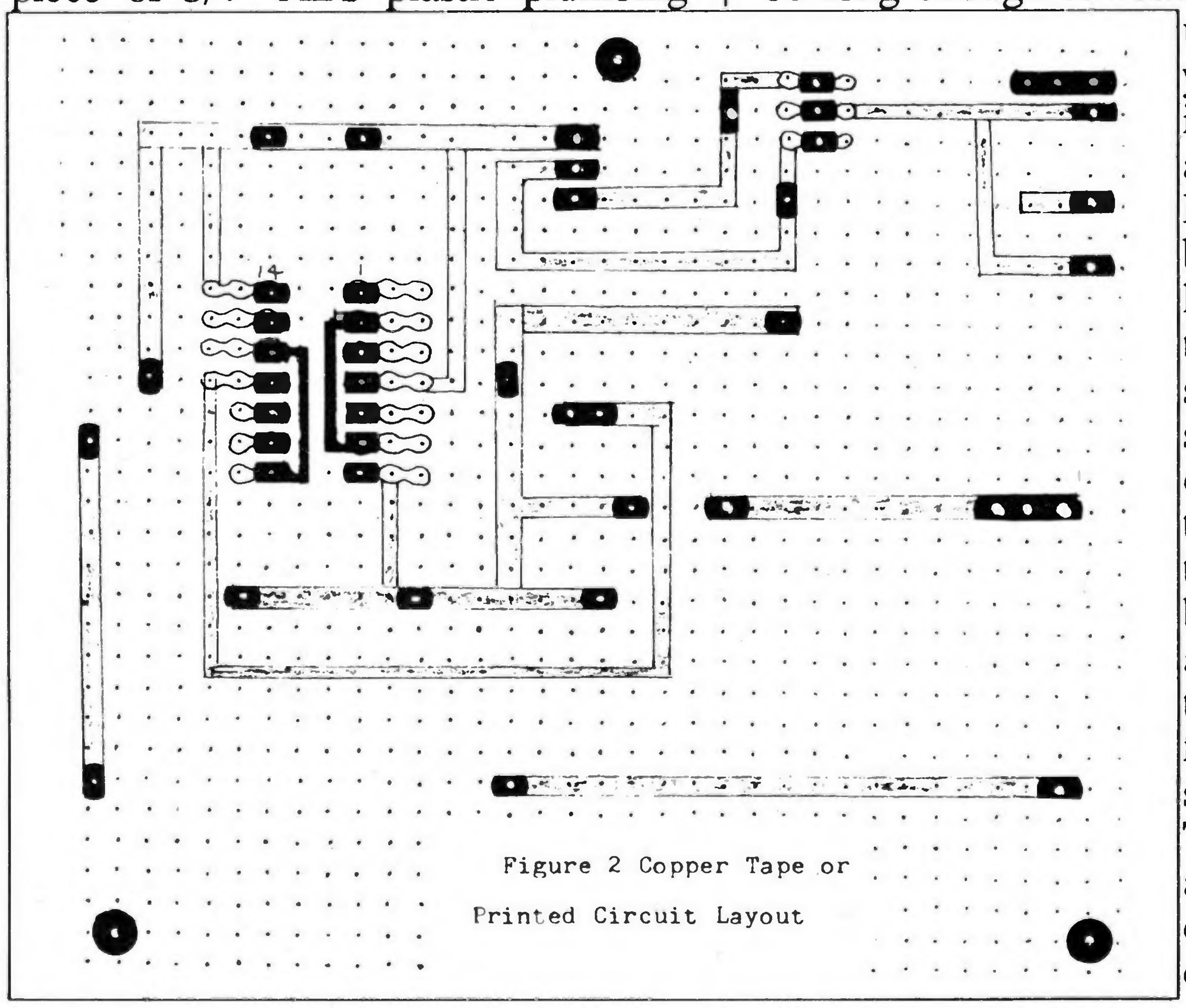
Construction

Figure 2 shows a layout for copper stick-on tapes and patterns which is readily converted into a printed circuit. If you are into printed circuits, the size should be left as as. Fig. 3 is the component placement diagram. The whole thing goes into a Radio Shack box. The bottom of the box is used as a front panel. The test push-button and the on-off switch are mounted on this panel below the speaker, and, a grid of holes is drilled in the plastic to allow the sound to escape. The finished circuit board is installed in the box, below the speaker and fastened to the panel with three bolts equipped with sleeves long enough to make sure that the printed circuit is clear of the two switches. The assembly arrangement can be seen in Fig. 4. The speaker is held in place with epoxy cement. Fig. 5 is a front view of the complete alarm.

The probe is constructed inside a piece of 3/4" ABS plastic plumbing pipe or short adapter. Two 6/32 brass bolts are fastened through a plastic disc that is cemented onto one end of the pipe with 5 minute epoxy cement. Roughen the plastic surfaces with sandpaper before applying the cement. This applies also to the speaker mounting. The pipe provides something solid for attachment to the top or wall of the sump. Before cementing the disc in place, split the two ends of the wire in a length of rubber or plastic insulated two-wire drop cord. This wire should be long enough to reach the location upstairs where you expect to install the alarm box. Mount the bolts into holes drilled in the disc and solder the stripped bare copper ends of the wire into the slots in the bolt head. Use a flux stripper to remove all flux from the solder joint. This should also have been done to the copper tape or printed circuit board. Now slide the pipe over the wire until the disc is in contact with the end of the pipe. Epoxy cement the disc in place. The drop cord can be any length required inside a house.

When the disc cement has cured, give it an exterior coat of epoxy to seal any pin holes that might exist. Except for about 1/4" at the end of the bolts, coat the rest of the probe bolts with epoxy. When this cement has cured, squeeze the rest of the pipe full of clear silicone rubber. To aid in the escape of air during the filling process, drill a small hole in the wall of the pipe near the disc. Squeeze in the silicone until it is coming out of the hole. Fig. 6 shows the construction detail for the probe.

This alarm has a very high sensitivity to water and moisture so it is essential that *no part of the wiring between the probes and the alarm box be exposed to the atmosphere, dampness or water.* The probe should be mounted rigidly in the sump with the probe tips a half inch or so above the water level that turns on the pump. The box should be installed upstairs, perhaps on a kitchen wall. While current is negligible in the standby mode, it is desirable to shut it off when the alarm goes off to conserve the battery while you hunt for a bucket. There will be no problem hearing this alarm throughout the ground floor of a modern house.



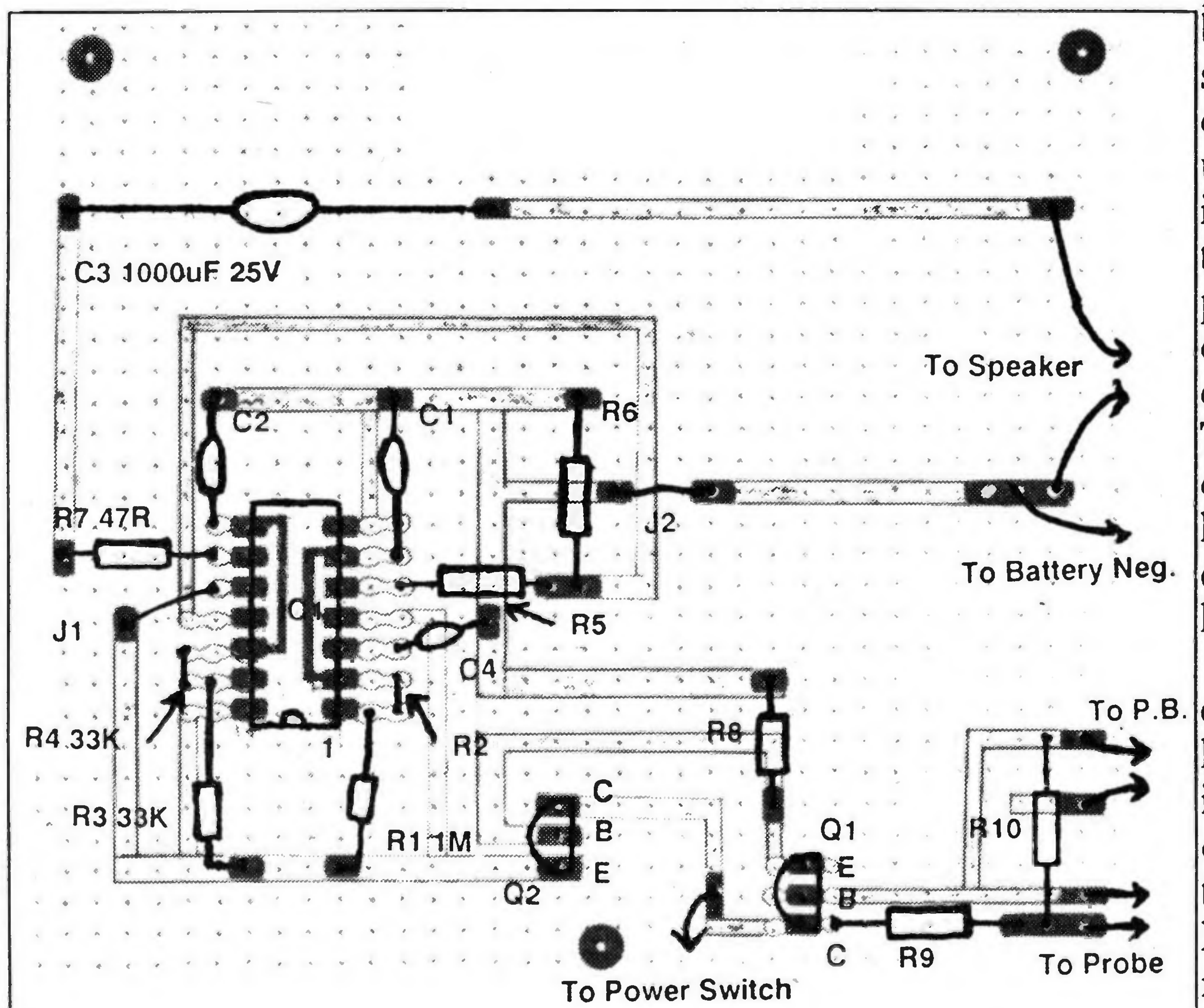


Fig 2 (Top) The copper tape layout of the Flood Alarm. Fig. 3 (Bottom) The parts placement guide.

Parts List

Resistors

All resistors 1/4W unless otherwise stated.

R1	1M
R2	680K
R3,4	33K
R5	2K2
R6	6K8
R7	47R 1/2 Watt
R8	68K
R9	56K
R10	100K

Capacitors

C1	0.47uF min. 15V
C2	0uF022 15V
C3	1000uF 15 v.
C4	0.1uF 15V

Semiconductors

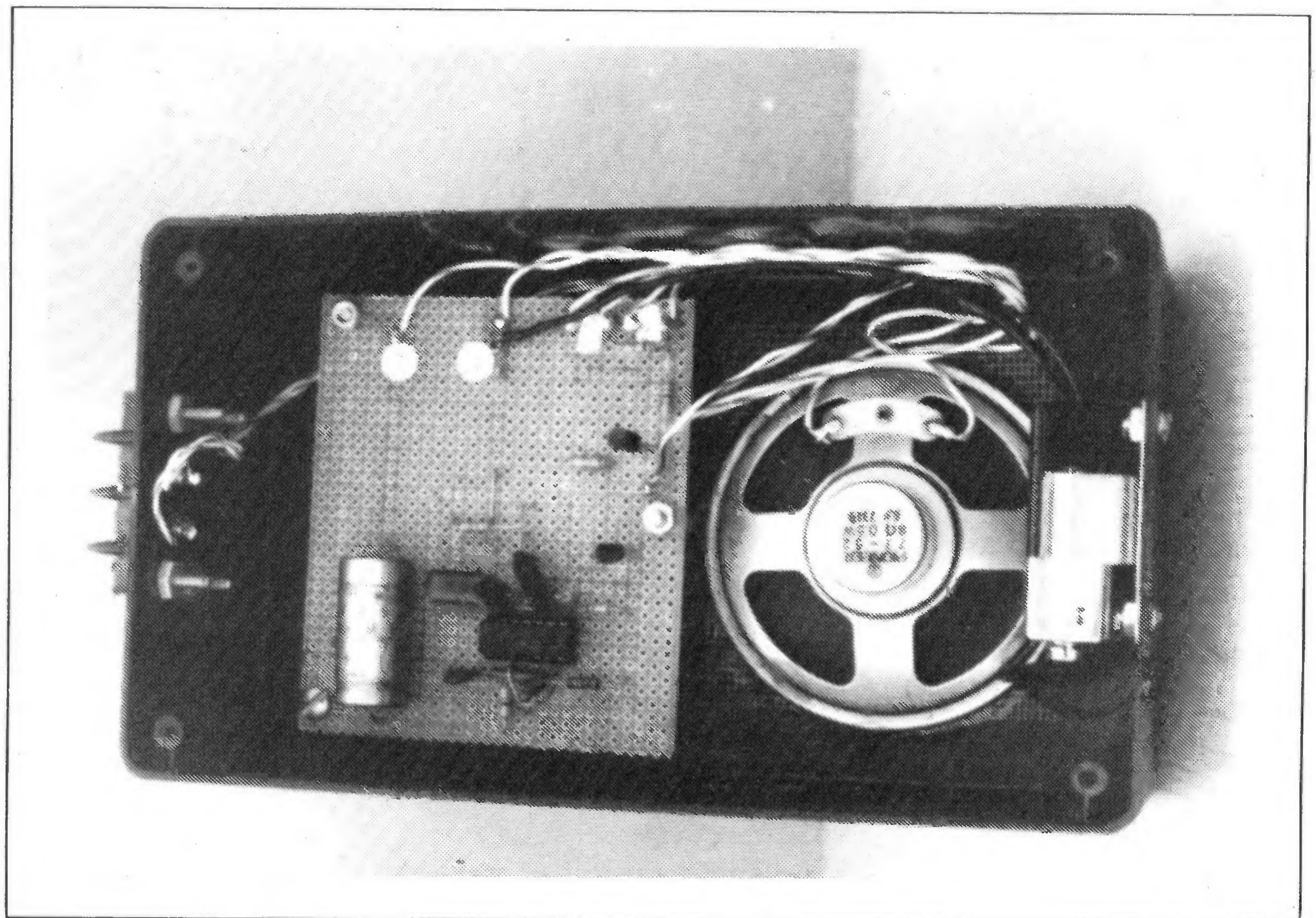
Q1,2	3904
IC1	LM556 dual timer.

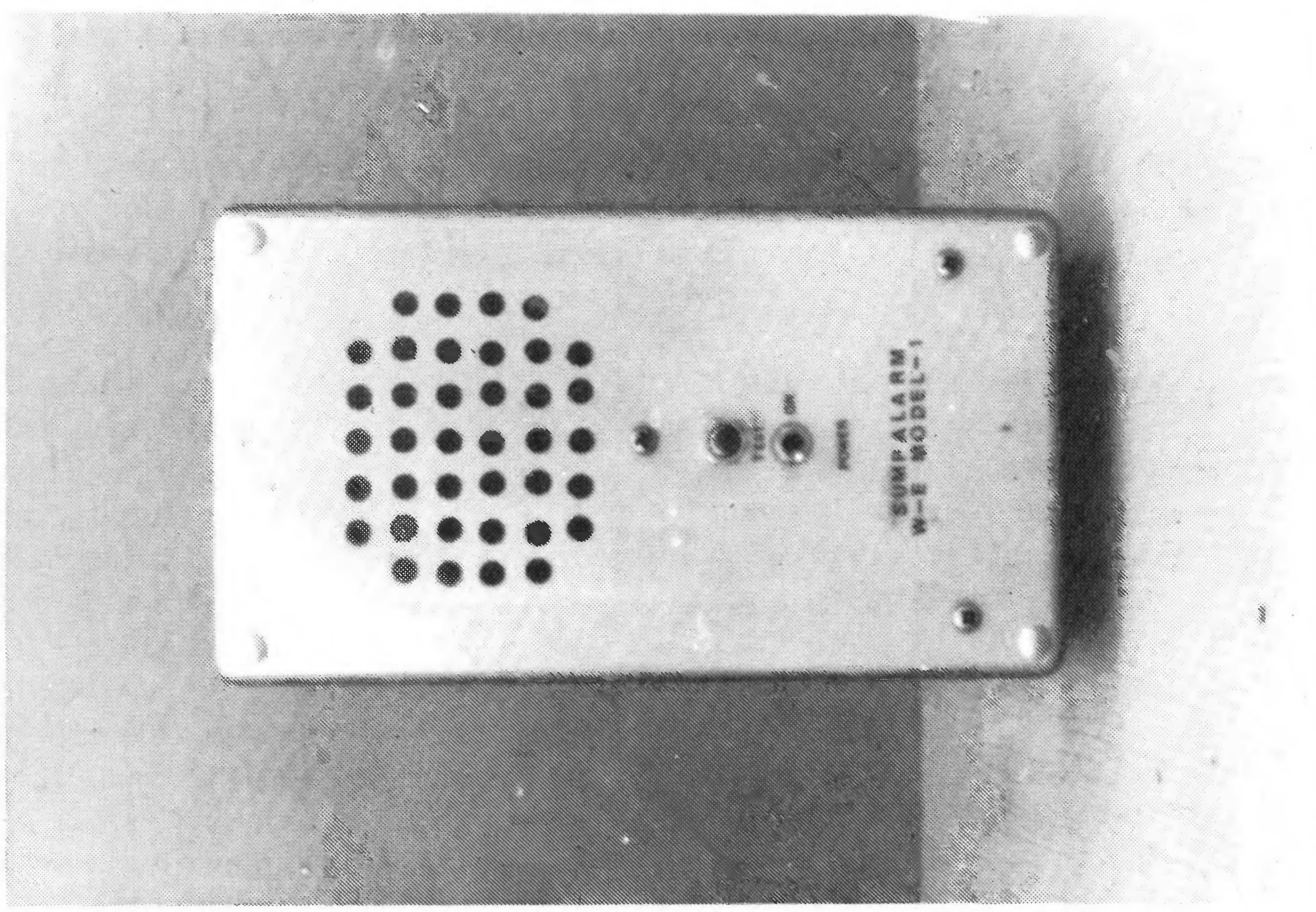
Miscellaneous

S1	Mini. toggle switch on-off
S2 Mini. P.B. Switch N.O. (R.S.#275 1547)	
Battery	9V alk.
Case	Radio Shack #270-625
Loudspeaker	salvage from a discarded pocket radio

Note: In an alarm system it is desirable to have components rated well above the minimum requirement. 15 volt is the minimum recommended.

Harold Wright is a freelance writer from Belleville Ontario.





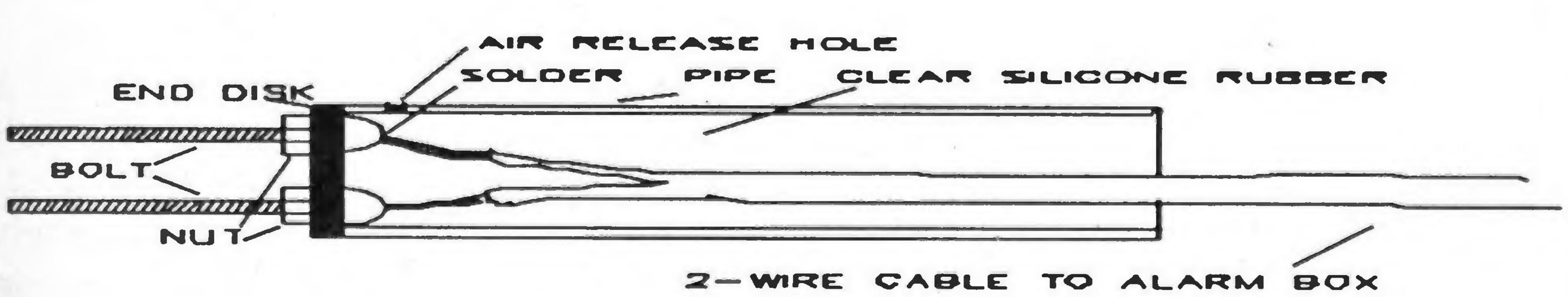
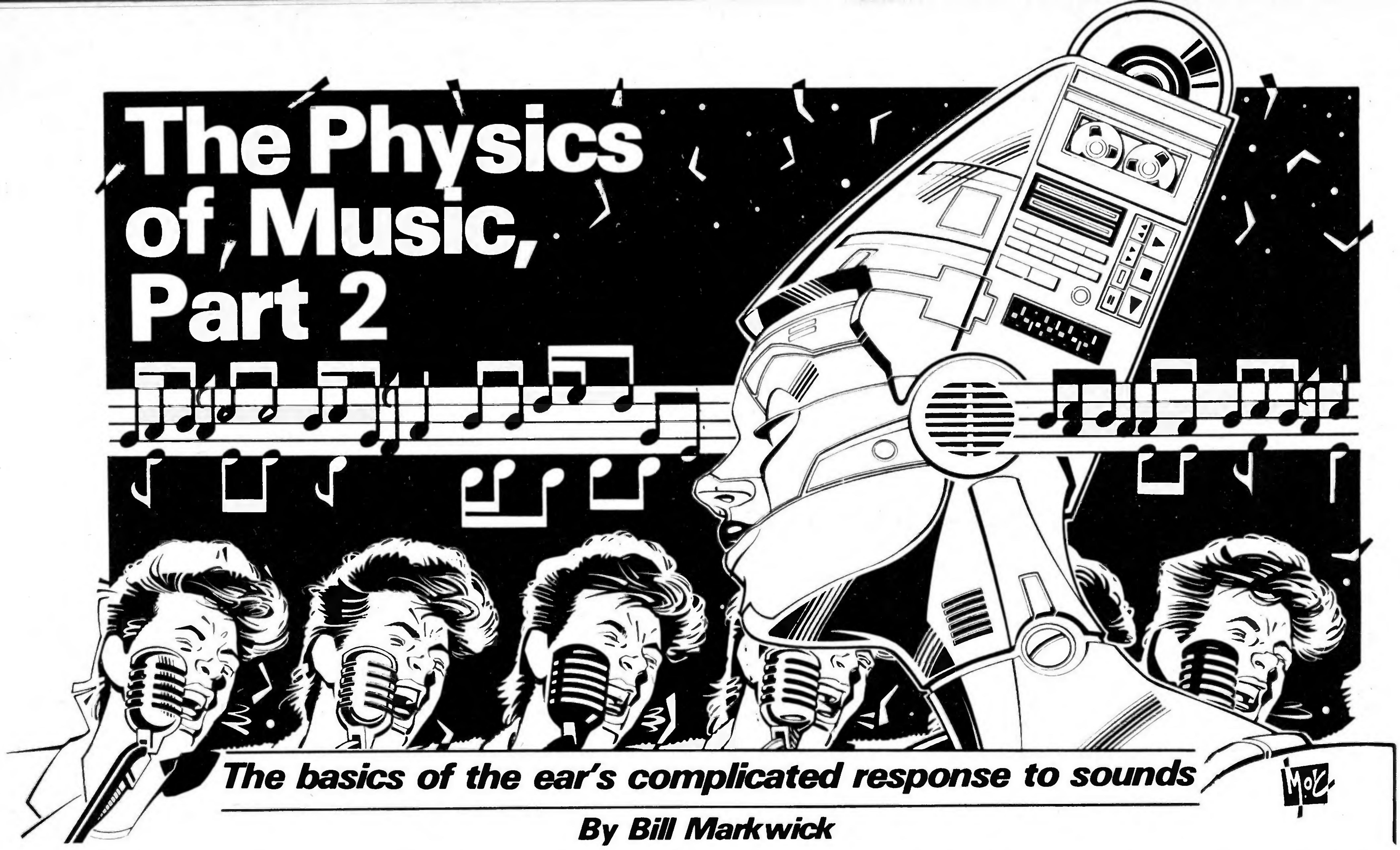


Fig. 4 (Top) The assembly inside of the box and Fig. 5 showing the front view of the completed alarm. Fig. 6 (Below) shows the detailed construction for the probe assembly.



The Physics of Music, Part 2

The basics of the ear's complicated response to sounds

By Bill Markwick

Last month, in our introductory article, we touched on a few of the mysteries of the ear's complex functioning. This month, a bit more detail on how the human hearing response is anything but flat. In fact, the ear/brain mechanism is the most sophisticated audio device imaginable.

The previous article touched on the decibel, the workhorse unit of the audio technician, and an indicator of the ear's enormous dynamic range in handling the softest to the loudest sounds. There was also a mention of how the ear's frequency response changes with loudness. This month, we'll go into these in more detail.

Dynamic Range Review

The average sound intensity which the ear can hear is about 10^{-16} watt/cm^2, and the loudest, at the threshold of pain, is about 10^{-4} watt/cm^2. This is a dynamic intensity range of a thousand billion. Expressed in the logarithmic compression of the decibel, this is 0dB to 120dB from softest to loudest.

If one sound has 10 times as much power as another, the difference in their intensity levels is 10dB, or 1 bel. In the midrange frequencies (say, 500 to 2,500Hz) and at typical listening levels, we perceive this 10dB increase as a doubling of loudness. It should be noted that this convenient relationship holds true only under certain conditions; with bass sounds, for instance, and at low levels, much more power is required to produce the sensation of loudness doubling.

The Ear

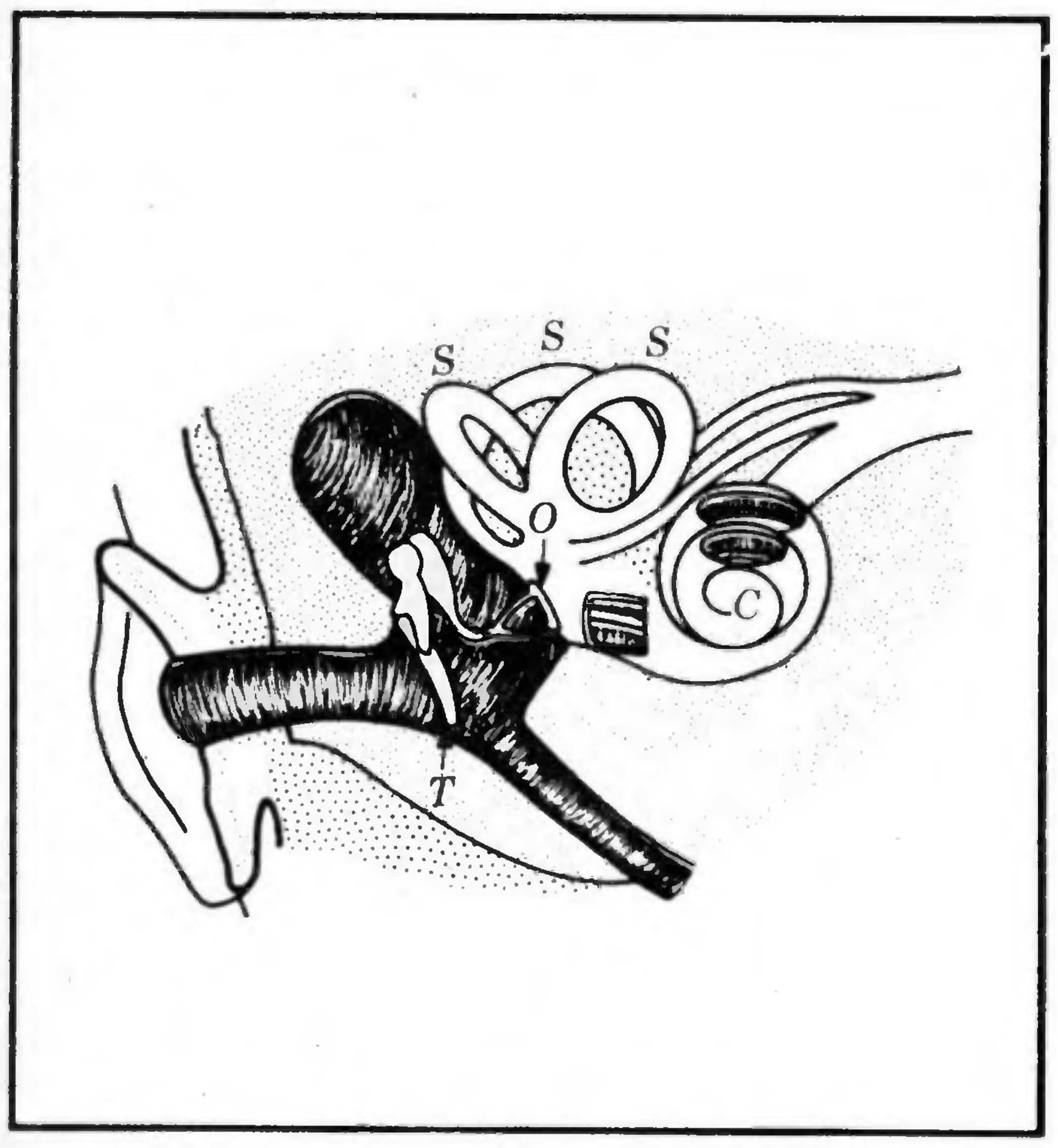
The mechanical parts of the ear are a miracle in themselves, before we even begin considering the processing capability of the brain. The eardrum, or tympanic membrane, vibrates as a result of the sound's variations in the air pressure. The amplitude of these vibrations is incredibly small; ordinary conversation results in a displacement of only one one- hundred-millionth of a centimeter, about the diameter of a hydrogen molecule. The eardrum then transmits these variations in air pressure to the three small bones of the middle ear, the *hammer, anvil,* and *stirrup.* The mechanical advantage provided by these bones results in a pressure change of 30 to 60 times.

The *cochlea* of the inner ear is where the variations in pressure stimulate the sensation of hearing. Its name means "snail" in Latin and refers to its coiled shape. Its inner workings are so complex that whole books can be (and have been) written on its functionings. To oversimplify: the cochlea is lined with groups of microscopic hair cells of various sizes, each group responding to a certain band of frequencies. It's quite possible for extremely loud sounds to damage these cells, resulting in hearing loss. In fact, the cochlea does such a good job of discriminating frequencies that a single tone of sufficient loudness can cause deafness at only that frequency, a biological notch filter. In most cases of short-term exposure to loud sounds, the hair cells will repair themselves. In long-term exposures, or with extremely loud sounds, the damage may be permanent.

There is normally a faint background noise which we can hear in quiet enough surroundings. This signal-to-noise effect is usually not a problem, but can develop into a ringing called *tinnitus*, which may or may not indicate oncoming deafness. It's interesting to note that Beethoven's deafness was said to be severe tinnitus, rather than a drastic decrease in sensitivity. Temporary tinnitus can be induced by short-term exposure to loud sounds; people who say that they come away from rock concerts with their ears ringing are speaking literally.

Thresholds and Sensitivities

We usually read that the minimum sound we can hear has been defined as 0dB, where zero is defined as a particular intensity, and we tend to think that any sound of 0dB in quiet enough surroundings produces the sensation of hearing in anyone. In fact, this figure was arrived at by measuring all sorts of subjects using tones of many different frequencies. The figure represents the average response of a number of people to midrange frequencies, about 800 to 2000Hz.



The fundamental parts of the inner ear. T is the tympanum, or eardrum, and C is the cochlea. The circular canals S at the top are organs of balance not connected with hearing. (McGraw Hill)

Outside the midrange, the ear requires a much louder sound before the impression of hearing is reached. The chart shows, for instance, that at 110Hz (the A string on a guitar), the threshold is about 40dB higher than at the midrange. The 10kHz range, corresponding to the upper "brightness" harmonics of a sound, is about 20dB higher than the mids.

In addition, there's a wide variation between individuals. The figures given are only a starting point, a guide to the ear's variations with frequency.

Threshold Shifts

As mentioned above, the ear can be overloaded by exposures to loud sounds. The threshold of hearing can be shifted upwards, sometimes permanently. Often, though, the effect is temporary. The shift can be as much as 40dB for a very short time if the sound level has been 80dB or more; it can be as high as 10dB for long periods. There also may be shifts in pitch (pitch being our subjective perception of frequency).

If you listen to loud music for any length of time, you'll have noticed without doubt that the high frequencies ("treble") appear to be reduced. Everything sounds slightly duller. This effect usually goes away in time, but threshold shifting of this magnitude must surely indicate an abuse of hearing.

Loudness

Loudness is our subjective perception of sound intensity. Because we're largely unconscious of the complex workings of our hearing mechanism, we tend to think of loudness as being rather straightforward: turn up the stereo and it gets louder. Nothing to it.

In fact, our perception of loudness depends on both frequency and the level of intensity itself. The graph of equal-loudness curves demonstrates this. Each curve graphs the frequency and intensity that will produce the sensation of equal loudness to average listeners; the curves are based on a midrange intensity in steps from 0 to 120 phons (about the same as a decibel; see below). For example, at the threshold of audibility, OdB is the minimum only between 800 and 1500Hz. At 100Hz, the intensity must be raised about 40dB for perception to occur.

At an intensity of 60dB, there is only about a 10dB difference between 100 and 1000Hz for equal loudness, and at 100dB there's hardly any difference. Note that there's a consistent dip around 3 to 4kHz in every curve, indicating that the ear is so sensitive in this area that the intensity must actually be *reduced*.

The Phon

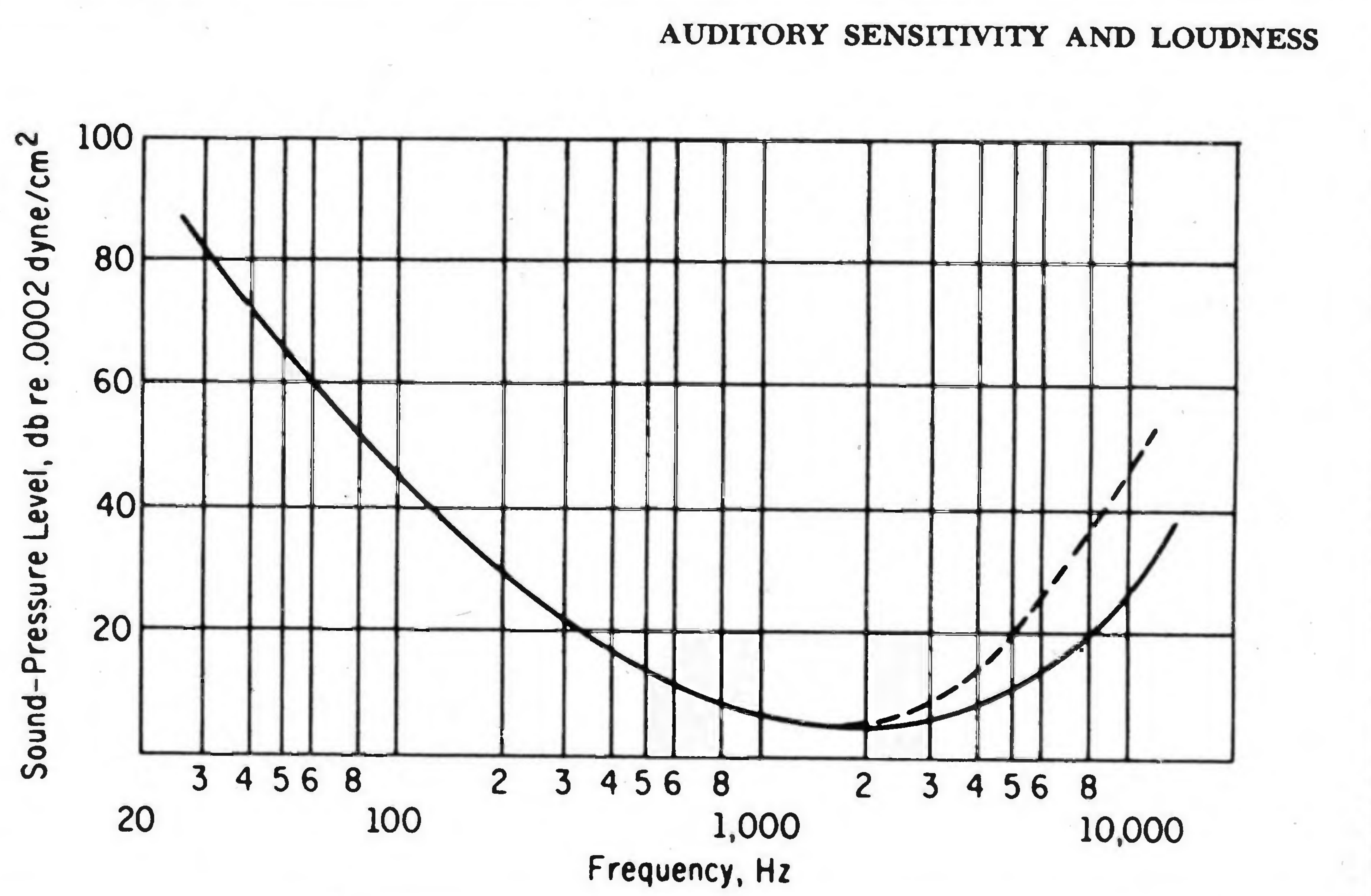
Not a unit you run across every day, the phon is used to designate loudness levels. It might be said to be to loudness as the decibel is to intensity (audiologists will cry that I've oversimplified things – the proper subjective unit is the *sone* – but we're close enough).

If a number of different tones all intersect the 50 phon contour at the same point, they all have the same loudness, regardless of the actual intensity or frequency.

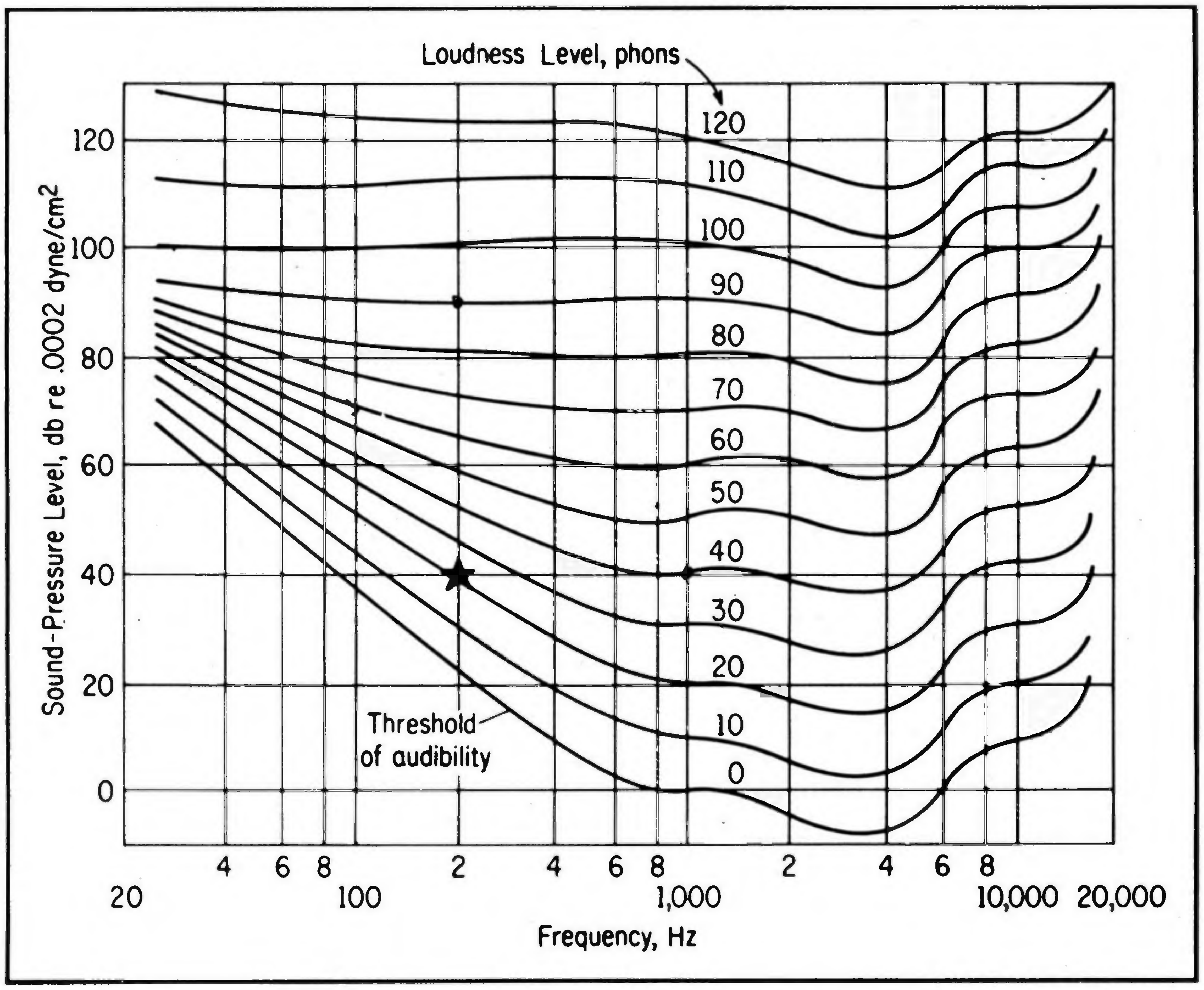
As an illustration of how complicated it can all get, and why I won't bother splitting hairs between phons and sones, imagine a huge cathedral organ playing a chord at the same loudness as say, a flute or piccolo. We just *know* that the organ is louder, and will swear blind that it is, despite all the physical evidence to the contrary. Perhaps it has to do with the harmonic content, or perhaps there are subjective factors that just refuse to hold still for physical measurements.

The Loudness Control

The equal-loudness curves illustrate the function of the hifi loudness control. If you're listening at 100 phons, the curve is fairly flat: an intensity of 100dB produces equal loudness pretty much across the frequency spectrum. If the neighbours bang on the wall and



The sensitivity curve based on average hearing. The vertical axis is sound intensity in decibels, with OdB representing the threshold of hearing. The horizontal axis is in Hertz.



Equal loudness countours. Each curve is based on a midrange intensity of a certain level; the curve then shows how much intensity is required to produce equal loudness at other frequencies (Intext Publishers).

you drop the level to 60 phons, a glance at the curve would indicate that a bass note of 100Hz falls an extra 10dB in loudness, as does a 10kHz treble frequency. In other words, dropping the volume has a drastic effect on the perceived frequency response; it's like turning down the bass and treble as well.

To compensate for this, the manufacturers of stereo amps add a loudness control. Usually it's a simple switch, though expensive units might have an adjustable potentiometer. In theory, the loudness control is supposed to boost the bass and treble if you turn the volume down, and cut them if you turn it up.

In actual practice, the poor loudness control is used more as an effect to get a thick, boomy sound. Since the great majority of popular music is electronically doctored to an enormous extent, I don't suppose it makes much difference if you add even more exaggeration to already exaggerated sounds. If you listen to acoustic music, however, it can be a bit painful when guitars sound like double basses. Ah, to each his own.

Volume

What then of volume? The word implies loudness levels, but as we've seen, the volume control on your stereo is really an intensity control. The "volume" is supplied by your ear/brain interpreting physical quantities. It's of interest to note that the word never appears on professional audio equipment; the label is usually "level",

Pitch

Pitch is to frequency as loudness is to intensity. The usual frequency range given for the ear is 20Hz to 20kHz, but like the previous measurements, this is just a generalization. Some people can hear to 25kHz or more, and some cut off at 10kHz. The ear's high frequency response diminishes with age and can be affected by illness or long exposure to loud sounds (though it's remarkable how the brain compensates — most will swear that nothing has changed).

Our sense of pitch is not as ill-behaved as our sense of loudness. By and large, pitch and frequency are locked together and are not affected quite as much by intensity levels. There are graphs available which show that subjects listening to pure tones report that tones below 500Hz sound lower in pitch with increasing intensities, and sounds above 3000 appear higher. Still, we don't often listen to pure tones for enjoyment.

There is a scale of pitch using a unit called the *mel*. This unit replaces the Hertz when it comes to subjective measurements. For example, if a listener hears a 1000Hz tone (given a mel value of 1000) and when asked to choose a tone of one-half the pitch, he may well pick 400Hz (many people will). The 400Hz tone is then given a mel value of 500, because it appears to be one-half the pitch, or one octave down.

There is one practical application of this phenomenon when it comes to music. The majority of musical instruments are designed by acoustical rules, and the designers don't worry about pitch versus frequency, largely because most instruments have a limited range of fundamental frequencies. When it comes to pianos and organs, however, the great obtainable range means that the very highest and very lowest notes will not sound true if they are tuned according to theory. We'll be looking into this theory in a future issue, but for now, we can say that keyboard tuners have to adjust the extreme notes at both ends to compensate for this drifting apart of pitch and frequency. It's probably safe to say that the pitch/frequency problem arises so seldom that we can ignore it for most purposes.

Response to Tones

Highschool experiments pointed out that two tones identical in frequency and phase (i.e., peaks and valleys occurring at exactly the same time) will add together; the amplitude of the resulting wave is the sum of the individual amplitudes. Similarly, the result of two tones identical in frequency but 180 degrees out of phase is a tone with an amplitude equal to the difference of the individual amplitudes. Such exacting conditions of frequency and phase tend to happen only under laboratory conditions. It's unlikely that two musicians could hold their pitches that closely, though it might happen with synthesizers.

A much more likely occurrence is two tones that are similar but not identical. In this case, the result tends to be the formation of *beats*, a pulsation in

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amplitude equal to the difference between the two; for example, a 267Hz tone and a 260Hz tone would produce a beat note at seven times per second.

Obviously, two tones far enough apart will be heard as separate tones; from listening to an orchestra we know that we can distinguish a vast array of tones and tonal colours (though it often takes training to improve this facility). If the two tones are fairly close together, say 400 and 600Hz, we can often detect sum and difference frequencies of 200 and 1000Hz. Of course, this depends greatly on the tones themselves; we might hear the phenomenon with two flutes, for instance, but not with a kazoo and a flute.

Electronic technicians may point out the fact that sum and difference tones result when tones are passed through a non- linear system; i.e., the system introduces a distortion which results in the creation of tones in the output not present in the input. The harmonic series generated (which we'll be covering in more depth) results in any extra sounds that we hear. The non- linearity as far as music is concerned may be the ear itself; as we've seen, there is a variation in our perception of intensity and frequency as these parameters themselves change.

It would be an interesting experiment to take two tuning forks 100 or 200Hz apart and see if the sum and difference tones can be heard. The sum tone is said to be more difficult to hear.

If you have a guitar handy, you can try this. Finger an E on the second fret of the fourth string and pluck this note together with the open A or fifth string. Listen carefully for the difference tone; try sounding the notes separately and then together until you can detect it. What you're hearing is the difference note resulting from the interval of a fifth; the E (164.8Hz) minus the A (110Hz) gives a resultant of 54.8Hz. This is a very low note, one that you would associate more with the bass or the organ, so its amplitude is not all that high coming from a guitar body or guitar amplifier. Don't worry if you can't perceive it; it's no reflection on your talent for music or acoustics. It often takes a lot of practice to separate the familiar musical sounds into their constituent parts, or even some of them.

In the next article, we'll be examining how the ear hears complex sounds, and we'll touch on basic acoustics, looking at phenomena like sound location, echo, reverberation, and other spatial effects.

Sources: most of the information in the first two instalments comes from these books, all highly recommended for a good read as well as references:

College Physics, Weber/Manning/White, McGraw-Hill

Music, Physics and Engineering, Olson, Dover Publications

Sensory Experience, Christman, Intext Educational

Oxford Companion to Music, Scholes, Oxford Press

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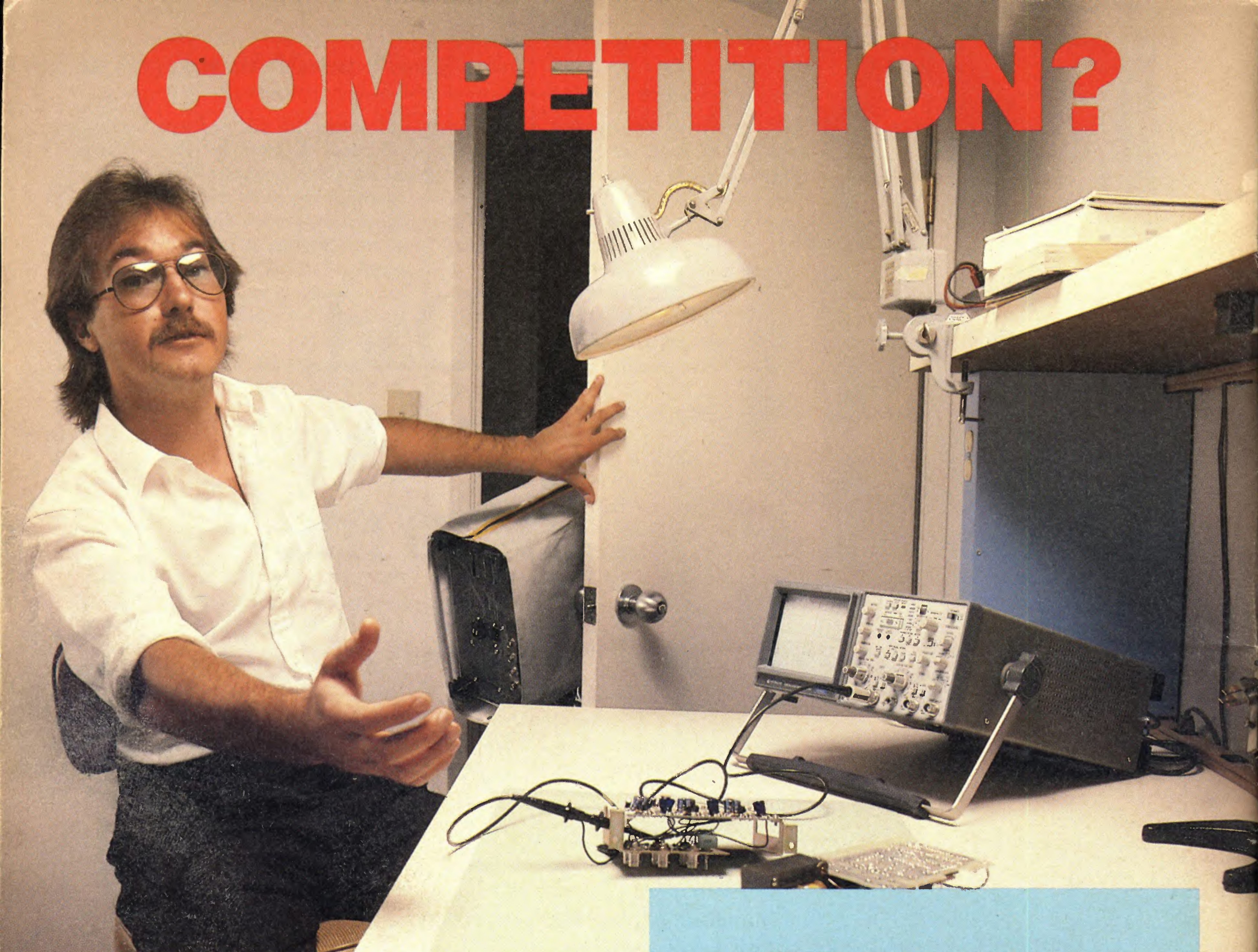

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