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## G.S.R. MONITOR

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SIX PAGE

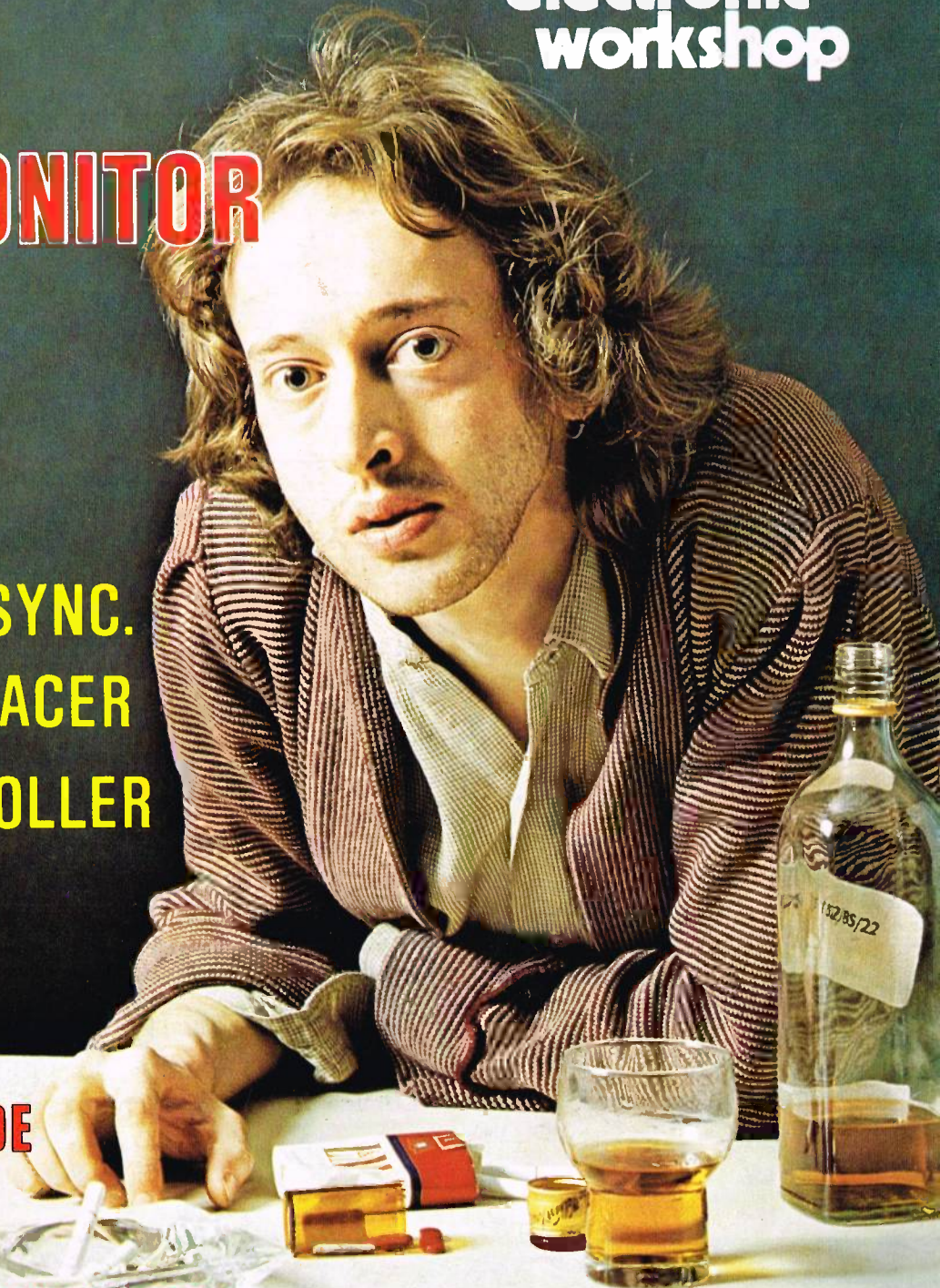
## MULTIMETER GUIDE

CHOOSING A METER

A BASIC

## DIGITAL SOUND SYNTHESIS

SYSTEM





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## PROGRAMMABLE TRAFFIC

It may not be long before your favorite radio traffic reporter will be able to accurately forecast, in minutes, how long it will take you to reach your destination — and even suggest alternate routes based upon shorter travel times.

Bob Benedetti, an investigative reporter for CFCF television in Montreal, Quebec, and former helicopter-based traffic reporter, has developed a method of accurately predicting traffic movement by using a tiny hand-held programmable calculator.

Throughout 1975, Benedetti was providing to his listeners extremely accurate forecasts of times to different destinations. This accuracy was hardly based upon intuition. Cradled on his lap in the helicopter was a Hewlett-Packard programmable pocket calculator. In his pocket were five magnetic cards, each the size of a stick of chewing gum, upon which Benedetti had recorded a series of traffic flow estimation problems.

Hovering over a section of highway, Benedetti would clock the passage of cars through a predetermined length of road. Programming the calculator by inserting a magnetic card corresponding to the task, Benedetti would then key in the test distance, time measurement and distance to the destination. The calculator would provide the travel time in minutes.

Says Benedetti, "In my initial tests, I tried using a simple four-function calculator, but the constant repetition of the same problem was just too difficult while trying to keep my eye on the road

below me. The programmable HP calculator allowed me to develop programs in my spare time and simply enter data into the machine when I needed it.

Since leaving his position as a traffic reporter, Benedetti has further improved his traffic monitoring programs as well as used the calculator for such diverse needs as real estate and income tax. He is presently offering the traffic monitoring programs to interested reporters.

## NEW TECHNOLOGY USED

Two new Motorola products have recently been announced, they are a series of r.f. power transistors and a precision voltage reference brief details of each are given below.

The new r.f. power transistors extends r.f. power output capabilities to 80 Watts in the 100 to 500 megahertz range.

The devices are designed for broadband operation as Class A, AB, B and C transmitter amplifiers in u.h.f. communications equipment operating from a 12-28 Volt power supply.

The stable 2.5 Volt reference source, type number MC1403/1503 has been designed for critical instrumentation and D-A converter applications, the low-cost monolithic circuit features a maximum output voltage variation of only 1% (+25mV) and a typical temperature coefficient of 10 ppm/°C.

Laser trimming of resistive networks as a routine process during normal manufacture provides a high yield to a very tight tolerance specification.

This chip also represents the first utilization of a p-channel J-FET in a

## MICRO-68 KIT

After two years production of the Micro-68 computer San Diego Electronic Product Associates has announced kit form availability. Cost is U.S. \$385.00 complete with power supply and cabinet. The Micro-68 uses the industry standard 6800 microprocessor which is now manufactured by Motorola, AMI, Fairchild, Hitachi, and Thomson CSF.

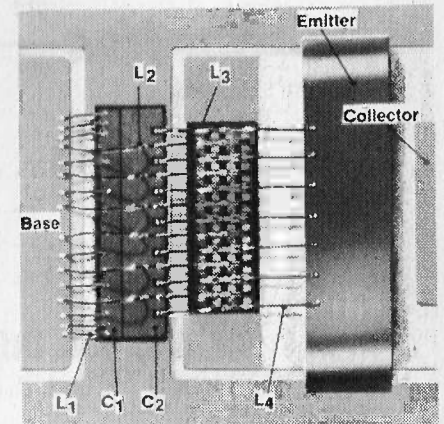
The kit comes complete with a 16 key hexadecimal keyboard and six digit hex display. Sockets are provided for 768 words of RAM (128 words supplied with kit).

The following commands are part of MON-1, inspect and change, load users program, run users program, insert break points, save stack, vector interrupts, sixteen bits of I/O are provided to the side connector, and the main bus is available at the front connector. Full bus buffering provisions are provided on the board. A piggy-back teletype/CRT/Audio Cassette Adapter is available.

The Micro-68a is fully compatible with the Micro-68b for later upgrading into a larger system.

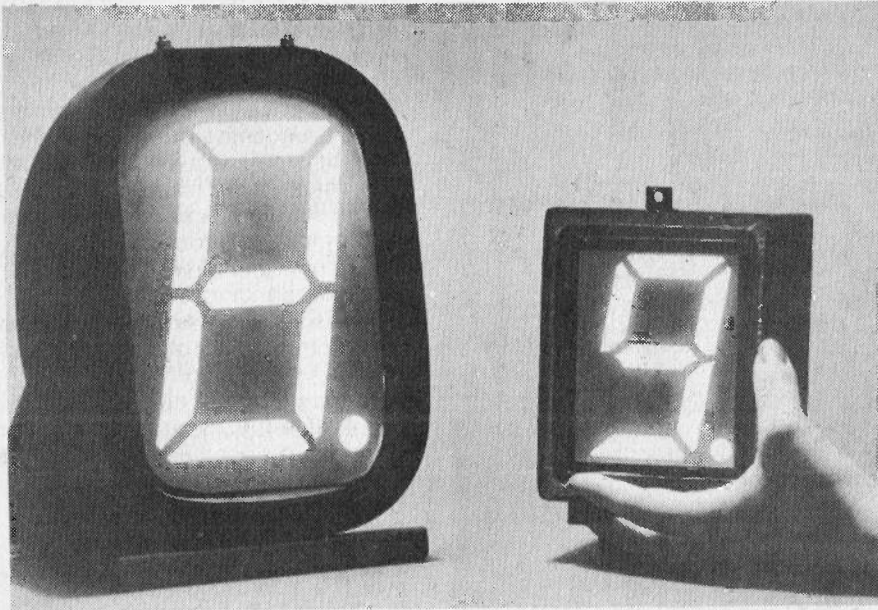
For additional details contact: *Electronic Product Associates, Inc., 1157 Vega Street, San Diego, CA 92110.*

linear integrated circuit at Motorola (a relatively new production technology). Ion implantation is the technology responsible for this capability.



Looking more like a hybrid integrated circuit than a discrete transistor, Motorola's newest line of UHF power amplifier devices features double tuned input matching networks to multiple transistor array in order to achieve broadband operation — 100 to 500 MHz — with power output as high as 80 Watts.





99.998%. Because of complex timing relationships within logic circuitry, conventional service techniques using oscilloscopes and voltmeters are not adequate to easily locate faults to the component level.

The 5004A checks operation of microprocessor-based products where data streams are long and complex. It recognizes and displays a unique hexadecimal number (signature) associated with each data node in the circuit. Signatures displayed on the 5004A are compared with correct signatures printed on the schematic of the circuit under test. If a wrong signature appears, the technician is guided, with the help of service notes, through the circuit to the faulty component.

Products must be designed with signature analysis service in mind. However the cost of designing signature analysis into a complex microprocessor-based product can, in most cases, be more than offset by savings in production costs because of fewer printed circuit boards and fewer interconnections required.

Information on this product is available from *Inquiries Manager, Hewlett Packard (Canada) Ltd., 6877 Goreway Drive, Mississauga, Ontario.*

### BIG BRIGHT CHARACTERS

A high brightness character display tube which operates on a new principle has been developed by the English Electric Valve Co., Ltd., The display can be manufactured in sizes up to about 25 inches diagonal and can display special characters.

The 7-segment tube operates in a manner similar to a cathode ray tube. A front faceplate carries a high luminance, high-efficiency phosphor energised by a flood beam of electrons from the cathode. Placed between the cathode and the faceplate is a seven-segment mask with a lead from each of the segments brought out separately so they can be switched.

It is extremely easy to switch from one character to another at electronic speeds, only low level driving logic is required.

The displays come in colours of Green, Red, Blue, White and Yellow.

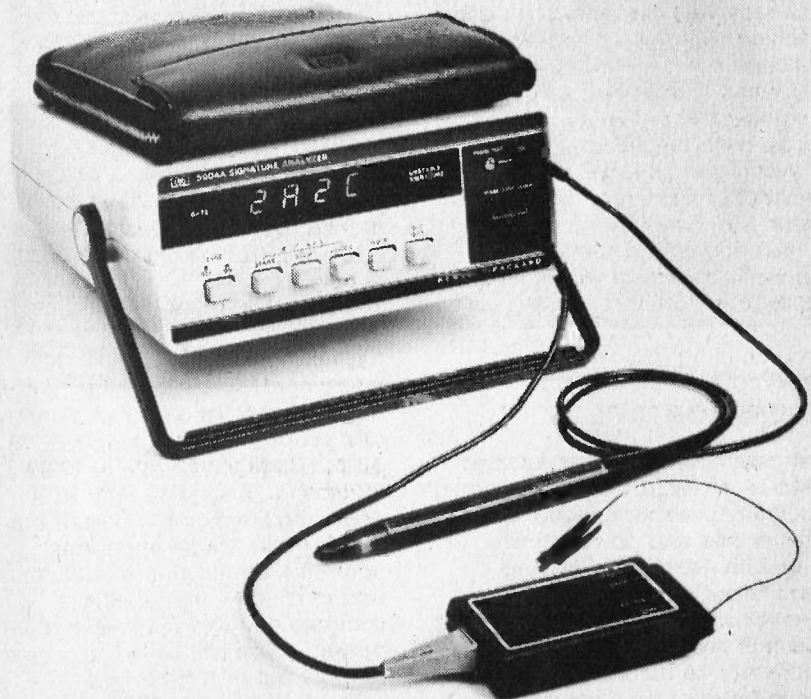
### JUST ASK ME!

LED or liquid crystal? The question may never occur in the future, not because one will supercede the other but because your watch may be able to tell you the time — literally. No, its not science fiction, a patent has recently been granted to Intersonics of New York for a battery operated watch that combines a numerical display with a speaker and bubble memory that enables the watch to tell you the time in any language the buyer requires.

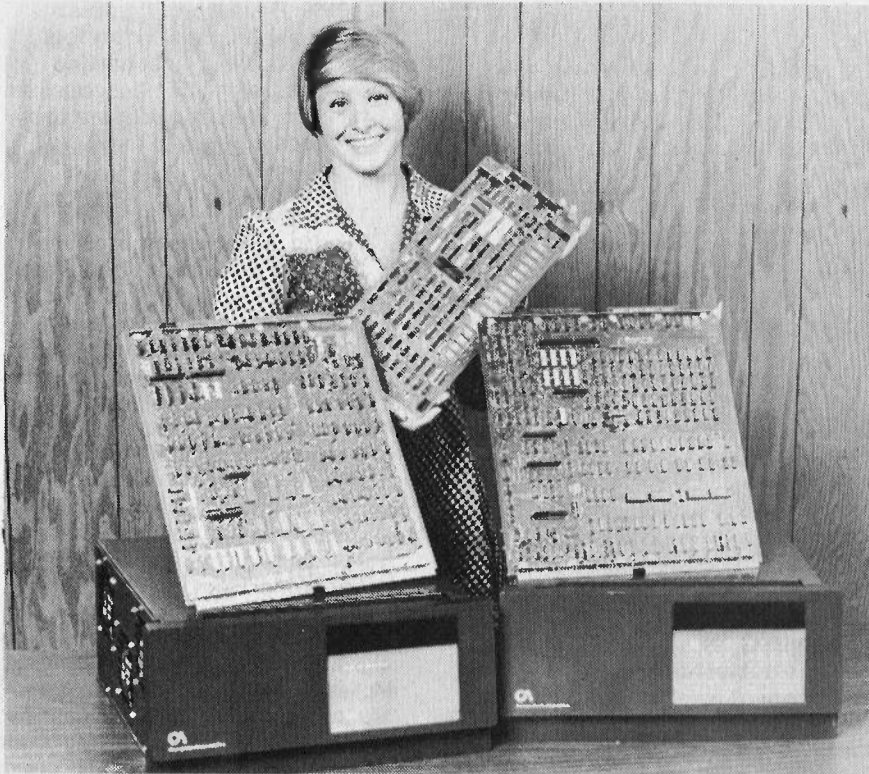
### SIGNING IN

Field troubleshooting to the component level of microprocessor-based products designed with Hewlett-Packard's new signature analysis service technique is greatly simplified with this new service instrument.

Called the Model 5004A Signature Analyzer, the new instrument is designed specifically for use in signature analysis servicing. It locates faulty bit streams in microprocessor-based circuits with an accuracy of







*Naked Mini — 4 Family claimed to put an end to compromise in minicomputer selection by OEM and volume users through design modularity, upward and downward compatibility, exclusive input/output flexibility, and a very broad range of memory products. The Family computers are LSI 4/30, LSI 4/10, and LSI 4/90 (left to right). Packaged versions come in operator's (left) or programmer's console.*

## MINI-FAMILY

A new minicomputer family that is claimed to shatter previously existing price/performance barriers, while broadening the range and level of products available to OEM and volume user markets from a single source has been announced by Computer Automation, Inc.

The new line of NAKED MINI-4 computers includes three processors with a kinship based on total compatibility of hardware and interchangeable software.

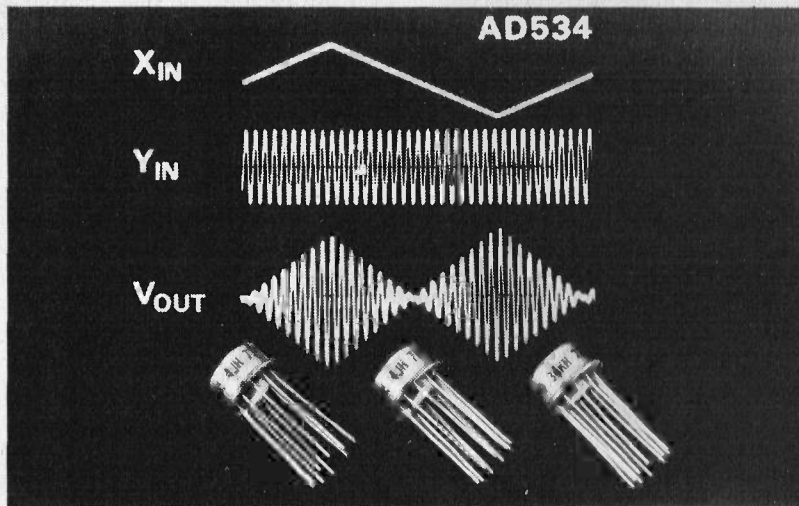
Highlighting the new family is the LSI 4/10, a full 16-bit minicomputer on a board priced as U.S. \$645. The LSI 4/10 incorporates two custom n-channel MOS chips, 4k words of RAM memory, and 4 input/output channels, all packaged on a half size (7½ x 15 inches) circuit card. On-board battery backup is an available option.

## LASER TRIM

A new laser-wafer-trimmed monolithic multiplier (AD534) is available in five versions including the AD534L which features a maximum multiplication error of  $\pm 0.25$  per cent at 25°C, claimed to be the lowest of any IC. The new AD534 is the latest in a series of monolithic multipliers from Analog Devices; it requires no external components, and features feed-through of no more than 0.12% on the X input and no more than 0.10% on the Y input. Maximum offset voltage is 10mV; Nonlinearity is 0.1% maximum, and noise is only 1mV r.m.s. over a wide (10Hz to 5MHz) bandwidth.

"Since we use a unique, automatic laser-trimming technique that allows us to trim resistors at the wafer level, we can offer our customers the performance of a module with the package and price advantages of an IC."

Devices are available through *Tracan Electronics Corp., 558 Champagne Drive, Downsview, Ontario M3J 2T9.*



ANALOG DEVICES AD534 MONOLITHIC, LASER-WAFER-TRIMMED MULTIPLIER.

## RADIO CONTROL

A communication has recently been received from the Department of Communications regarding frequencies and power allowed on model control bands. Having subbed out the sub-paragraph references the basic information is that it is proposed to amend the Radio Act, to increase from 4 to 8 the number of frequencies in the

72MHz band used for radio control. The proposed bands being 72.08, 72.24, 72.40, 72.72, 72.76, 72.80, 72.84 and 72.96 MHz. And to prescribe a maximum power limit of one watt for "radio apparatus" operating on all v.h.f. model control frequencies. — this does not instigate any change in allowable power. There will be no change to the 27 MHz or 53MHz bands.

The Department invites manu-

facturers, users, associations, groups and interested persons to make any submissions they wish concerning these proposed regulations. Submissions should be addressed to the Director, Operations Branch, Telecommunication Regulatory Service, 300 Slater Street, Ottawa, Ontario, K1A 0C8 and should be post-marked not later than 60 days after the date of this notice (dated May 6, 1977).



# GSR MONITOR

Learn to reduce tension levels with ETI's galvanic skin response meter. Design by Barry Wilkinson — editorial by Jan Vernon.

THE BEST WAY TO START EXPERIMENTING with biofeedback is to use a galvanic skin response monitor, a device which measures changes in skin resistance. In September 1976, we published an article which covered the background and theory of biofeedback and we discussed the various types of biofeedback instruments which are available. The GSR monitor is the most simple to use, the electrodes can be simply attached to the fingers with Velcro straps and the technique of using the machine can be quickly learned.

Skin resistance changes with changes of emotional state. When tension increases, the skin resistance falls — when tension decreases there is an increase in skin resistance. (Some biofeedback instruction manuals speak in terms of conductivity rather than resistance and state measurements in mhos, and the meter we use gives a positive deflection for decreasing resistance.)

The connection between skin resistance and tension is not fully understood. Tension affects sweat glands and with the changes in the sweat glands there is a change in the membrane permeability of the skin and this change in permeability is the major cause of changes in electrical activity.

Almost a century ago, a scientist named M. Ch. Fere discovered the resistance of the skin to a small electric current changed in response to aroused emotions. This information has since been used in various ways; one obvious example is the polygraph, or lie detector, which responds to the tension generated when a person is lying.

It was not until 1961 that Dr. J. Kamiya, whilst conducting a series of experiments with brain waves, found that with feedback his subjects developed the ability to produce 'Alpha waves' at will.

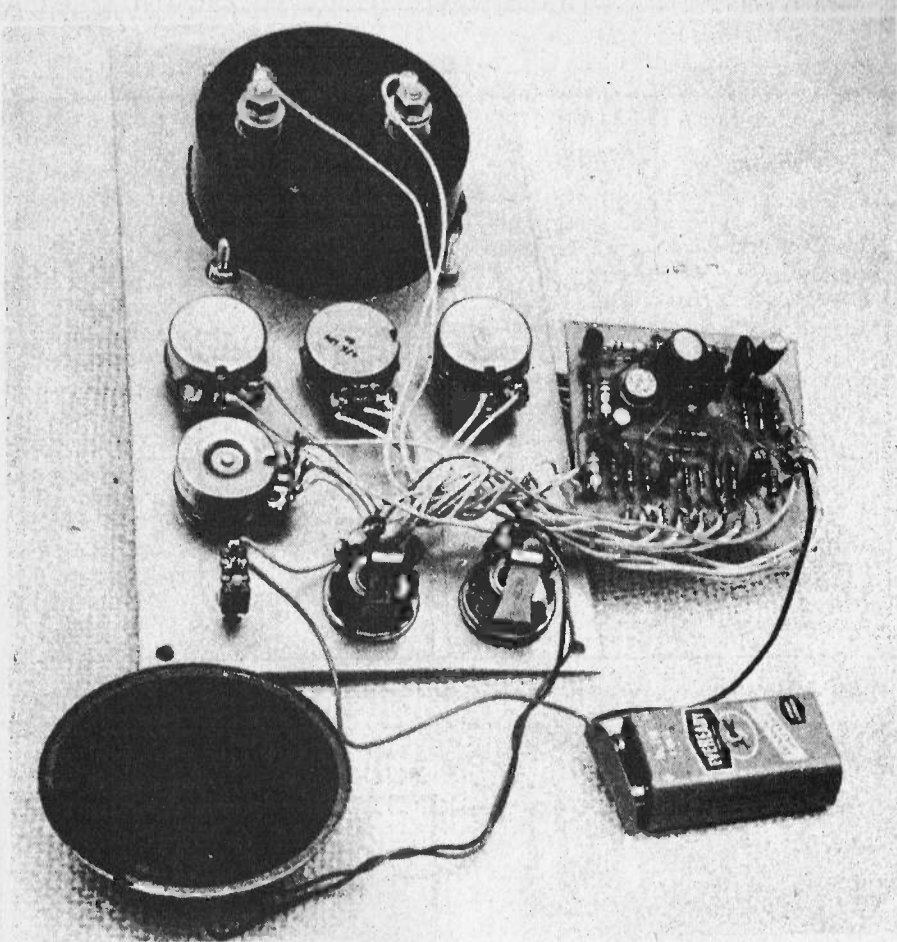
Dr. Kamiya's experiments created considerable interest and started investigations into whether other bodily functions could be brought under conscious control. Since that time it

has been demonstrated that with feedback it is possible for people to control heart beat, blood pressure and temperature — all previously considered to be automatic bodily functions mostly beyond conscious control.

Of course it should be stated that various mystics and yogis have previously demonstrated this type of ability but the fascination of biofeedback is the speed and ease with which this type of control can be learned.







Biofeedback has exciting medical possibilities. GSR machines are being used by therapists for the treatment of many disorders related to tension. The average person will find a GSR machine mainly useful for relaxation training. With the GSR machine it is possible to recognise tension and learn how to decrease tension levels. This type of training is so effective that the machine quickly becomes unnecessary.

However not everyone suffers from tension. The biofeedback machine can be a fascinating toy to play with. Discovering that you can bring an internal bodily function under conscious control with the same ease that you can twitch your nose is most interesting. And of course you can then perfect this ability just as you perfect your ability at a game like tennis. For many people this is reason enough to build this machine.

### What you do with it

The ETI GSR monitor has an on/off switch, a sensitivity control and fine and coarse level controls. The machine also has a connection for headphones.

To start relaxation training, you'll need a comfortable chair, low lighting and no distractions. Taking any type of

drug can interfere with your ability to relax. This applies to alcohol and cigarettes. Attach the electrodes to the fleshy part of the first two fingers on one hand — firm but not too tight (the non-dominant hand is recommended). Set the sensitivity control to minimum and the 'fine' level control to mid-range. Turn the volume control to minimum. Now you have to set the level with the 'coarse' level control (when the sensitivity is set low the 'fine' level control need not be used). Start with the 'coarse' control at full anticlockwise and turn it up until the meter needle starts to move. Carefully set the needle to mid-range. Now the instrument is set-up in its minimum sensitivity position.

Having mastered setting up with minimum sensitivity try to set the GSR monitor with the sensitivity set half-way. It will require delicate adjustment of the 'coarse' level control. Now the effect of the 'fine' level control can be seen. This control enables you to set the level on a high sensitivity setting.

Although the GSR machine measures minute changes in skin resistance, the level of skin resistance varies considerably from person to person so a wide range of settings is provided.

Now turn up the volume and observe that the meter reading is accompanied by a medium pitched tone. (A convention has developed to link high-pitched tone with tension increase and low pitched tone with a decrease in tension.) Now you relax and bring the tone down and the needle back to zero.

How? Basically you are supposed to find this out for yourself. After watching the needle for some time you will notice it move up or down. Something has happened to cause a change in your skin resistance. You would be barely aware of what had caused the change but aware enough to try to reproduce the effect. Eventually your awareness grows and so does your ability to control your tension. Many people find that relaxation of the stomach muscles makes the difference. It varies from person to person.

There are several relaxation techniques which work very well. One method is to tense all the muscles of the body as hard as possible, hold them tense for several seconds then very deliberately relax all muscles. There are several books and cassettes available which describe relaxation techniques. The techniques work. The biofeedback machine makes it possible to monitor progress.

As you relax, the needle on the meter and the audible tone will decrease. When the needle reaches zero, reset it again towards the fsd end of the scale and repeat the procedure.

Twenty minutes is the recommended time for a training session. After about one or two weeks of daily relaxation training, it should be possible to produce the same level of relaxation without using the machine and the machine can simply be used occasionally as a reference.

### Construction

Construction is not critical although we recommend you use the pc board as it makes things easier. Before soldering the components made sure they are orientated correctly. External wiring can be done with the aid of the overlay-wiring diagram.

### Probes

Probe construction and electrical contact is not nearly as critical as with most other biofeedback machines.

Commercial GSR machines use a pad of soft steel wool which is held firmly onto the finger by a short length of Velcro strap (Band-Aids work fine!). However, any method ensuring a firm contact between probe leads and the



# GSR MONITOR

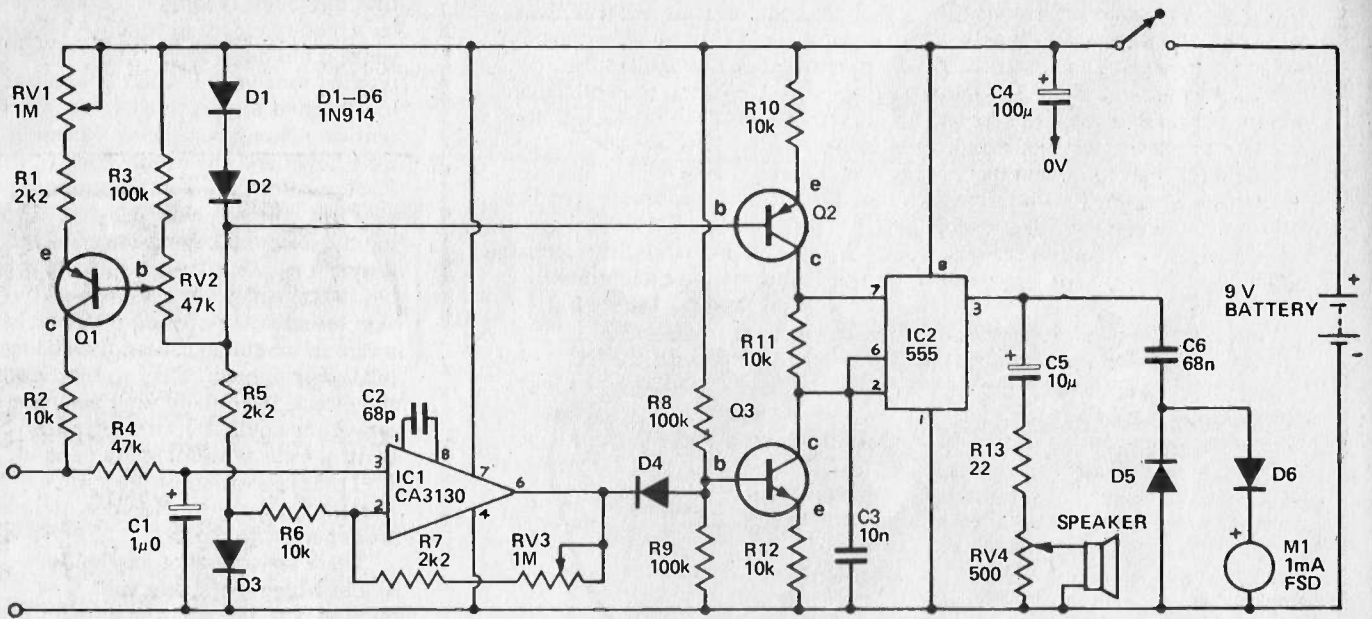
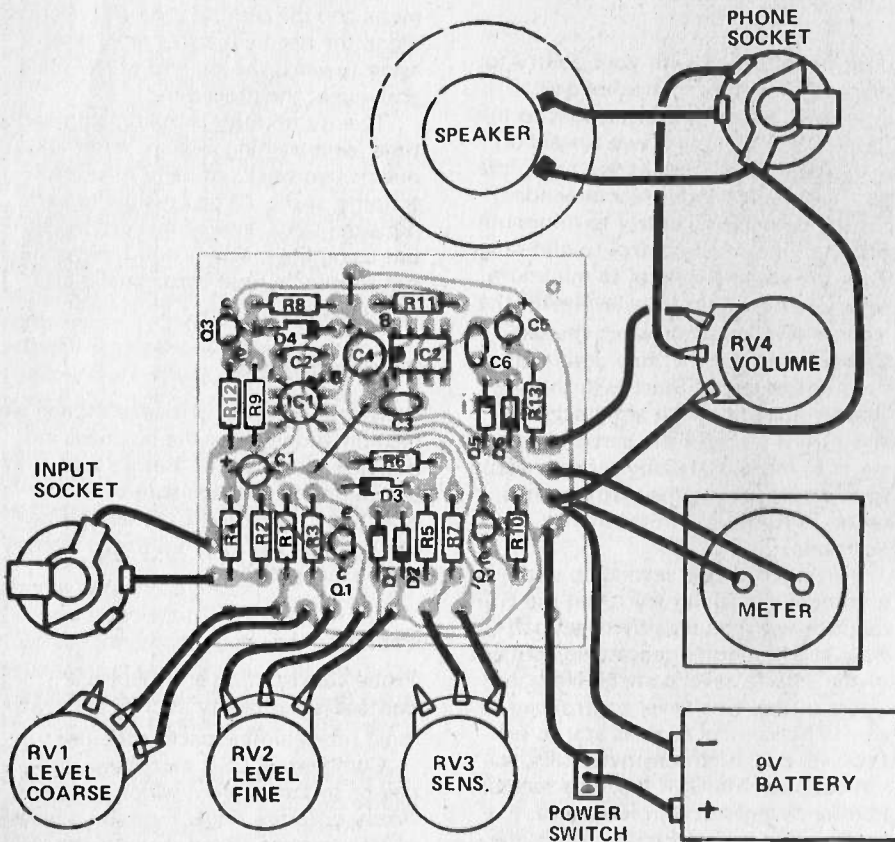


Fig. 1. Circuit diagram of the GSR monitor.

Fig. 2. Component overlay and interconnection diagram.



## PARTS LIST

Resistors all 1/2 W 5%

R1	2k2
R2	10 k
R3	100 k
R4	47 k
R5	2k2
R6	10 k
R7	2k2
R8,9	100 k
R10-R12	10 k
R13	22 ohms

Potentiometers

RV1	1 M log
RV2	47 k lin
RV3	1 M log
RV4	500 ohm lin

Capacitors

C1	1 μ 16 V electro
C2	68 p ceramic
C3	10 n polyester
C4	100 μ 16 V electro
C5	10 μ 16 V electro
C6	68 n polyester

Semiconductors

D1-D6	Diodes 1N914
Q1,2	Transistors 2N3906
Q3	Transistors 2N3904
IC1	Integrated Circuit CA3130
IC2	Integrated Circuit NE555

Miscellaneous

- PC board ETI 546
- Meter 1 mA FSD
- Zippy Box 196 x 113 x 60
- Two phone jacks
- Four knobs
- Small speaker
- Six AA battery holder
- Pickup probes



## How It Works

This project measures the skin resistance and displays it on a meter. An audio tone gives an aural indication of the meter reading. The meter operates in reverse sense to a usual resistance meter: low resistance gives full scale (or high tone) and high resistance gives zero (or low tone). Skin resistance can vary over a large range but the variations studied in biofeedback experiments are small — so an offset is needed.

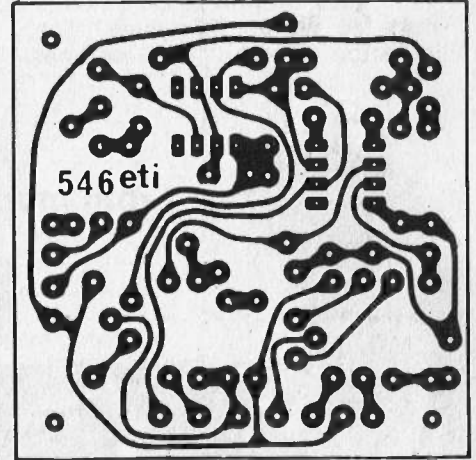
Transistor Q1 acts as a constant current source — the actual value can be varied over a large range by RV1 and over a limited range by RV2. These act as the coarse and fine level controls. This current is passed via R2 to the probes. The voltage developed across the probes is proportional to the skin resistance and is fed to the input of IC1. This amplifies the signal with reference to

0.6 V (drop across D3) and the gain is variable by RV3.

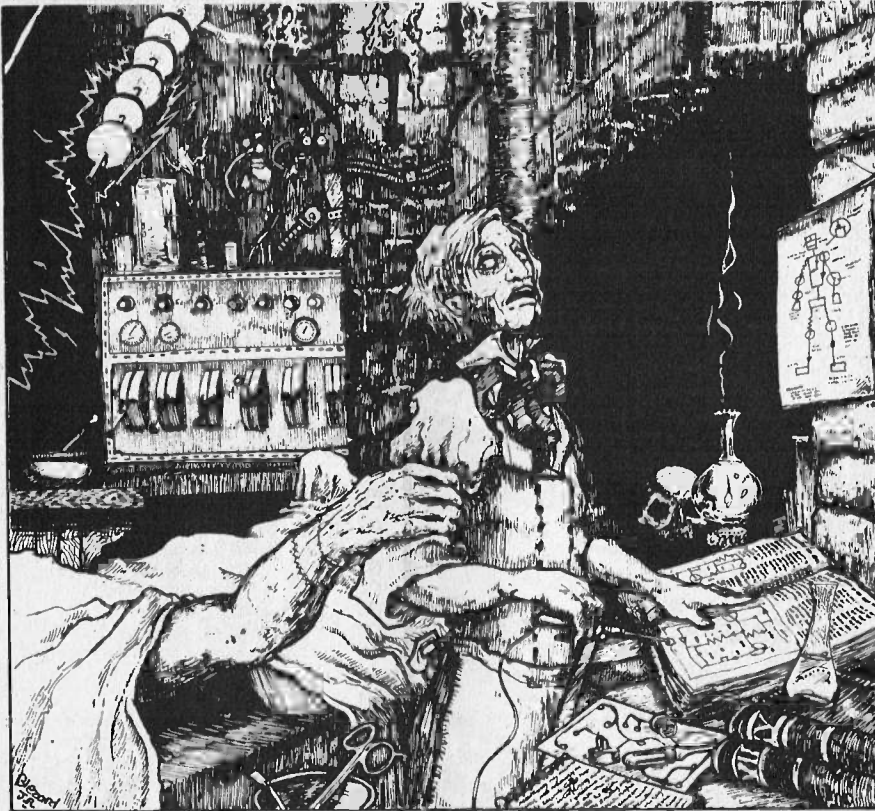
The second IC is an NE555 oscillator where Q2 provides a constant current (about 60  $\mu$ A) to the capacitor C3. When the voltage on C3 reaches 6 V the IC detects this and shorts pin 7 to ground, discharging C3 via R11. This continues until the voltage reaches 3 V at which point the short on pin 7 is released allowing C3 to recharge. The output of the oscillator is connected to a speaker via the volume potentiometer RV4 and the meter via C6 and the diodes D5 — 6.

We vary the frequency of the oscillator and the meter reading by robbing some of the current supplied by Q2 into Q3. In this way the frequency can be lowered and actually stopped. Transistor Q2 is controlled by IC1 completing the connection between the probes and the output.

fleshy part of the finger will do. One method which works very well is to bind tinned copper wire around a guitar finger pick (or solder to a steel pick). Two probe connections are of course required — one for each of the first two fingers.



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BY NOW, MOST of us are familiar with the music synthesiser which has provided us with the means of accurately imitating conventional musical instruments and also the ability to create fantastic new sounds — a feature amply demonstrated by many modern rock groups.

The question now to be asked is where do we go from here? The limitation of the conventional

synthesiser is that it is monophonic, i.e. only one note can be played on it at any one time. The obvious next step would be a polyphonic synthesiser, i.e. the capability of playing many notes simultaneously.

This presents us with problems if we are going to base the polyphonic system on existing monophonic designs, where control voltages are used to determine pitch, tone and volume.

The two usual methods of monophonic keyboard decoding are

shown in Fig. 1; 1(a) is merely a long chain of equal resistors, the output voltage being tapped off each node by its corresponding key, in 1(b) each key has its own potential divider. Both these configurations have the limitation that if two or more keys are pressed together the output voltage obtained is not representative of any required frequency and the oscillator will "mistune". It follows therefore that both these configurations are unsuitable for a polyphonic system.

**From monophonic to multiphonic**

# DIGITAL SOUND SYNTHESIS

The theory of a practical system  
By C.J. Gimson

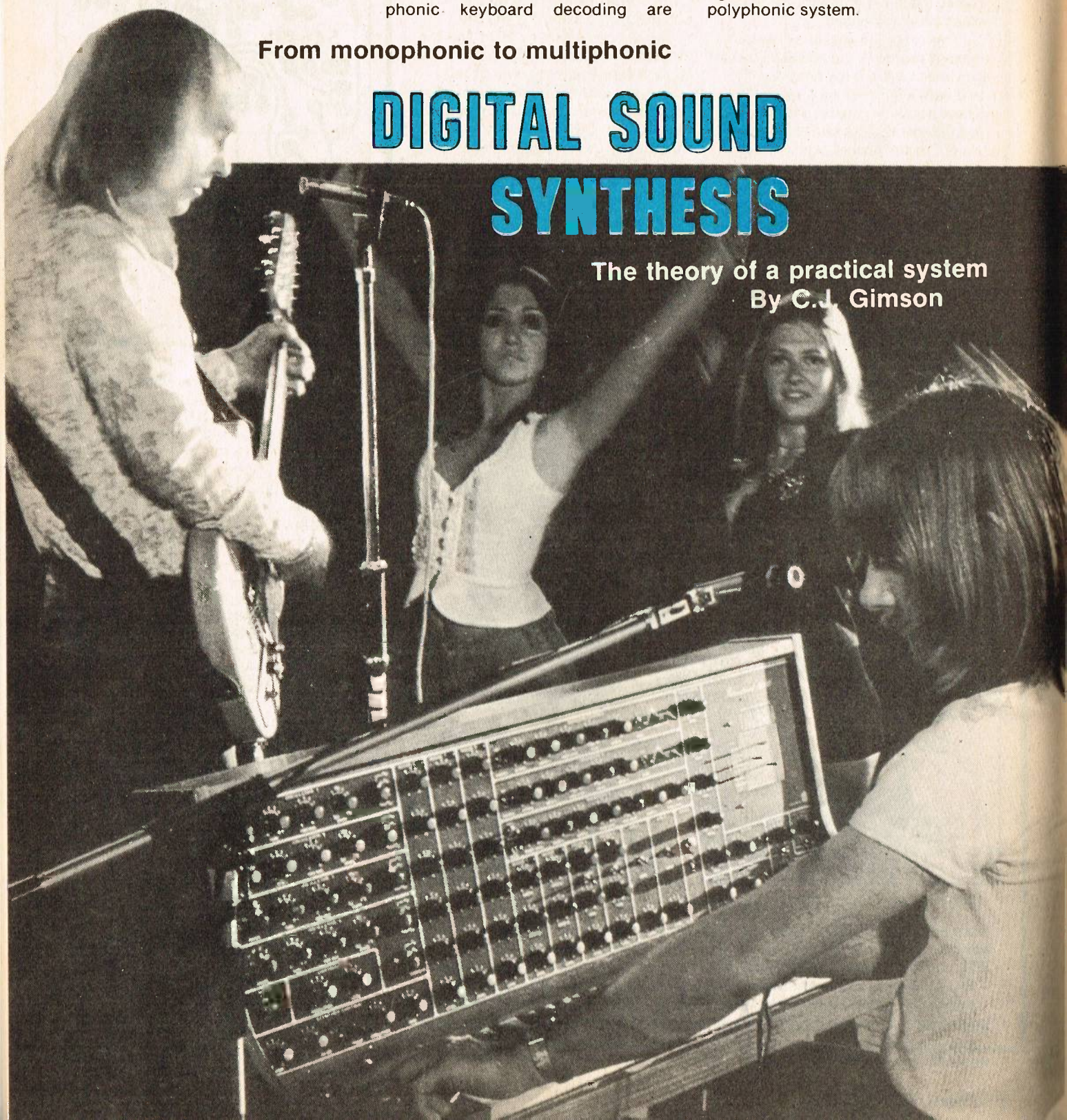






Fig. 1 Two methods of keyboard decoding used in the multiphonic synthesiser

For every note playable we need an oscillator, filter and a sound envelope shaper, therefore for a true polyphonic 4 octave system we would need 49 groups of oscillator, etc. — an incredible cost, most of which would be wasted since the average musician has only 10 fingers to play with.

Why not therefore design a system that enables you to play a limited number of notes (say 6) simultaneously. This is called a MULTIPHONIC system. Various digital techniques that could be used in the design of a basic multiphonic synthesiser follow. Why digital? A few of the advantages of a digital system are listed below.

- 1) Guaranteed stable over a wide temperature range (for standard TTL = 0-70 degrees C)
- 2) Minimum of "setting up" procedures, i.e. preset pot's etc.
- 3) Built in noise immunity and power supply ripple rejection.
- 4) Permits complex signal manipulation at extremely high speeds.
- 5) Using large scale integration (LSI) circuitry, hardware can often be reduced to just a few IC's. After initial development anyone who can solder can build complex circuits and expect them to work first time on applying power.
- 6) The inherent high speed of digital circuits permits multiplexing of complete circuits, i.e. it allows several different channels to "timeshare" one common circuit function. Thus system component count can be further reduced.

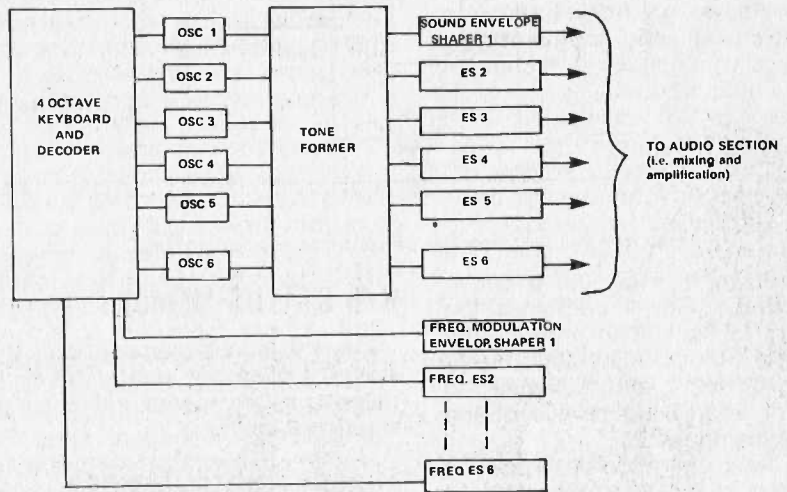


Fig. 2 Block diagram of a basic multiphonic system

Referring to Fig. 2 which shows the block diagram of a simple 6 note multiphonic system. It will be noted that, for ease of description, the system has been split up into four sections:

- 1) Four octave keyboard and decoder.
- 2) Oscillators.
- 3) Tone shaping.
- 4) Envelope shapers.

Detailed circuit description is deliberately kept to a minimum since it is the intention at this stage only to cover the techniques used in the system.

## SECTION ONE

The function of section 1 (the four octave keyboard and decoder) is to

select up to 6 keys that have been pressed simultaneously out of a possible 49 keys and output a binary code to each oscillator, corresponding to the required frequency. The circuit also provides the trigger signals to initiate the envelope shapers and frequency modulation envelopes (used to modulate the keyed note with a predetermined envelope). The outputs of the latter are "mixed" with the keyboard output before the binary code is outputted to the oscillator, i.e. in the decoder circuitry, not the oscillator circuitry.

To understand the operation of this rather complex circuit it is best to consider its operation in 3 consecutive phases A, B and C, one cycle comprising the three phases. The relevant circuitry for phases A, B and

Fig. 3a Keyboard decoder phase one block diagram

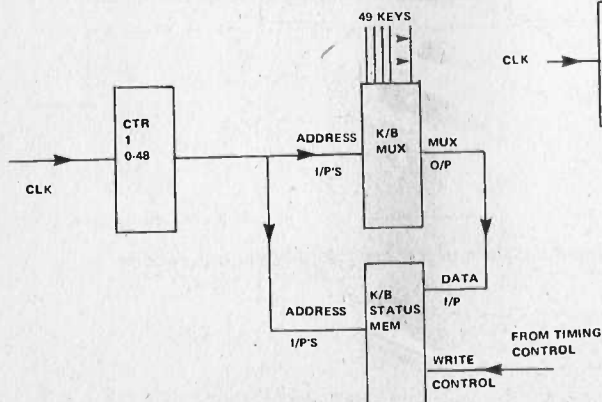
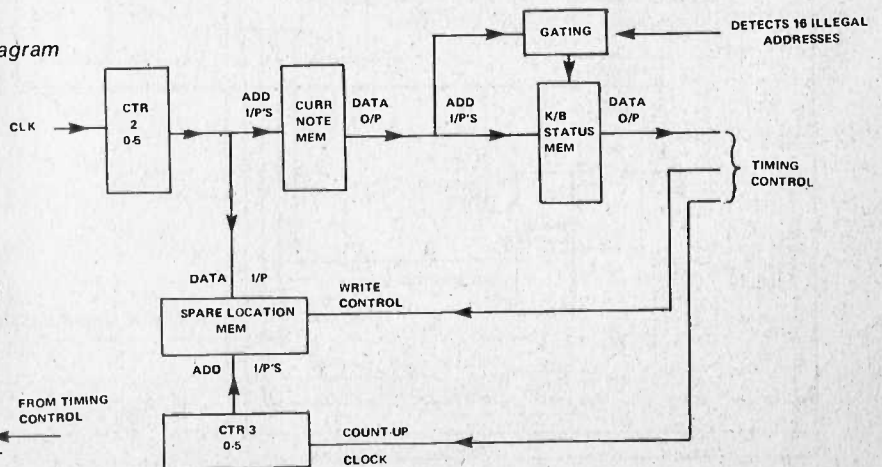


Fig. 3b. Keyboard decoder phase two block diagram



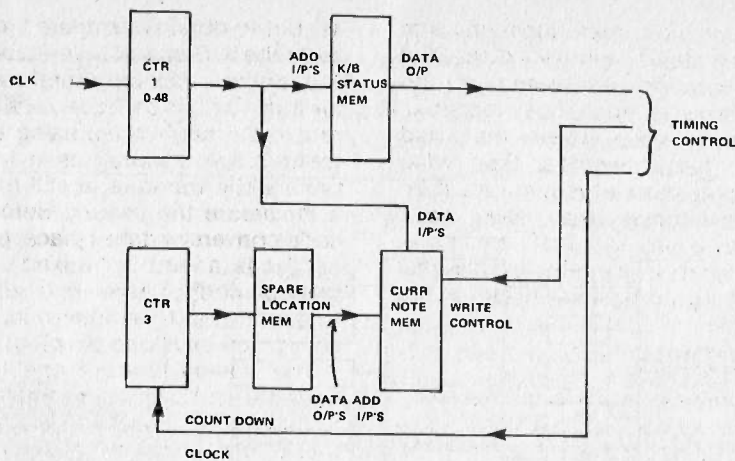


Fig. 3c Keyboard decoder phase three block diagram

C is shown in Figs. 3a, b and c respectively; Fig. 4 combines the circuitry of Fig's. 3 to produce the complete block diagram, multiplexer's (mux) 2 and 3 handle the different addressing modes of the various memories.

The basic operation of the circuit (Fig. 4) is to compare the keyboard (K/B) status of two consecutive cycles (one cycle equals one K/B scan), if a difference is detected it means that some keys have been released or new ones pressed or both, when this occurs the working memories are corrected accordingly.

### K/B STATUS MEMORY

The K/B status memory holds the status of all 49 keys during this cycle (later to be compared with the K/B status last cycle).

### CURRENT NOTE MEMORY

The addresses of any keys that were pressed last cycle are contained in the current note memory (the key address = the address of the K/B mux for each key = 0-48) the memory has 6 locations, one for each of the permissible note outputs, obviously

if 6 keys are not pressed, then not all 6 locations will be needed, the addresses of these "spare" or "empty" locations are stored in consecutive spare location mem. locations.

Referring to Fig. 2 which shows the block diagram of a simple 6 note multiphonic system. It will be noted that, for ease of description, the system has been split up into 4 sections:

- 1) 4 octave keyboard and decoder.
- 2) Oscillators.
- 3) Tone shaping.
- 4) Envelope shapers.

Detailed circuit description is deliberately kept to a minimum since it is the intention at this stage only to cover the techniques used in the system.

### PHASE ONE OPERATION

Phase one operation is to store present K/B status (Fig. 3a). Counter (Ctr) one counts through 0-48 addressing the K/B mux and the K/B status mem, the mux therefore scans the K/B and the status of each key (0=pressed, 1=off) is written into the mem (the mem address = key no, mem content = status). The circuit now switches to phase 2.

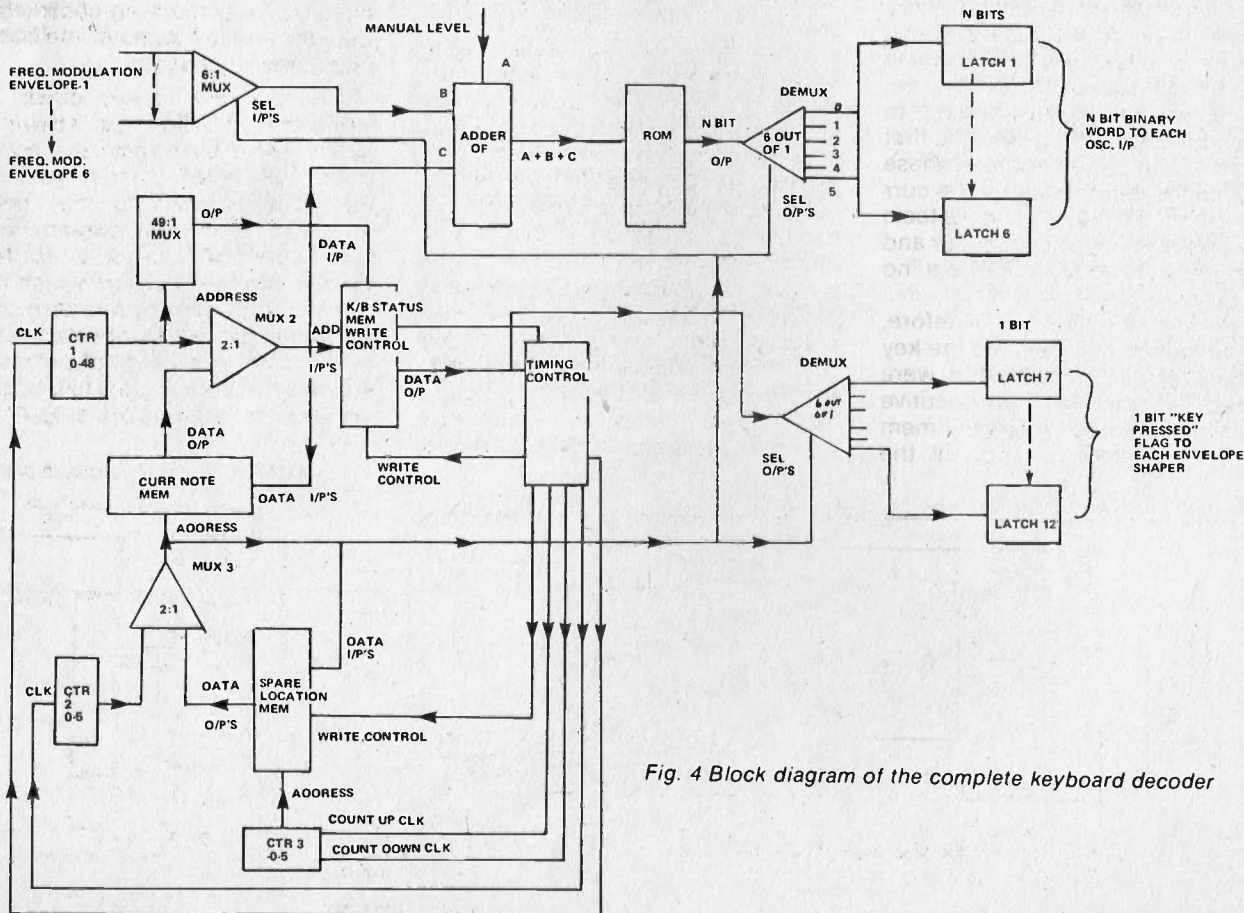


Fig. 4 Block diagram of the complete keyboard decoder



## PHASE TWO OPERATION

In phase two the circuit is arranged to compare note status's of present and past cycles (Fig. 3b). Ctr two counts through zero to five addressing the curr note mem, ctr three is initially cleared to zero, the output of the curr note mem (i.e. the key no's pressed **last** cycle) address the K/B status mem (which contain the K/B status **this** cycle) hence for each curr note mem location, if the K/B status mem output is low it means that that particular key is still being pressed and so the curr note mem contents at that location are still valid. If the status mem output is high however, it means that the key is no longer pressed, it follows therefore that the curr note mem location at which this occurs is no longer valid and is "spare" so the curr note mem address is stored in the first spare location mem location and then ctr three is incremented.

When this occurs the curr note mem contents (i.e. the old key but no longer pressed) remains in the mem until a new key no is written in its place. Each time the status mem is addressed, after its output has been inspected it is cleared at that location. This process repeats for all 6 curr note mem locations, the circuit then switches to phase three.

There are 49 keys therefore the key number is a 6 bit binary code, however 6 bits give us 64 states therefore 16 states are illegal, i.e. there is no key corresponding to those addresses. When power is first applied to the circuit some of these illegal codes might occur in the curr note mem, external logic detects these codes if they should occur and forces the status mem output to a "no note pressed" state.

At the end of phase two therefore, the curr note mem contains the key numbers of all the keys that were pressed for both the 2 consecutive cycles, the spare location mem contains the addresses of all the

spare curr note mem locations and since the status mem was cleared at every location addressed during phase two and since those locations addressed were notes that had already been detected, then what remains in the status mem must be any new notes that have been pressed, if any. All that remains in phase three is to detect these new notes and store them in any spare curr note mem locations.

## PHASE THREE

The curr note mem is addressed by the spare location mem which itself is addressed by ctr three, therefore the curr note mem must be waiting at one of its spare locations.

Counter one counts through 0-48 addressing the status mem, if a low is detected at the mem output, this indicates a new key so the status mem address (equals the key number) is written into the curr note mem, ctr three is incremented so that the curr note mem moves to its next spare location. At the end of ctr one's count the present cycle is completed and phase one of the next cycle starts. The timing during phase two with three keys pressed is shown in Fig. 5, it shows that if we monitor the status mem addresses and output during phase two, when the mem output is low, the mem address is the number of a key that has been pressed.

If we connect the status mem address bus and its output to the data inputs of a one to six demultiplexor and address the demux select inputs with the curr note mem address (ctr two output = 0-5) and latch the demux outputs, we will have done what we initially set out to do — detect and identify up to 6 keys that have been pressed simultaneously, the demultiplexed mem output provides 6 "key pressed" signals that are used to trigger the volume and frequency modulation envelopes.

But wait a minute — the key numbers increase linearly from 0 to

48, but to obtain a tempered musical scale the K/B output must increase in a logarithmic fashion, therefore some means of code conversion is required. This is done using a ROM (read only memory) as a look-up table while the data is still in serial form before the demux. Before this code conversion takes place, the K/B output is added or "mixed" with a manual control level and also the frequency modulation envelope (see section on envelope shaping).

The manual control enables the operator to "swing" the four octave K/B range anywhere in the 10 octave music spectrum by offsetting the ROM address by an equal amount for every note. The rom outputs are then fed into the demux and latched as before. These latches are updated every  $n$   $\mu$ S where  $n$  is the time to complete one cycle. ( $n$  is largely dependent on the mem and ROM access times).

## SECTION TWO — OSCILLATORS

A digitally programmable oscillator can easily be implemented using presetable counters as modulo-N dividers; Fig. 6a shows an 8 bit programmable divider made up of two 74193 presetable counters. Both counters are used in the count-down mode, the borrow of the least significant (LS) counter providing the clock for the most significant (MS) counter — see Fig. 6b of the borrow signal timing diagram.

The counters count down and when they overflow (i.e. attempt to count down past zero) the borrow output of the MS counter goes low, this is connected to the "preset inputs" pins of both counters hence the frequency control word N is loaded into the counters which then proceed to count down to zero again where the process is repeated and so on. Thus for every N clock pulses the MS borrow output goes low once, if we take the latter as the output then

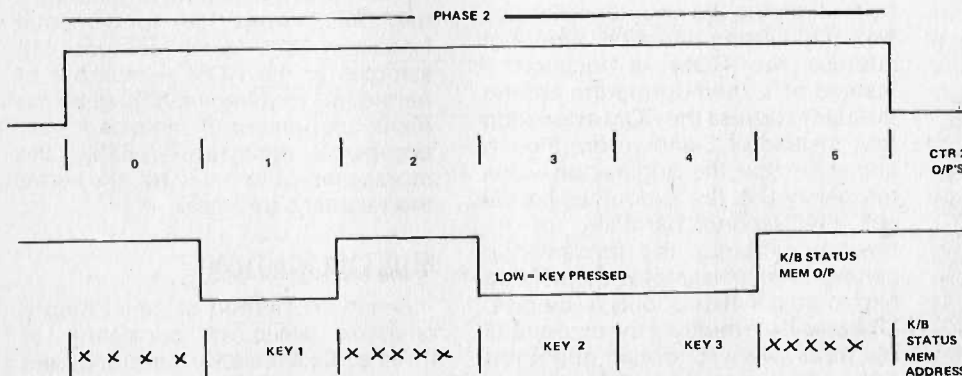
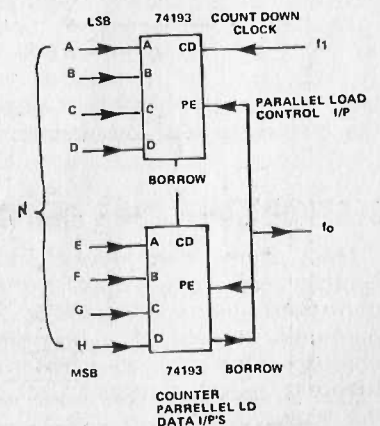


Fig. 5 Keyboard status memory timing diagram during phase two

XXXX = DON'T CARE

Fig. 6a Eight bit programmable divider



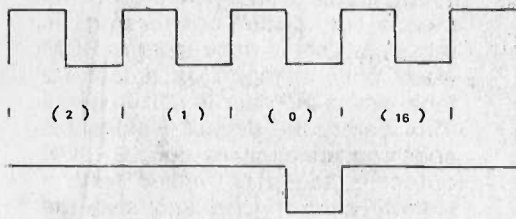


Fig. 6b Borrow output timing diagram for 74193 up/down counter

its frequency will be  $f_0 = f_i/N$  and is in the form of a narrow pulse train.

For  $N=8$  bits  $1 \leq N \leq 255$ , the range of control of output frequency depends on the range of  $N$  and hence the number of counters used, e.g. three 74193's gives us an  $N$  of 12 bits therefore  $1 \leq N \leq 4096$ .

An extension of (a) is the phase locked loop freq. divider/multiplier (b) shown in Fig. 6c. There is plenty of literature available on phase locked loops so we will not describe the circuit except to say that the VCO output frequency =  $n_1 f_i/n_2$ . This method is obviously more expensive than (a) since you need two dividers plus the phase lock loop circuitry.

Note: We mentioned in section one the need for a ROM to convert the linear K/B number to a logarithmic one, it should be obvious that different conversion tables are required for (a) or (b).

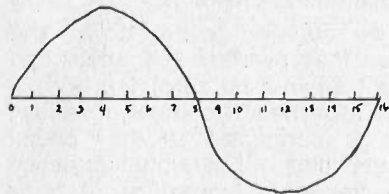


Fig. 7a Fundamental sine wave split into 16 samples

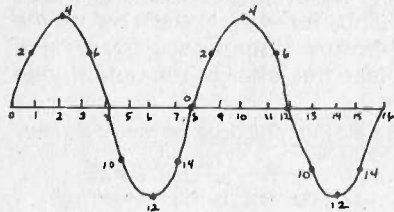


Fig. 7b Second harmonic obtained by multiplying ROM addresses by two

### SECTION THREE TONE SHAPING

Most of the conventional music synthesizers today use voltage controlled filters to modify the harmonic content of a predefined complex waveform (e.g. a square or triangular wave) in order to achieve the required tone. To use a direct

digital equivalent would of course require a digital filter, however a programmable filter over the frequency range required would be quite complex and very expensive.

In this multiphonic system we are abandoning this method of synthesis (called subtractive synthesis) and adopting an **additive synthesis** method, i.e. start with a sine wave at the fundamental frequency, generate the harmonics required and add all the waveforms together to produce the final complex waveform.

### ADDITIVE SYNTHESIS

The following section demonstrates the principles involved in a digital implementation of additive synthesis.

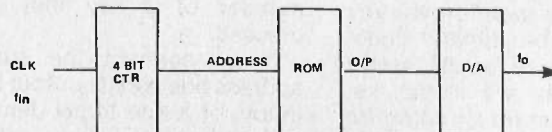


Fig. 8 Generation of a "quantised" sine wave

A sine wave split up into 16 samples numbered 0-15 is shown in Fig. 7a, if the sine wave amplitude at each sample point is stored in 16 consecutive locations of a ROM and the ROM addressed by a four bit counter counting continuously (Fig. 8), then the output of a D/A convertor connected to the ROM outputs would give a "quantised" version of the original sine wave.

If we now modify the ROM address by multiplying the counter output by two (i.e. during the first time slot address the ROM at location 2 instead of 1, then during the second time slot address the ROM at location four instead of 2 and so on) Fig. 7b shows us that the original sine wave frequency (i.e.  $f_{in}$ ) is doubled i.e. we get the second harmonic of  $F_0$ , however whereas the fundamental consisted of 16 samples the second harmonic consists of only 8 samples. Likewise if we multiply the ctr outputs by three we will obtain the third harmonic, containing  $16/3$  samples/cycle. The number of samples/cycle

= number of samples in fundamental harmonic number.

The act of quantising a sine wave produces undesirable frequency components as the spectrograph in Fig. 10 reveals. Besides the fundamental frequency we also get components derived from the sampling frequency  $F_s$  i.e. frequencies  $F_1 = F_s - F_0$  and  $F_2 = F_s + F_0$ . The effect is very much like that of a suppressed carrier waveform of frequency  $F_s$  "modulated" with a signal of frequency  $F_0$ ,  $F_1$  and  $F_2$  being the resultant sidebands, this effect also occurs at harmonics of  $F_s$  by lower in amplitude e.g. we obtain frequencies of  $2F_s - F_0$  and  $2F_s + F_0$  etc. Since all these frequencies are higher than the fundamental they can be removed with a low pass filter.

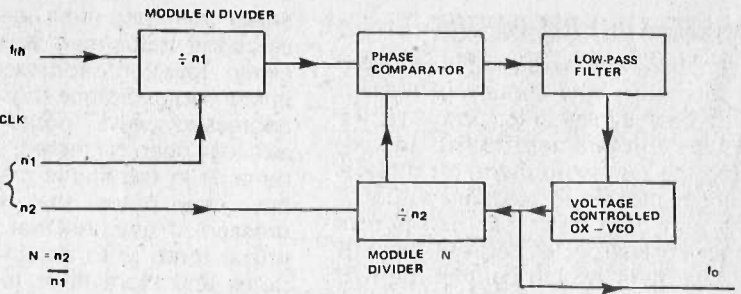
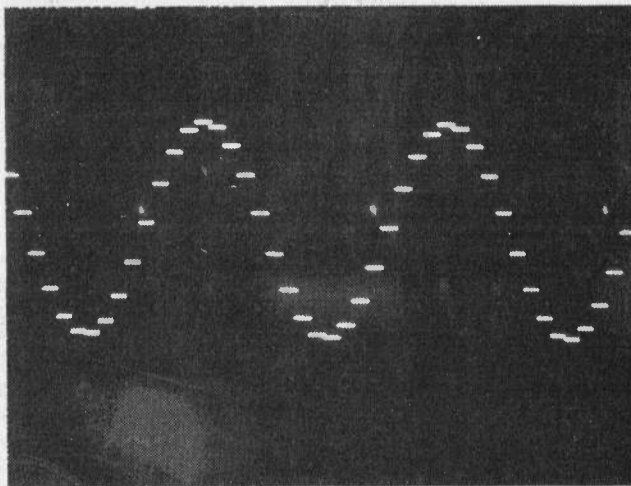


Fig. 6c Basic phase-locked-loop frequency multiplier

### MULTIPLICATION

A simple method of generating a complex waveform consisting of three equal amplitude harmonics and the fundamental is shown in Fig. 9. this would be quite effective but





A "quantised" sine wave formed by sampling a sine wave of frequency  $F_0$  at a sampling of frequency  $F_s$ .

wasteful of ROM, since all the ROM's are identical it would be much cheaper to use one ROM for the sine wave values and time sequence the harmonic values and time sequence the harmonic additions, the multiplications to modify the ROM address can also be performed in a ROM.

The concept of multiplication using a ROM is quite simple, if we want to multiply two 2 bit numbers together there are only 16 possible answers (since there are four possible multiplier values and four possible multiplicand values) therefore if we make the multiplier two bits of a ROM address and the multiplicand the other two bits of the address we end up with four bit address giving us 16 ROM locations. All we have to do is program each ROM location with the correct answer for that particular address; e.g. four bit address = 11 decimal = 1011 = (10)(11) = 2 X 3 = 6 decimal = 0110 therefore location 11 is programmed with 0110. This principle can be extended for any no of address bits and gives us a fast method of multiplication (or division).

Referring to Fig. 11 the ctr outputs

provide a four bit address field to the X ROM the harmonic number provides a two bit address field to the same ROM which is thus programmed with the result of the multiplication of the two fields.

### AMPLITUDE CONTROL

The sine wave ROM is modified this time with the introduction of a harmonic amplitude control, this enables us to multiply the original sine wave sample value by a constant (K). Thus by using a different value of K (via mux A) for each harmonic we can control the amplitude levels of each harmonic — a four bit K address field gives us 16 levels of amplitude control.

The ctr counts through its 16 states as before, each sample of the

waveform consists of four "passes" of the circuit.

**Pass One** The accumulator (acc) is cleared, the harmonic number two field = 00 (X1) therefore the X ROM outputs the required amplitude value which is added to the 0 (the contents of the acc) and the result stored in the acc. **Pass Two** The harmonic number is incremented to 01 (X2) i.e. X ROM outputs = ctr outputs X2, the sine wave value is multiplied  $K_2$  and the result is added to the previous result (contents of acc) and the new result stored in the acc.

This process is repeated for **Passes three and four**, each time the acc being "topped up" until after the fourth pass it contains the total contributions of all four frequency components, this value is then latched in the output buffer and outputted to the D/A convertor. The whole process is then repeated for the next sample and so on.

Each sample therefore consists of 8 ROM accesses plus the propagation delays of the latches, mux and the adder, using high speed logic and bipolar ROM's the time/sample  $< 1$  microsecond. If we limit our instrument top freq to 8kHz then the highest ctr clock period =  $125/16 \mu S$  or  $8 \mu S$ . Since one sample takes  $1 \mu S$ , the output buffer will contain the same result for 8 samples at the highest input freq (because the ctr

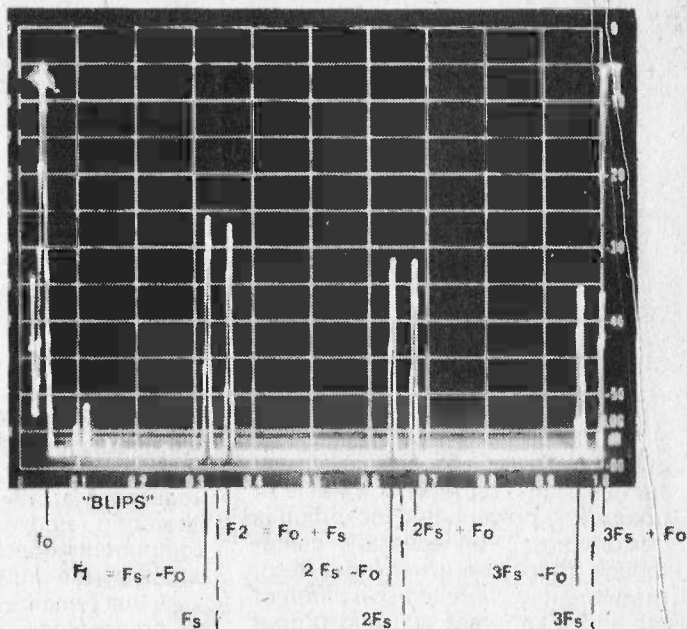


Fig. 10 Part of the frequency spectrum of the sine wave of the previous photograph. Note the "suppressed carrier double sideband" effect at the sampling frequency and its harmonics. Also note the "blips" after  $F_0$ , these are harmonics of  $F_0$  that are also produced by quantising a sine wave, they are low enough in amplitude to be ignored if an 8 bit binary number is used to represent the sine wave amplitude at each sample.

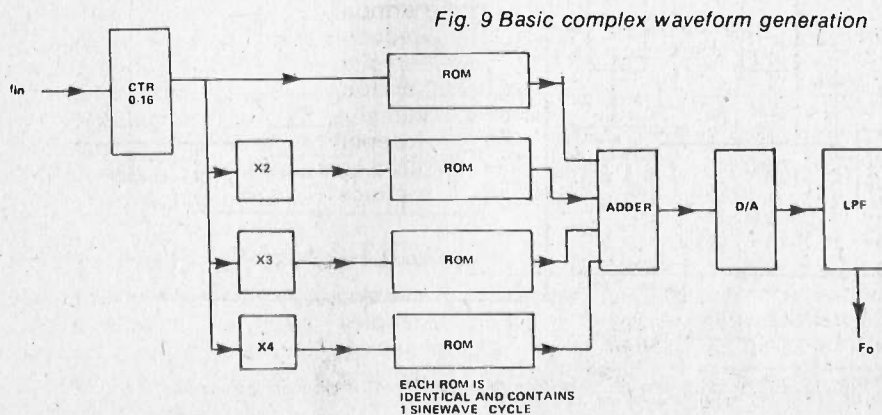


Fig. 9 Basic complex waveform generation

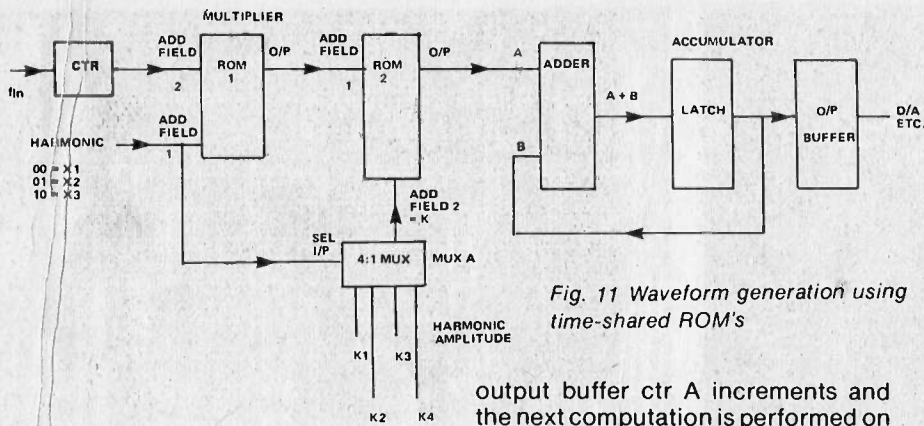


Fig. 11 Waveform generation using time-shared ROM's

output will be the same for 8 samples), this represents a waste of computing power since the circuit is performing 7 unnecessary calculations (more at a lower input freq), therefore if we were to use a different ctr and a different acc and output buffer, then we could do up to 7 different samples before the original buffer needed updating. Since our instrument uses 6 oscillators we can therefore use one tone former circuit for all 6 channels. This leads us to the circuit of Fig. 12 which is the circuit of Fig. 11 modified to enable us to process six inputs.

Counter A controls the multiplexing of the 6 counter inputs and the demultiplexing of the corresponding acc's and output buffers, ctr B provides the two bit harmonic number field and thus counts through four states for each sample. The ROM addressing etc. is the same as that in Fig. 11 except that after the result of pass four is stored in the

output buffer ctr A increments and the next computation is performed on a different ctr using a different acc and output buffer. Each output then undergoes a D/A conversion and is filtered to remove the unwanted freq. components that have been introduced by the multiplexing.

All that remains now is to define the sound envelope of the note and we will have seen some of the digital techniques available to the music synthesiser designer.

## SECTION FOUR

The sound envelope shaper defines the rate at which the volume of the note rises, its "hold" time or duration and the rate at which it decays.

In our instrument, there are three ways that we could approach the problem:

- (1) Since the envelope shaper is one of the cheapest sections of a conventional voltage controlled synthesiser we could use the same method (i.e. voltage control) here duplicated for each channel. Referring to Fig. 13 a voltage control envelope is fed into one

input of an analogue multiplier, the AC waveform whose amplitude we want to control is fed into the other input, the output will be the AC waveform amplitude modulated by the envelope. Thus the multiplier functions as a voltage controlled amplifier.

(2) Another approach would be to use a digital control envelope and modulate the AC waveform before it goes through the D/A convertor. (i.e. at the tone shaper output buffer outputs o/p's) A digital envelope can be constructed from up/down counters e.g. 74193's, a four bit version is illustrated in Fig. 14.

Initially assume the ctr is at zero with the "decode zero" output low, this in turn will disenable the count down clock input, the key is not pressed so the count up clock will also be disenabled. The ctr will start to count up (the "decode zero" output will go high after the first clock pulse but the count down clock input will still be disenabled by the key pressed signal) when the ctr reaches its maximum value the "decode 16" output will go low, disabling the count up clock.

The ctr will then stay in this state until the key is released, the count down clock will be enabled and the ctr will ramp down until it reaches zero again the "decode zero" output disenables the count down clock, the ctr is now back in its original state.

## CLOCK RATES

Both clock rates can be controlled externally giving the operator control over both attack and decay rates. By cascading several ctr's the resolution

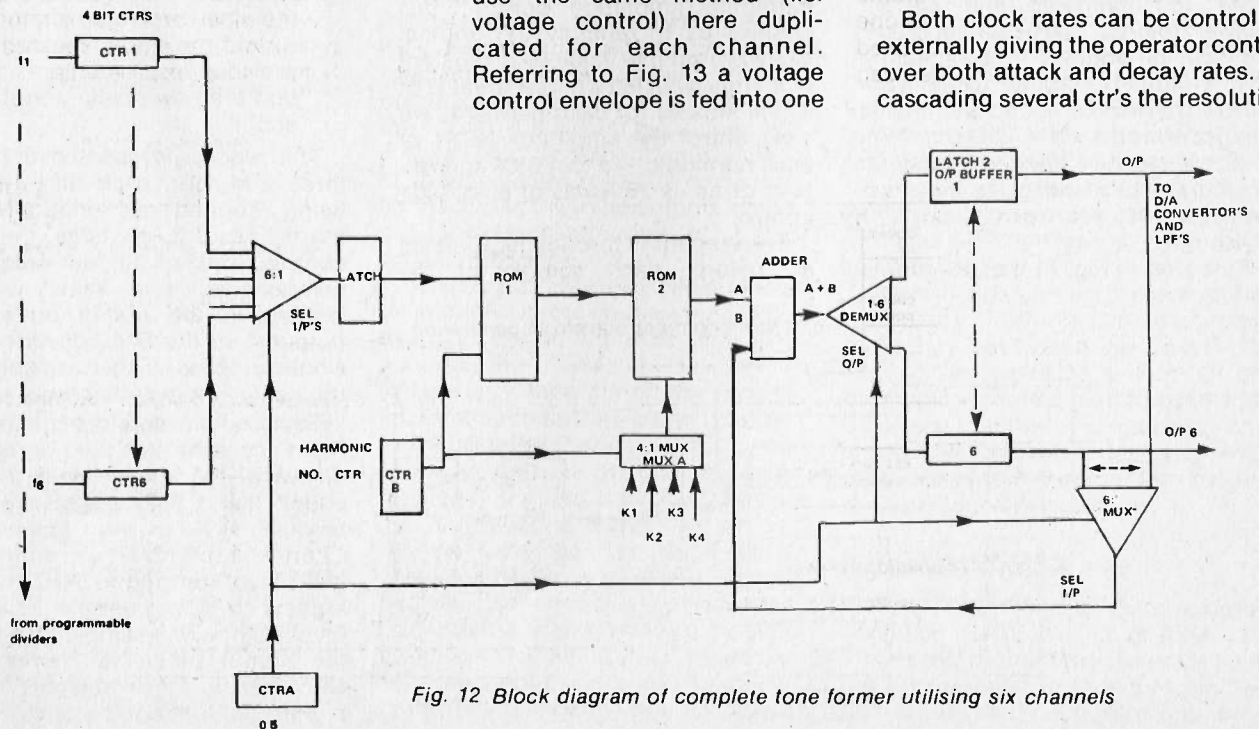
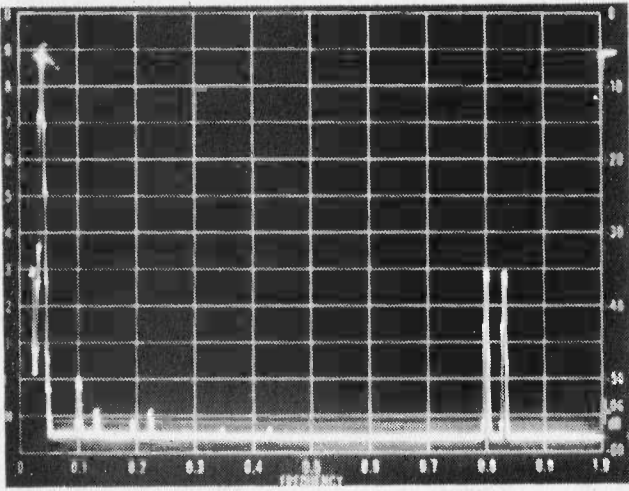
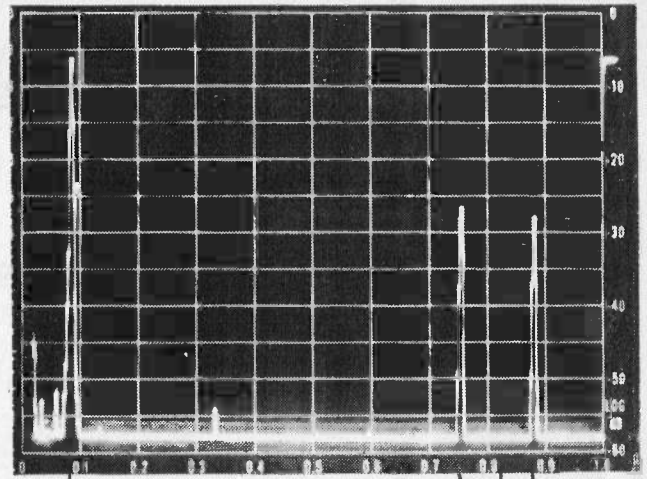


Fig. 12 Block diagram of complete tone former utilising six channels





The fundamental component and the first "set" of "sideboard" components. If the sampling frequency is kept constant and the fundamental frequency increased.



This shows how the component  $F_s - F_0$  and  $F_0$  move closer together until, at the limiting frequency of  $F_s = 2F_0$  they will coincide.

of the envelope can easily be expanded. Such an envelope can also be used as the K/B freq modulation envelope, as for the envelope shapers, one is required per note output, see Fig. 4. The six envelope outputs are fed into a six to one mux which is addressed by the note number (The curr note mem address during phase two of the K/B decoder routine), the mux output is "mixed" with the K/B number and the manual setting. Therefore each note is "mixed" with its own envelope value for each K/B decoder cycle.

We have already seen how a ROM can be programmed as a multiplier using the multiplier and the multiplicand as the ROM address fields, thus if we connect the volume modulation envelope outputs as one address field and the digitised waveform as the other we can

program the ROM accordingly to behave as a digitally controlled amplifier. We then perform the D/A conversion and filtering to the output of the ROM and then feed the analogue waveform directly into the audio section of the synthesiser.

The final approach is a mixture of digital and analogue circuitry and probably is the cheapest to implement.

A simple  $n$  bit switched ladder network D/A converter is shown in Fig.15. The state of each switch is dependent on whether that particular bit is a 1 or 0 ( $1=V_{ref}$ ,  $0=ground$ ).

The analogue output of the D/A is proportional to the (digital input)  $XV_{ref}$ , this if we connect our digitised

waveform to the digital inputs of such a converter and an analogue control envelope to the  $V_{ref}$  input we can accomplish our D/A conversion and envelope shaping at the same time.

So there we have the basic concepts and circuit ideas behind a complete and viable system. They will at least show how digital techniques can be applied to what is essentially an analogue system and they may well encourage various readers to "have a go". The author is working on a practical unit and we may be able to present further details in due course — should any readers have similar projects in mind or in operation we would be pleased to hear of their experiences.

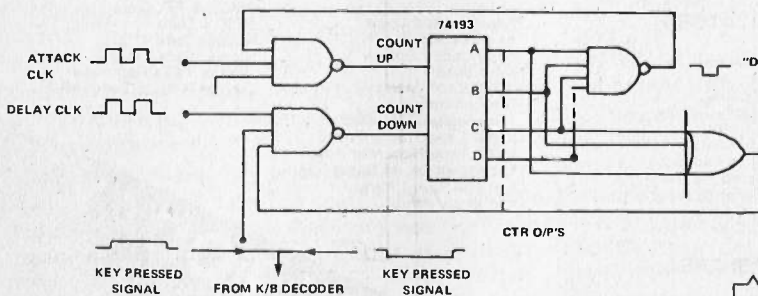


Fig. 14 A simple four bit digital envelope shaper

Fig. 15 Simplified  $n$ -bit switched resistor D/A converter

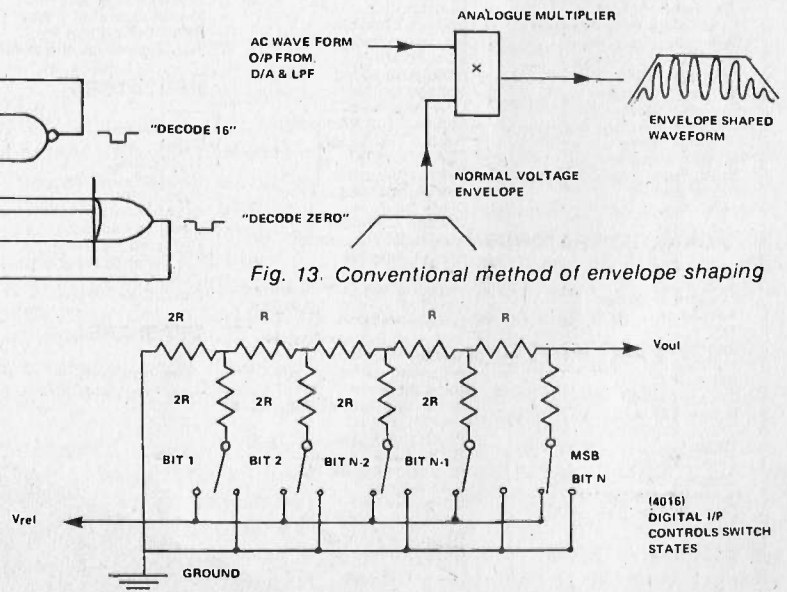


Fig. 13. Conventional method of envelope shaping

# a generation away

by Peter Sydenham

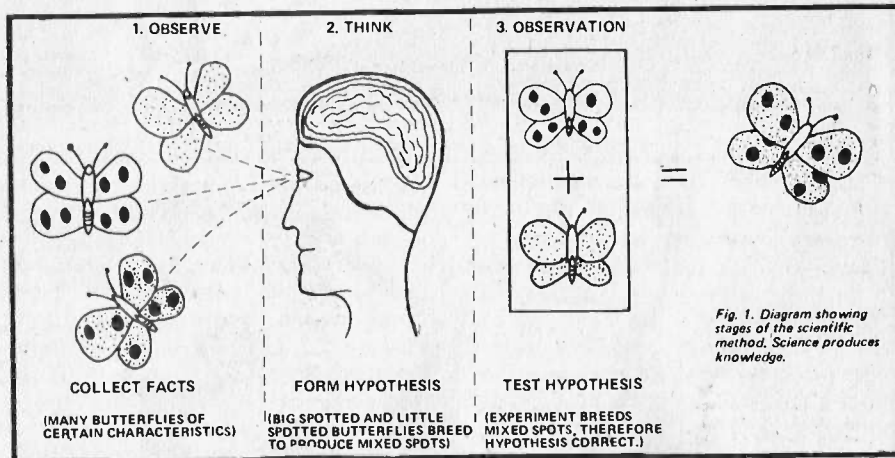
SCIENCE PROVIDES US WITH knowledge about existence. It is based on a procedure of collecting facts which are placed into apparently logical groupings in order to lead to stage two of scientific method — the realisation of one or more hypotheses. Man's imaginative powers then enable ideas about these facts to be "tried out" in the mind. (The mind creates what are called 'models'). After a brain-storming session some ideas emerge about the collected facts. These are likely contenders of generalised models that will describe many seemingly different ideas by one unified concept. Figure 1 depicts this process.

Having hit upon an hypothesis it is then tested by performing experiments upon it to see if more examples that would appear to also be correct are indeed allowed for. The hypothesis, as long as it is found satisfactory, is then held as current and applicable until a new case emerges that is not described adequately enough by it. The scientific process is then begun again to find a new hypothesis that is better than the earlier one.

Old hypotheses are not necessarily useless. They find their use in limited cases. We are quite satisfied in everyday life to regard mass as a constant entity but on some special occasions, in the design of some cathode ray devices for example, mass must be considered as being convertible to energy. Einstein's work predicted that conversion process.

New hypotheses produce new ideas for technology to take up and apply. Once it was *known* that the atom was divisible, scientists sought to split it further.

This brings us to the role of technology in the development of ideas. Technology and engineering is the broad discipline that devises machines and structures that do not exist as such in nature but using resources that are available naturally — see Fig. 2. Machines provide us with power conversion, with mechanisms and with measuring and information tools.



Technology is a sister requirement of scientific pursuit — inseparable partners in progress, each affecting the other's progress at varying degrees with time. Figure 3 shows an example of this interaction.

One often-seen mis-statement is that scientists build the so-called scientific machines. "Scientists put a package on Mars is the greatest scientific achievement yet made by man". If it had been a failure then it would have been due to engineering failure! The Mars' probe is rather the greatest *technological* achievement.

It is important to see how much technology compared with how much science goes into a manufactured product for this helps us predict when new ideas will come into practical use.

There is, however, another aspect to technology. Many lifestyle changing ideas do not occur as the result of applying science in a systematic manner. In fact many valuable machines and ideas arrive by way of an unknown, often poorly trained, inventor who applies an uncommonly good amount of common-sense to solving an immediate problem.

But society itself is also a strong influence on the application of new ideas. Somehow a new idea appears out of place. We now accept eye glasses as normal technology, but think how a person wearing a filtering false nose (a possibility for reducing hay-fever

allergies) would be received. Organ transplants were, and still are to some extent, opposed. Test-tube babies are currently controversial.

Many problems of society could be solved more easily if we were prepared to accept change and make what appears at the time to be sacrifice more willingly. We have seen over the past two years a strong swing toward the smaller car. Air travel is now cheaper than by sea — the reverse of a decade ago. A trans-world telephone call now gives more message content than a telegram for the same price.

This introduction and the previous part of this study sets the scene for what I see could be some aspects of future living. I possess no crystal ball; I claim no extra sensory perception ability, nor do I have a pact with the maker or devil! What is given now is composed from studying the past trends and extending them into the future, this being sprinkled with some personal ideas of myself and others.

## GETTING ABOUT IN THE FUTURE

Although there have been instances in history where knowledge of man has been lost by chance or by political decree (the 1930's burning of the books in Germany) — technological change has continued to advance in all civilisations (albeit sometimes extremely slowly). It is most unlikely that the "alternative" communes we



is the general reluctance to move on a downward trend of performance. Gasoline will still be available in the '90s so the choice will probably move toward smaller, better performance cars that stretch the gallon further.

Other likely developments are automatically steered vehicles running on specially modified highways. The cars would be guided by control units sensing guidance paths laid in the surface. Collision prevention by short distance doppler-radar and optimal route selection using telemetry signals picked up by radio or from transmitters also laid in the road can be implemented now that research is in progress on these devices.

The computing capability needed, including built-in redundancy to improve reliability, is now available in micro-processors that will soon be as cheap as a good transistor radio. Social influences, people's suspicions and mistrust and overall cost are the constraints on rapid developments in this area.

With the thirst for speed perhaps settled to a reasonable level the next thrust will be safety and again, perhaps, longevity of the vehicle. New ideas obtain much publicity — but promotion and worthwhileness of the product are not always related attributes.

Experimental Safety Vehicles reach advanced levels. Urathane bumpers are now being used; other safety features are gradually being introduced. Perhaps vehicles adhering to the surface will be displaced by slightly levitated ground-effect machines like the hovercraft. Again, experience has shown that these are not the complete replacement for all ground transport systems. As yet they are still noisy, power hungry and not as responsive to directional control as the wheel-borne car.

The electric street car is another development that may come back again in a new form. Melbourne, for example, has a workable mass passenger transit system that now gets people into and out of the city generally faster than by car — yet it was not so long ago that the street car was regarded as archaic. Today it is recognized that mass transportation routes are better for concentrated city mobilisation than a melee of cars.

Magnetically levitated vehicles running on relatively inexpensive tracks were forecast to be capable of over 500 km/h speeds. Development of short test tracks and vehicles continues but the pace of development is slow to provide economic alternatives to maintenance and repair of existing systems. The Maglev system proposed for Ontario, but eventually abandoned is shown in

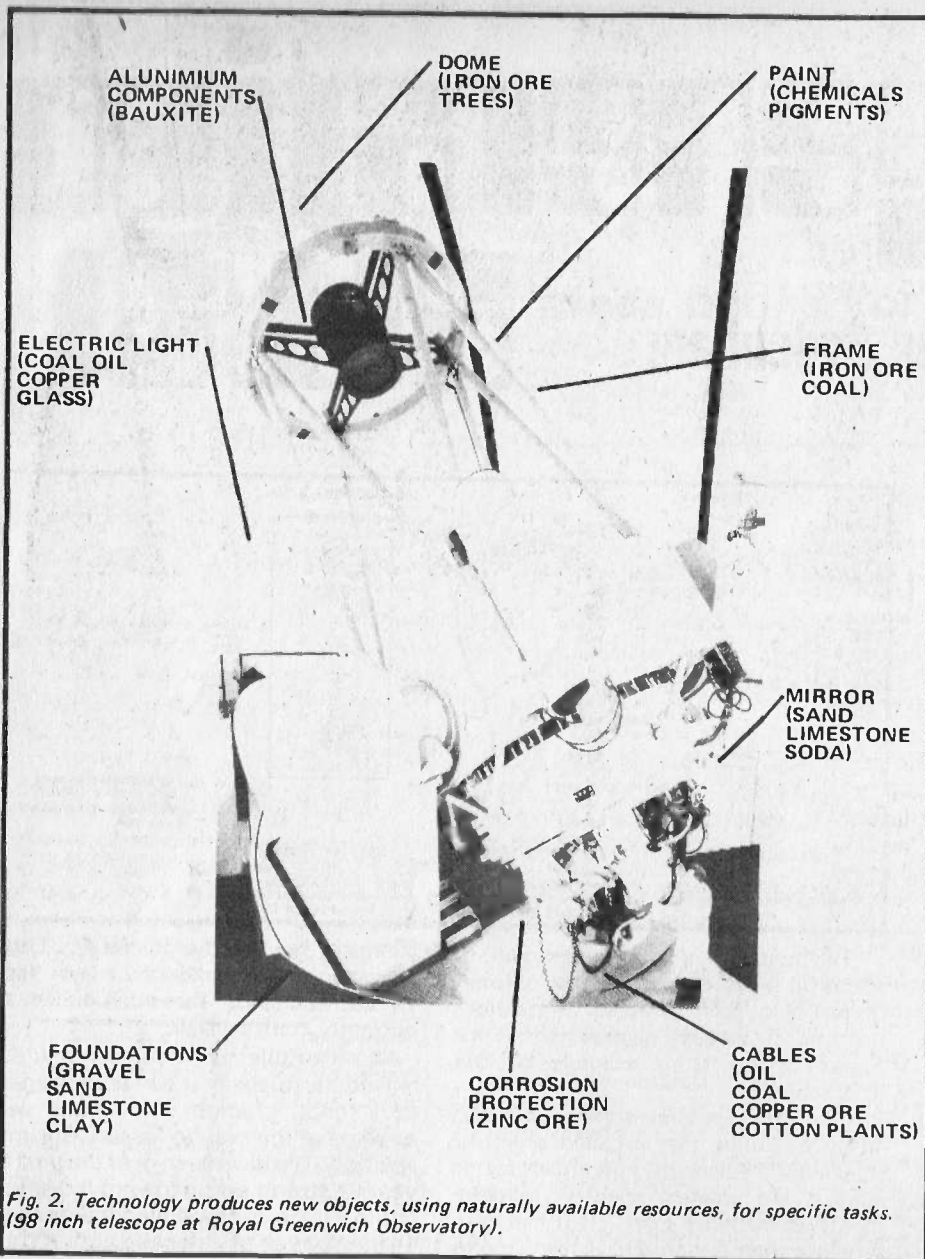


Fig. 2. Technology produces new objects, using naturally available resources, for specific tasks. (98 inch telescope at Royal Greenwich Observatory).

see today will be how man will live in the future. It would need a global catastrophe to destroy all technology so thoroughly that the survivors would have to live as cave men and reinvent all inventions again.

Technology of long-distance transportation — railways, ships and even cars — requires great financial investment. Few people can afford a hand-made car today — even mass-produced ones are becoming harder to reach. Thus, if big commercial business survives into the 2000s, or the State takes over, we can confidently expect changes to slowly emerge in transport. It takes about four to six years for a current design railway and its rolling stock to be built from conception. A new technology such as airships (a revival really), needs a decade and a half once a serious commitment is given to using it.

Electric cars are constantly being researched and developed — Fig. 4 — but it has become vitally clear that two areas of difficulty exist. The first is that the lead-acid battery is not adequate to power a car with performance that we have become accustomed to. The best produced to date is not an equal to the smallest family gasoline car. What is needed is much more effective electrical storage arrangement. High-temperature sodium-sulphur batteries, as pictured in Fig. 5, have been developed to prototype stage, but the manufacturers suggest these cells will not be available to car makers before 1980.

Ford's electric vehicle research and development program is concentrating on this kind of battery, which is also being considered in Europe and Japan.

The second difficulty, however, may be a more serious barrier to the widespread use of electric vehicles. This

Fig.7 . Remember that prototypes are quicker to materialise than service vehicles. For inter-city distances in big countries we need a speed of about 500 km/h to make journeys sufficiently shorter than the current alternative of the car or train. Airlight time is becoming limited by cost and airport turnaround time — door to door and with no connections to make, a 1000 km distance takes about three hours. Maglev inter-city systems, however, now must be designed in light of a new social barrier not obviously in existence five years back — they need great quantities of power to run at such high speeds. Societal values no longer ignore such demands on resources. Super conducting Maglev systems will require vast quantities of scarce helium — this may limit their widespread useage.

The bicycle is good for the health but its slowness and effort requirements do not suit most people who live far from their workplace. A compromise between the bicycle and the car seems how things should develop but social constants, personal comfort and the ability to carry passengers and loads require a wide degree of flexibility for the future personal transport vehicle.

Moving on to transport at sea we can confidently expect to see automatic ships navigating by electronic control. Position sensing devices are sufficiently developed for the task — especially when the Omega navigational network is complete across the globe. Computer control is quite capable of the data processing needed and machinery control is not extremely reliable and well defined. Automation of ships, however, would need global acceptance of the concept and more faith in machinery. Automatic fishing is also a realisable goal — for we can now detect where fish are in the sea.



Fig.3 Science and technology go hand in hand helping each other continuously. (Computer controlled engine-testing at Cranfield).

Ship-forms may shift to surface-effect designs — plans were announced in the US last year for design studies of a 100 000 ton naval cruiser that could move at speeds double those of today. Ship speeds are decided by physical limitations arising because of the wetted area surface drag and the disturbance caused as the water is physically displaced by the ship's motion. Raising speeds above 10 knots or so demands enormous increases in fuel consumption. Solutions to this are to go completely under like the submarine, for this also reduces the power needed, rise out of the water on skis, or the hover principle. One advantage of the latter is that the swell and roll of sea travel is greatly reduced. Hover ships can run today at speeds of 80 knots but problems with skirt sealing in rough weather appears to be a major current limit on the usefulness on the open sea. The history of naval architecture,

however, shows that ships change in only minor ways and at a slow pace.

Finally, in the air: what will happen there? There was once a time — just a few years ago — when air travel had become the pinnacle of transport comfort and speed. But today it fails to provide a fast enough overall journey time because of airport regulations of arrival before departure time, clearance at security barriers, checking of tickets, settling of passengers and the like. It seems, as a rule of thumb, that the actual flight time is about equal to the



Fig.4. The electric car can only provide satisfactory transportation for short land tasks. This is a pleasure version by ElecTraction.

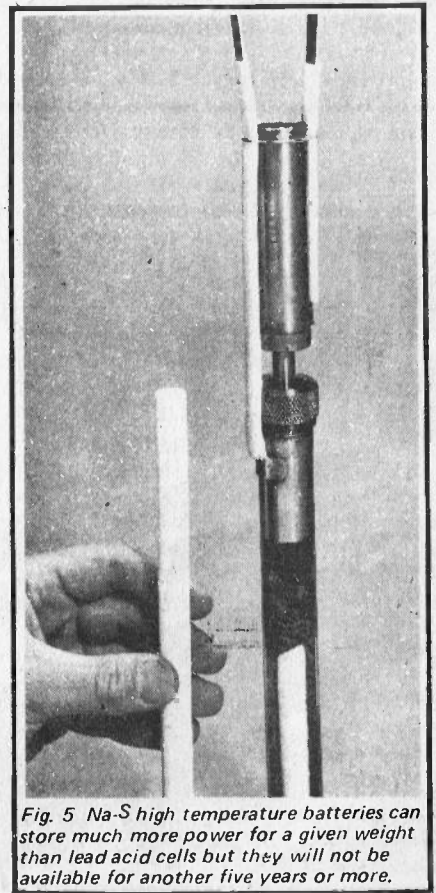


Fig. 5 Na-S high temperature batteries can store much more power for a given weight than lead acid cells but they will not be available for another five years or more.



sundry time involved for short international flights. Plans were published in the early seventies for cabins (in which people were assembled) ready to be attached to the plane. In some countries super highways link the remote airports from the city centres. Somehow these plans did not provide the answer now seen to be needed.

Supersonic transportation is finding difficult acceptance, and it is just not possible to state at present whether it is good or bad with any degree of certainty. Only time will tell; hypotheses need verification by experiment.

The air ship is a strong contender especially if a design needing less helium were invented (certainly not one based on hydrogen, for it is highly inflammable when oxygen is available). The hot air balloon is thirsty for energy due to huge heat losses from the balloon surface — new materials and processes may provide us with an insulated enclosure of light enough structure for these to become viable for long flights.

Several companies have been formed to exploit commercial freight transport by airships. The idea is appealing — quiet, safe, speedy, not plagued with terrain problems and capable of loads equalling many semi-trailer cargoes put together. Airships are an example of past design hopes being reborn due to better technological availability.

In the next part we will look at communications and entertainment developments of the future.

*(To be continued . . .)*

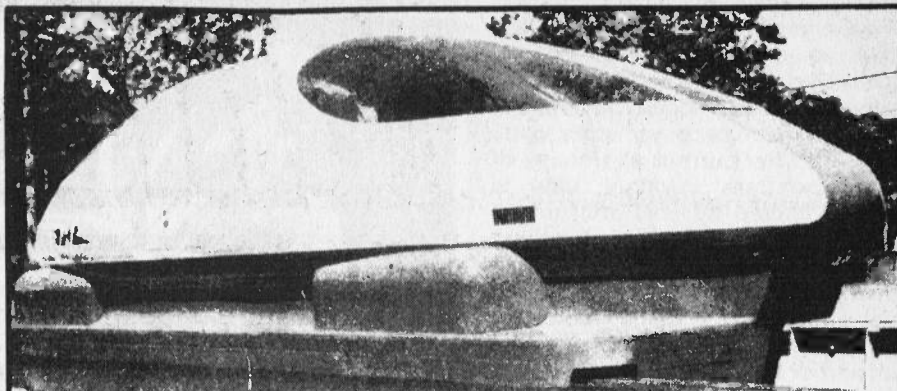


Fig.8. Maglev vehicles can provide great speeds but they will require much more development and testing before they replace current forms of railway.

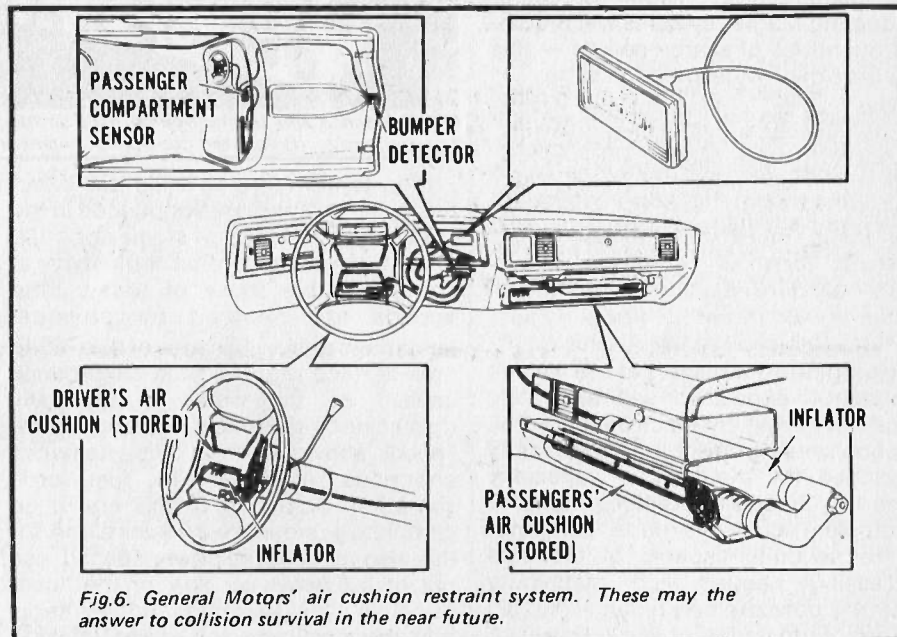


Fig.6. General Motors' air cushion restraint system. These may be the answer to collision survival in the near future.



Fig. 7. In November 1974, the Ontario government cancelled a \$25 million urban transportation development contract with the West German firm of Krauss — Maffei. A test track was to have been built at the CNE, using cars as pictured to the left.

# MULTIMETER GUIDE

## How to choose a meter to suit your needs

THE BUDDING experimenter, after purchasing a basic set of tools, commences building small circuits at the earliest opportunity. Very rapidly he meets the situation where a circuit, as built, does not work. So what now? If all wiring has been done correctly then it must be a faulty component — but which one? The simplest way to find out is to use a meter to measure voltages around the circuit.

Thus the first instrument that an electronics experimenter will buy will be some kind of multimeter capable of measuring the common ranges of voltage, current and resistance found in usual circuitry.

Upon investigating what is available the experimenter discovers that multimeters range in price from simple analogue meters at \$8 to sophisticated, highly-accurate digital instruments costing several hundreds.

The experimenter must ask himself — which is the most suitable for his class of work? Is it really necessary to spend several hundreds of dollars? Are \$8

multimeters worth having at all?

In this article we examine the factors which must be considered when selecting a multimeter in order to satisfy the conflicting requirements of minimum expense and suitability.

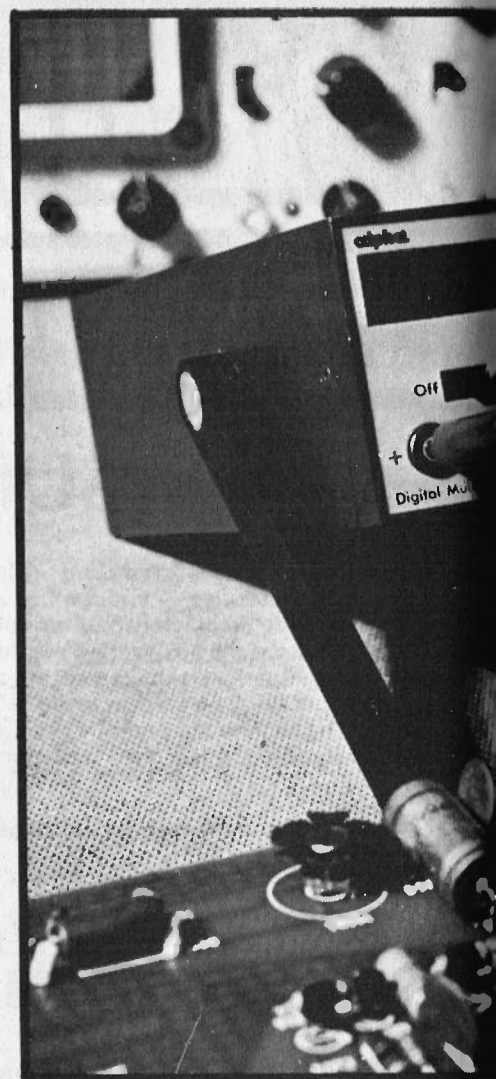
When selecting a multimeter the following factors are of importance:

- Input impedance
- Accuracy
- Resolution
- Ruggedness
- Number of ranges
- Frequency response
- Portability.

### INPUT IMPEDANCE

A multimeter must have as high an input impedance as possible if the circuit under test is not to be severely loaded. Loading leads to substantial errors in the measurement and, if severe, may even damage components.

The input impedance of analogue meters is usually expressed in ohms per volt. Thus the impedance depends on the voltage range selected. Typical



### THE MOVING-COIL METER

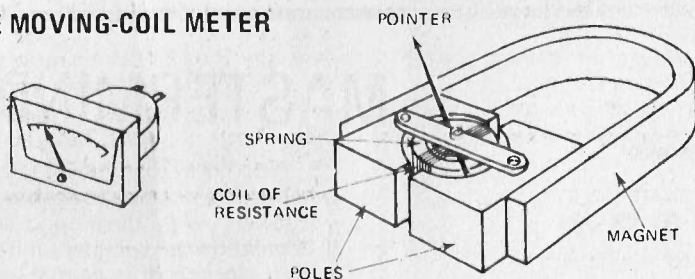


Fig. A.

If an electromagnetic coil is suspended in the field of a permanent magnet, it will be caused to rotate, when energized, by a force proportional to the energizing current.

In the moving-coil type of meter, as Fig. A shows, the field of the permanent magnet is arranged to pass across a cylinder in which hangs the coil of the meter. A fine spiral tension-spring restrains the

rotation by providing a linearly increasing torque as the coil rotates. Attached to the coil is a pointer that moves across a scale, thus indicating current.

As the number of turns is increased, to improve sensitivity, the designer must use finer wire to keep the mass of the coil small. As a consequence of this requirement, sensitive meters usually have a higher resistance, and are more delicate.

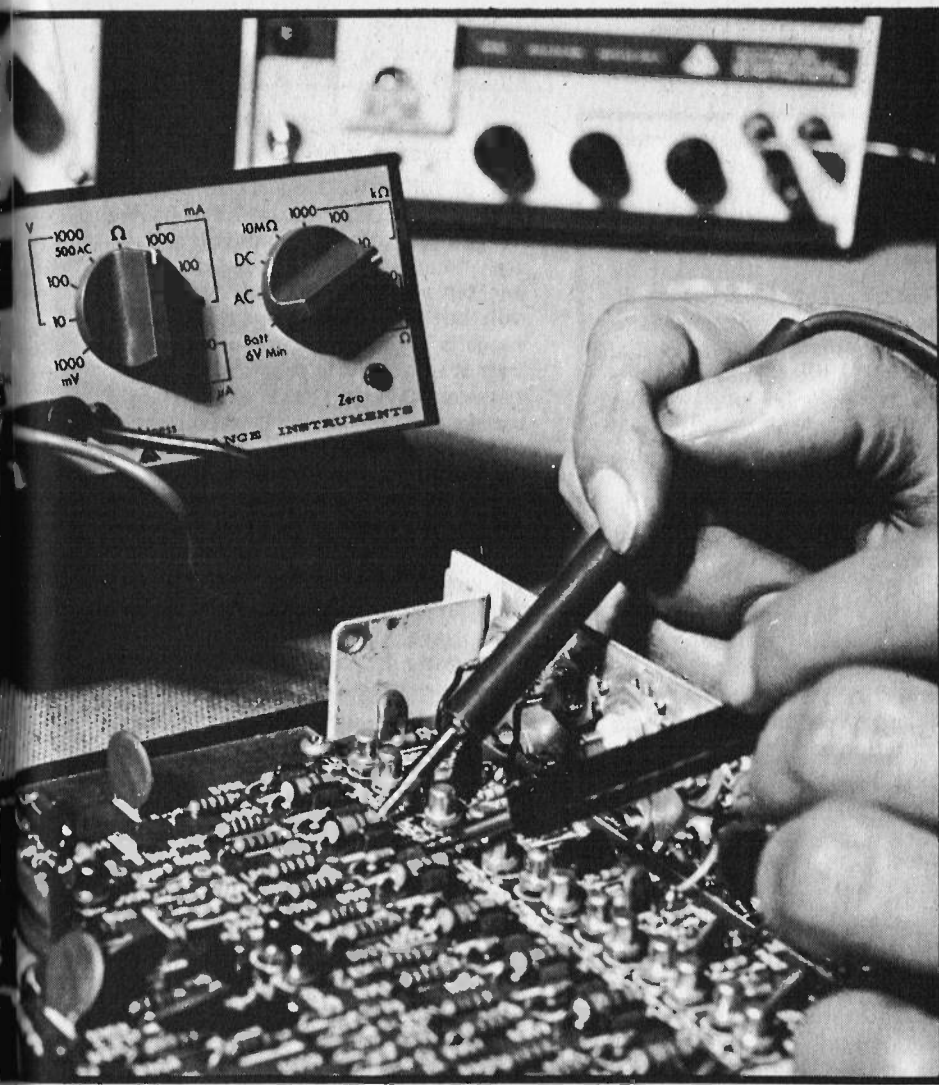
inexpensive meters have impedances of 1000 to 100,000 ohms per volt. Thus when measuring voltage a multimeter is in effect a resistor in parallel with the resistor (across which the voltage is being measured) within the circuit and it reduces the effective value of both — to something lower than the value of either. Thus, as a voltmeter is in effect a resistor, connecting it across a circuit will inevitably change the resistance of that circuit, and the meter must shunt current away from the circuit.

This brings us back to the reason for quoting the sensitivity of voltmeters in ohms per volt. Multiplying the sensitivity by the fsd range in use, gives the resistance of the meter circuit that will be shunting the component. Cheaper multimeters will have sensitivities ranging from as low as 1000  $\Omega$ /volt to as high as 100k  $\Omega$ /volt

To illustrate loading effects, consider the circuit in Fig. 1. By Ohms law we know that the voltage between points A and B is 0.75 volts.

Now let us see what happens when we use a 1000 ohms/volt meter on the 1 volt range to measure this voltage. The 1000 ohms of the meter in



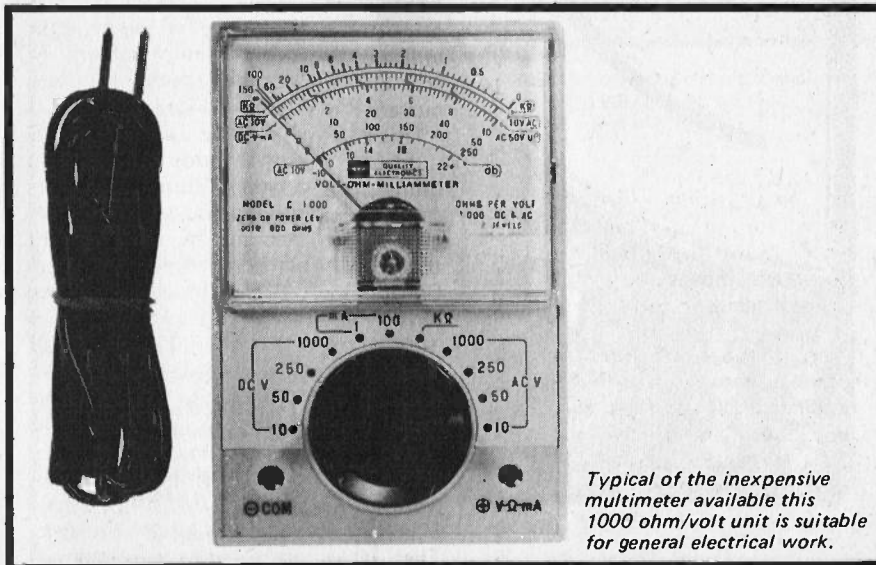


parallel with R2 will produce a combined value of 500 ohms. Thus the voltage read by the meter will be 0.5 volts instead of 0.75 volts – an error of 33 per cent!

It is the degree of this shunting effect that is important – in theory it can never be completely avoided, for some

energy must flow into the measuring system from that being measured. In electronic measurements the rule of thumb is that for accuracy, the resistance of a voltmeter should be at least ten times that of the circuit – a hundredfold is better still.

However with the simple moving-coil



Typical of the inexpensive multimeter available this 1000 ohm/volt unit is suitable for general electrical work.

When using any meter with switched ranges, always start off by selecting a meter range much higher than your estimate of the quantity to be measured.

This precaution safeguards the meter should the quantity be much larger than expected.

type of meter a higher input impedance also requires a delicate meter movement which is relatively easily damaged. A good compromise would seem to be a meter having an ohms/volt rating of between 10 000 and 50 000.

In more expensive meters – those employing electronic amplifiers and those using digital techniques, input impedances are usually at least one megohm and hence loading of the circuit is seldom a problem.

### ACCURACY

The typical cheap multimeter has an accuracy of the order of 3 to 5% and this is further reduced by parallax reading errors. Better quality analogue instruments have 1% accuracy and mirror backed scales to reduce parallax reading errors.

Digital multimeters are at least 1% or better, with 0.2% being typical. Sophisticated units costing several thousand dollars may well have accuracies down to 0.001%. The way accuracy for a digital meter is quoted is far from being as simple as given here, but for our present purposes the simple statement given suffices.

As to what accuracy is needed, it is seldom that an experimenter, even one at fairly advanced level, needs an accuracy better than 1% and, mostly, even the 3 to 5% of a simple meter is good enough. So don't get carried away by accuracy, if you can afford 1% or better – great. But you will not be too badly off if you can't.

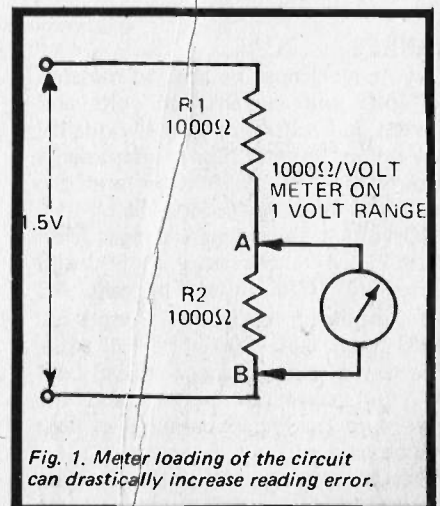
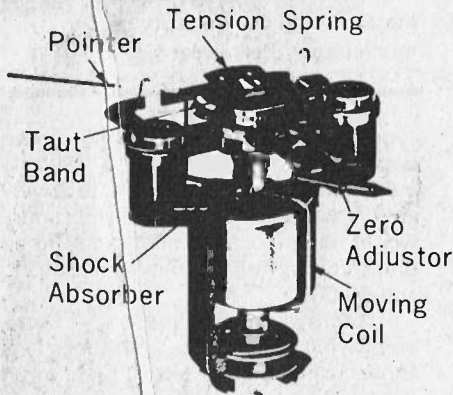


Fig. 1. Meter loading of the circuit can drastically increase reading error.

# MULTIMETER GUIDE

## TAUT BAND SUSPENSION SYSTEM



Better quality analogue multimeters usually employ a taut band suspension system in the meter movement. This system, although more

expensive, has several important advantages over conventional moving coil movements.

The movement still employs the moving coil principle but now the coil is suspended by means of a platinum alloy band. Since, now, no pivots, jewels or hair springs are used errors due to pivot friction and roll of the jewel are completely eliminated. Additionally the meter will maintain correct reading regardless of orientation.

A shock absorber is usually fitted to the movement that incorporates dual bumper stops. Thus the movement is rendered insensitive to mechanical shock.

The use of a taut band movement ensures good linearity, freedom from backlash, freedom from effects of vibration and shock and much greater instrument reliability.

meter has 1, 10 and 100 volt ranges and is quoted as having an accuracy of 3% of full scale. Now let us suppose we are trying to measure 1.1 volts. We cannot read it on the one volt scale as the meter would read over range. On the ten volt scale we read about one volt but our accuracy on the ten volt range is 3%, that is,  $\pm 0.3$  volts. So the best we can say is that the voltage is between 0.7 and 1.3 volts. Hardly satisfactory for working on transistor amplifiers for, with this measurement, we would not be sure whether it was one or two base emitter junctions (0.6 to 0.7 volts per junction for silicon).

Had we a meter with a 3 volt range we would have read around 1.1 volts with an accuracy of  $\pm 0.09$  volts and the degree of ambiguity would have been vastly decreased.

## RUGGEDNESS

Drop an \$8 multimeter and you may as well not bother to pick it up. The case will probably shatter and the meter movement will almost certainly be ruined. The more expensive units have poly-carbonate cases which could be bounced off a concrete floor (if you are game enough). The more expensive units will also probably use a taut-band meter movement rather than the simple moving-coil variety. Taut-band movements are virtually impervious to shock.

Some years ago we bounced such a

## RESOLUTION

Resolution is often more of a limitation than is accuracy for, if the meter movement is small, it is difficult to read accurately. For example, when trying to read 1.5 volts on a 10 volt full scale meter, it may only be possible to say that it is somewhere between 1 and 2 volts. Hence the bigger the movement the better.

In the case of a digital meter the resolution is a function of the number of digits in the display. Thus a three digit display (999) can resolve to one part in 1000 and hence the accuracy must be better than 0.1% to make full use of the available resolution. Conversely it is little use having more than three digits in the display if the accuracy is only 1%.

## RANGES

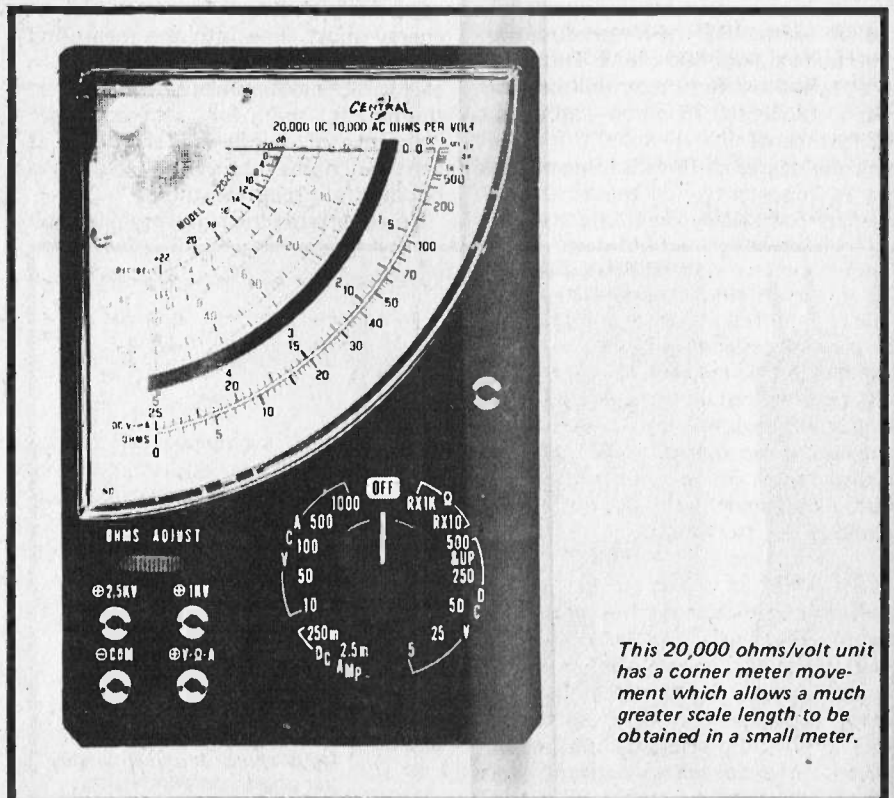
Any meter must be able to measure dc volts and current, ac volts and current and resistance to really qualify as a full multimeter. Some instruments also include dB calibration and the facility to measure capacitance.

DC voltage should have ranges from 1 to 2.5 volts full scale to 500 and preferably 1000 volts full scale. AC volts should cover from 2.5 volts full scale to at least 300 volts full scale. The lowest current range should be 1 mA full scale, or better, and the maximum reading should be at least one ampere.

Resistance scales should enable you to read from one ohm to at least one

megohm with reasonable accuracy. Note that on cheaper meters cramming at the top of the ohms scale will prevent reading values in excess of 100k ohm at all.

Finally the ranges should ascend in the 1, 3, 10 ratio at least. Ten to one scale ratios lead to some difficulty in reading voltages that are just in excess of one range. For example assume a

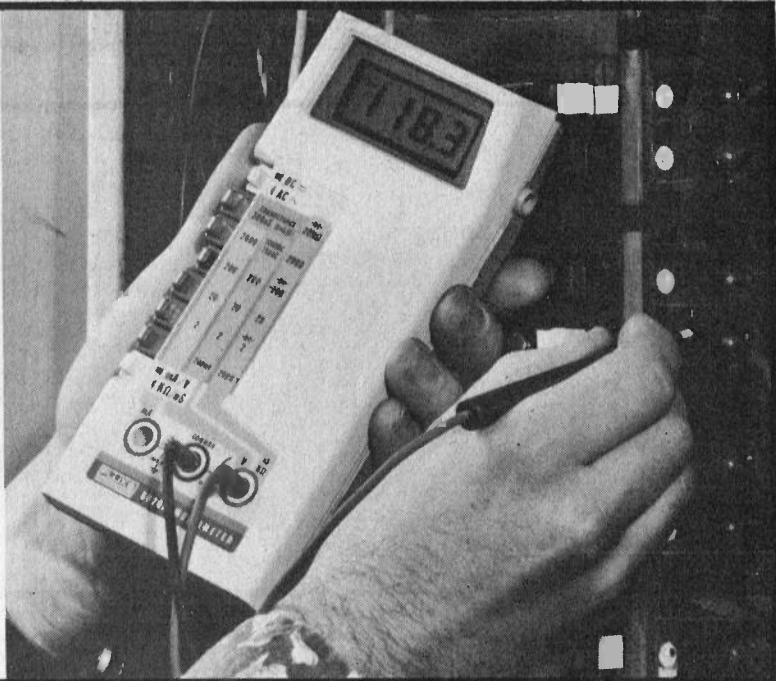


*This 20,000 ohms/volt unit has a corner meter movement which allows a much greater scale length to be obtained in a small meter.*



# MULTIMETER GUIDE

The Fluke 8020A digital multimeter employing a liquid crystal display. A single Alkaline 9V battery provides 200 hours of operation with an indicator to show the last 20 hours of life. Has 27 ranges with resistance resolution of 0.1 ohm on 200 ohm range to 10 kilohms on 20 megohm range. Available for \$184.00 including duty but plus taxes (F.O.B. destination) across Canada from Allan Crawford Associates Ltd.



taut-band meter off the floor hundreds of times (in order to take photographs) without any damage occurring to the meter whatsoever (a Weston 660 series multimeter).

Ruggedness is very much a function of price. The more you pay the better the case and the movement used. The switches will also be larger, more robust and with silver-plated contacts. So although an \$8 meter may appear to offer the same facilities as a more expensive unit it will certainly not last as long.

Steer clear of ultra-miniature meters. These are very fragile as well as being difficult to read. If you can afford it buy a meter with a taut-band movement — they are expensive but will be worth the money.

## FREQUENCY RESPONSE

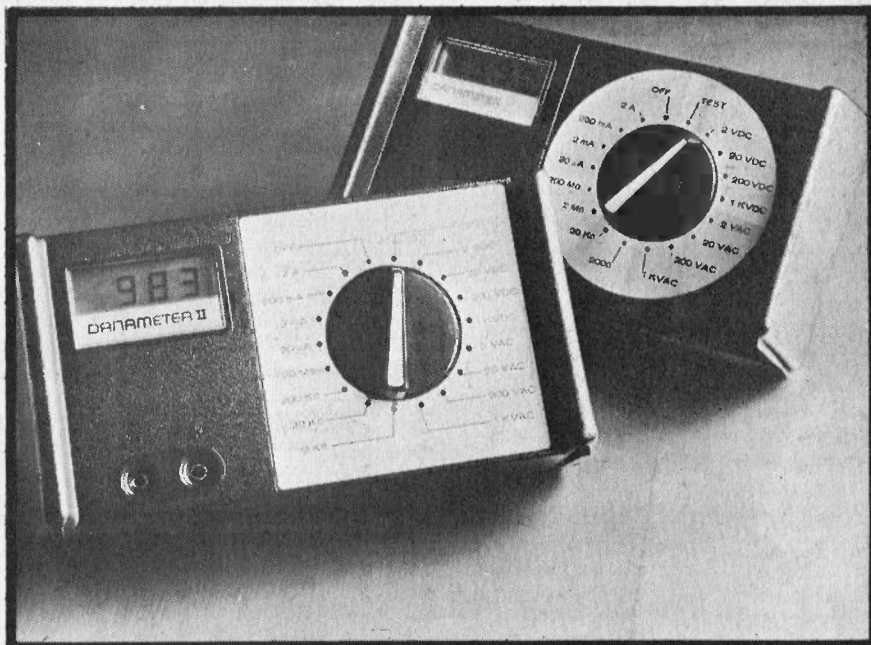
The ac ranges of a multimeter are of little value if the frequency response of the instrument only extends to a few hundred hertz. Such an instrument would only be useful for measuring 60 Hz line voltages.

If possible obtain a meter that has a frequency response that at least covers the audio spectrum. This is almost indispensable if you are working on audio equipment and do not have a cathode-ray oscilloscope.

## PORTABILITY

Most multimeters are portable as the simple kinds only require a couple of dry cells to power the resistance measurements. Multimeters that have amplifiers built in are sometimes restricted to line only operation.

For the experimenter a multimeter should definitely be capable of battery



These Danameters are the cheap end of the range from Dana Laboratories. AC accuracy is 1.15% (Danameter) and 0.6% (Danameter II);

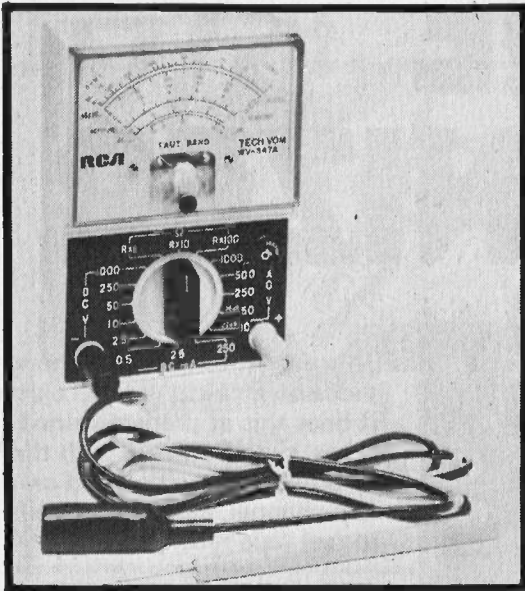
operation. Therefore if a transistorized or digital multimeter is to be purchased make sure that it has rechargeable cells or is capable of running for extended periods on dry cells. Line only types are fine for the laboratory but not for the hobbyist.

## ANALOGUE OR DIGITAL

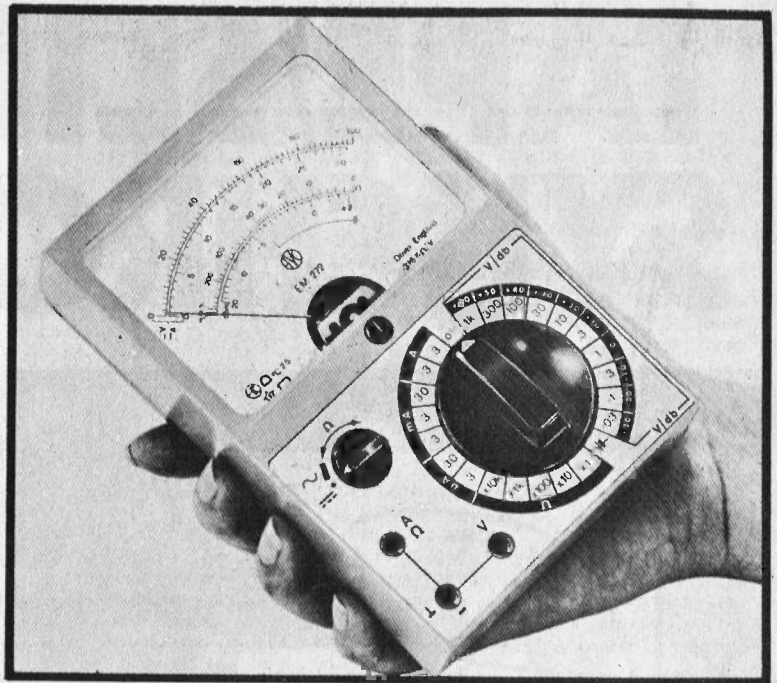
An analogue measurement is essentially one that is made continuously. A digital measurement on the other hand is made in a series of discrete steps.

The same basic quantities can be measured by both digital and analogue methods. For example, a conventional clock has a pair of hands which traverse a calibrated dial in a continuous sweep, and there is a theoretically infinite number of steps between any two calibrated points on the clock face — measurement is continuous and is therefore an analogue process.

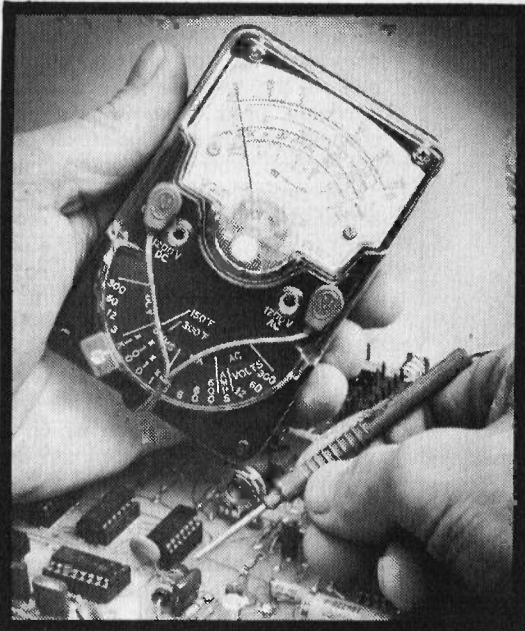
A digital clock on the other hand indicates the time in discrete steps, each of one minute (or one second).



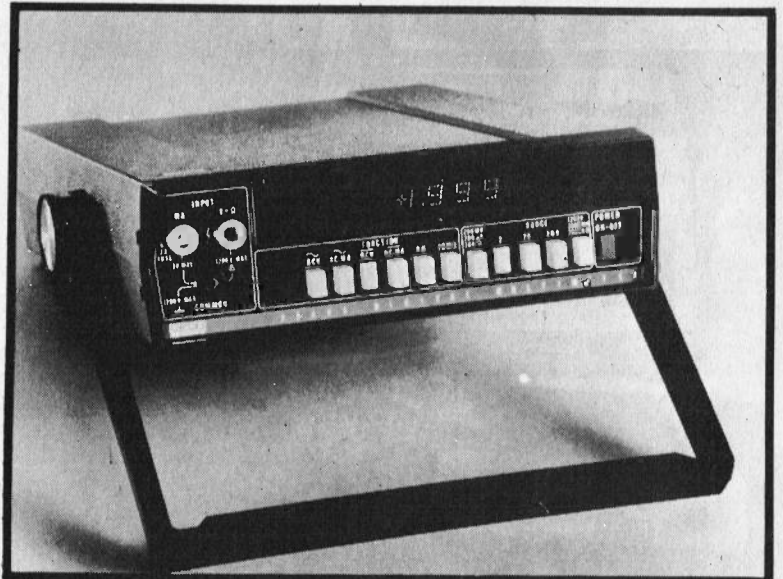
The Tech VOM is a 20k $\Omega$ /V multimeter.



This electronic multimeter from AVO features 10 Meg impedance on dc and 316k $\Omega$ /V on ac. The 39 ranges of this instrument cover all the measurements you are likely to need.



The Triplett Model 100-T hand size multimeter features two temperature ranges and an accessory thermistor probe for checking-circuitry hot spots, and also is capable of clamp - on AC measurements - basic price around \$120.



The Fluke 8000A digital multimeter offers 0.1% accuracy with three and a half digits.

There is no ambiguity of reading. It is either 8:23 or 8:24 one cannot misread it.

This is one of the great advantages of digital readouts. There are no reading errors due to parallax or scale resolution, and in the case of electronic digital instruments no friction or hysteresis to cause mechanical errors.

Hence even the cheapest of digital multimeters has better than 1% accuracy, (actually accuracy should be stated the other way - a meter is 99% accurate, not 1%). whereas an analogue meter with a mechanical movement of 1% accuracy is quite

expensive and still subject to further reading errors caused by parallax and scale resolution.

Until recently digital multimeters were priced beyond the reach of the amateur experimenter the cheapest being well over \$100. However now there is a choice, albeit restricted at less than that amount.

Such prices make the digital instrument competitive in price with the best of analogue transistorized multimeters and - they have better accuracy.

All digital multimeters have input

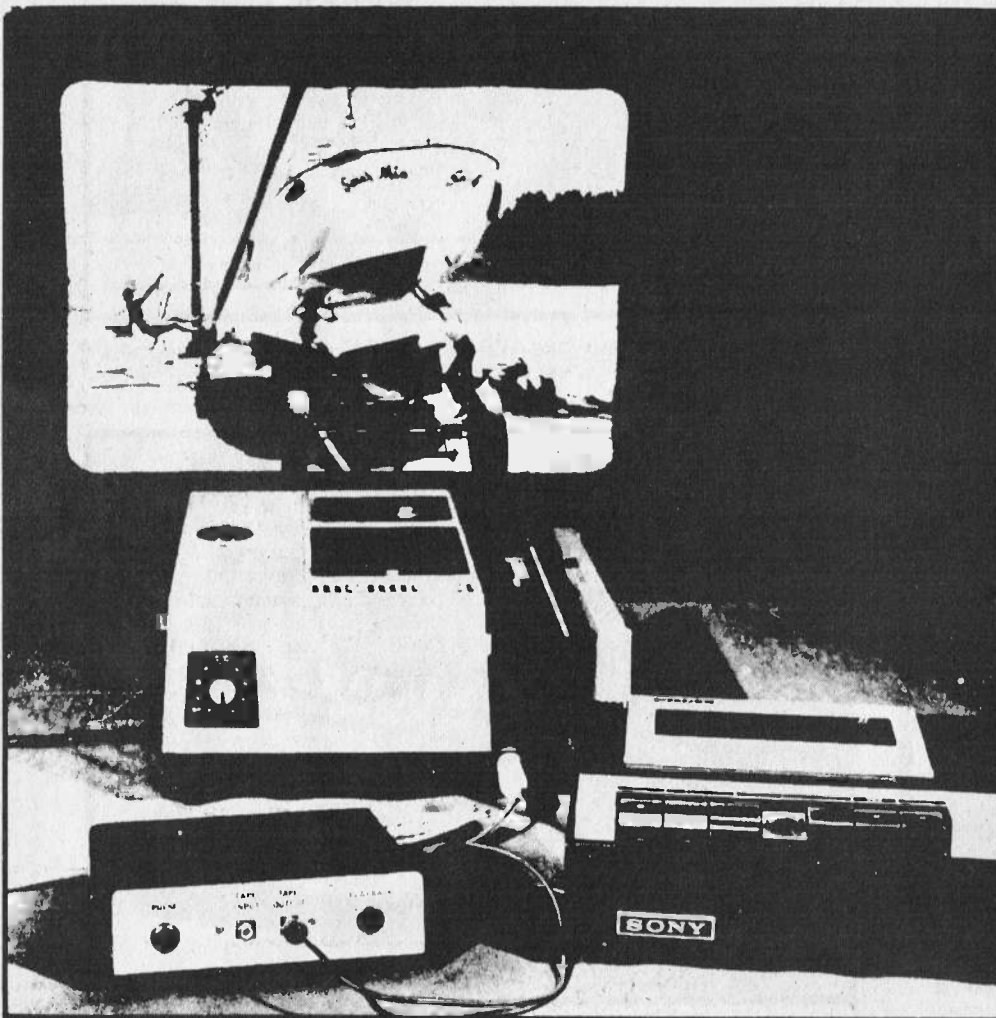
impedances of one megohm or better and hence loading is seldom a problem with such instruments.

Digital instruments are sensitive to noise and a dc voltage with superimposed hum and noise may give incorrect and/or jittery readings on some instruments. Analogue instruments on the other hand tend to reject and average out superimposed noise.

It is doubtful that digital meters will ever completely replace analogue meters. But they will almost certainly replace those at the higher priced end of the analogue range.



# TAPE/SLIDE SYNCHRONIZER



This unit automatically changes slides on an automatic projector. It does this at predetermined times, synchronizing with the commentary prerecorded on a two-channel, cassette or reel-to-reel tape recorder.

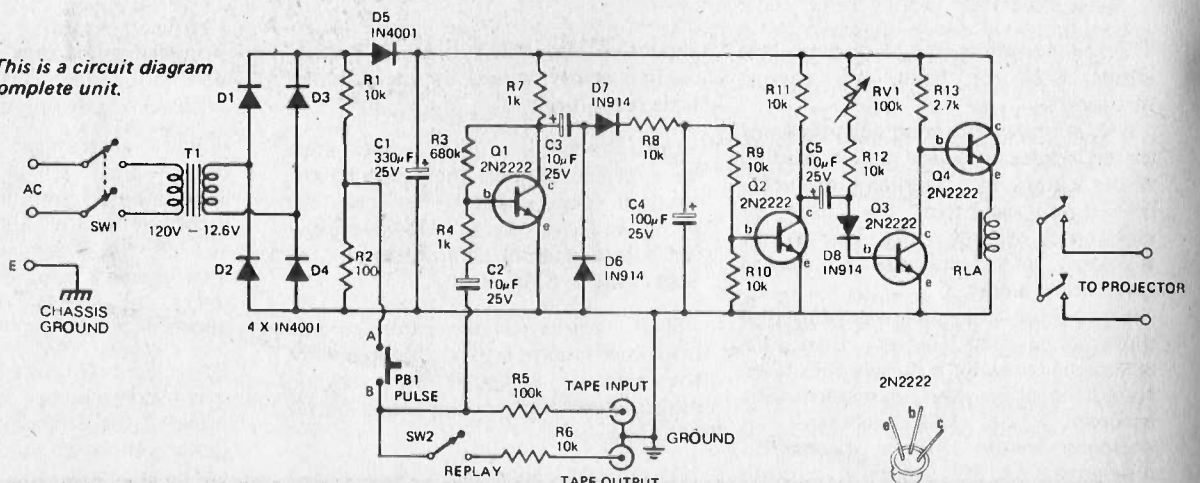
Practically all tape recorders sold today have two-channels, and when used to record commentaries for slide shows, only one of the two available channels is normally used. The automatic slide changer described in this article utilizes the second, normally unused channel.

The projector's slide mechanism is actuated by short tone bursts recorded onto this second channel at the points where slide changes are required. The tone that is used for this purpose is derived from the full-wave rectified (but unsmoothed) line frequency.

To record the tape initially, the slides are loaded into the magazine of the projector in the order in which they will be shown. The commentary is then recorded onto Channel 1 in the normal way, and the pulse button on the front of the control unit depressed whenever a slide change is required. This changes the slide and simultaneously records a control tone onto Channel 2.

Once the tape has been prepared, the control unit can be used automatically to switch the slide projector at the

Fig. 1. This is a circuit diagram of the complete unit.



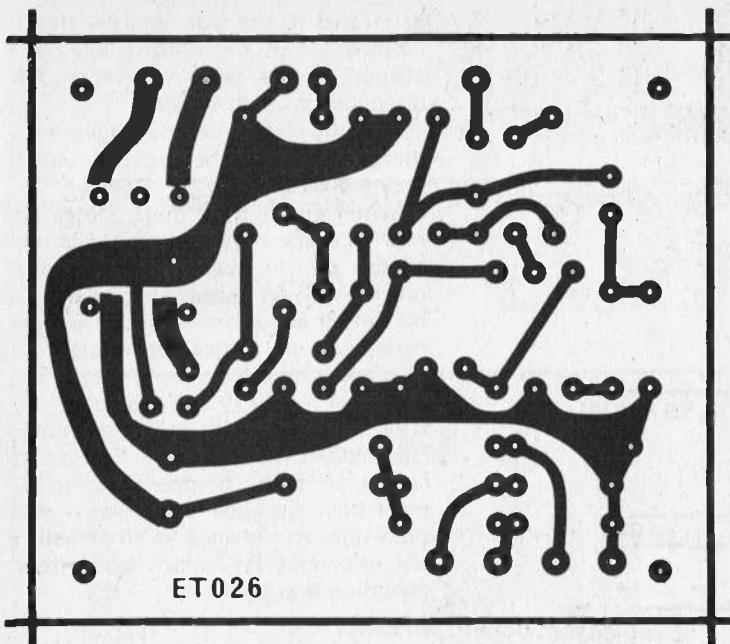


Fig. 2. Foil pattern of printed circuit board — full size.

predetermined times in synchronization with the tape recording.

### CONSTRUCTION

The circuit diagram of the complete unit is shown in Fig. 1.

The unit may be assembled on matrix board, tag strips, or, preferably, on the printed circuit board, the foil pattern of which is shown in Fig. 2.

Figure 3 shows how the components are assembled on the printed circuit board. Note that resistors R5 and R6 are mounted on the front panel of the unit — as shown in Fig. 4.

Having completed assembly, check the orientation of diodes, transistors and electrolytic capacitors.

Figure 5 shows how the completed printed circuit board and remaining components are located within the case. Ensure that all wiring carrying line voltage is adequately insulated and the metal case is well earthed.

### CHECKING THE UNIT

Figure 6 shows how the various units should be interconnected — both for checking and for subsequent recording of the tape. The relay output lead of the control unit is connected to the slide projector's external control socket; the second (normally unused) input socket of the tape recorder is connected to the input socket of the control unit, and a microphone is then

### How it works

The sync. pulse is derived from the line. It is simply the 120 Hz rectified but unsmoothed output from the secondary of transformer T1.

This 120 Hz signal is attenuated by R1 and R2 to achieve a level suitable for recording onto the tape.

Diode D5 isolates the filter capacitor from the pulse generating network.

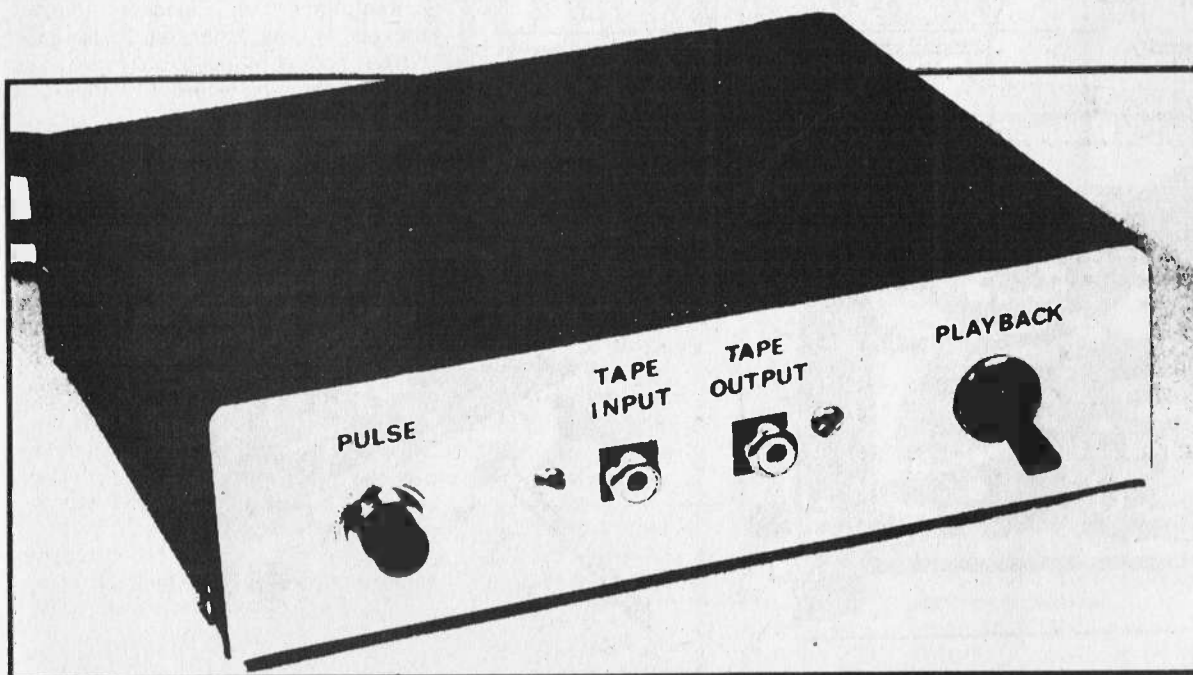
When push button switch PB1 is pressed, the signal from R1, R2 is fed to the tape recorder and also, via C2 and R4, to the remainder of the control unit.

The 120 Hz signal is amplified by Q1 and then rectified and smoothed by D6, D7, C3 and C4. Capacitor C4 takes a few cycles to charge, and when it does Q2 turns on.

The action of Q2 turning on, causes C5 to momentarily to remove the bias from Q3. The length of time for which the bias is removed is determined by the setting of RV1.

Transistor Q4 is an emitter follower and applies power to the output relay during the time that Q3 is turned off, and so RV1 in effect controls the length of time that the relay contacts remain closed. The contacts of this relay then actuate the slide change mechanism of the projector.

During the replay period, the control pulses from the tape recorder are fed into the control unit via R5, C2 and R4 and then actuate the unit in the same manner as described above.





# TAPE/SLIDE SYNCHRONIZER

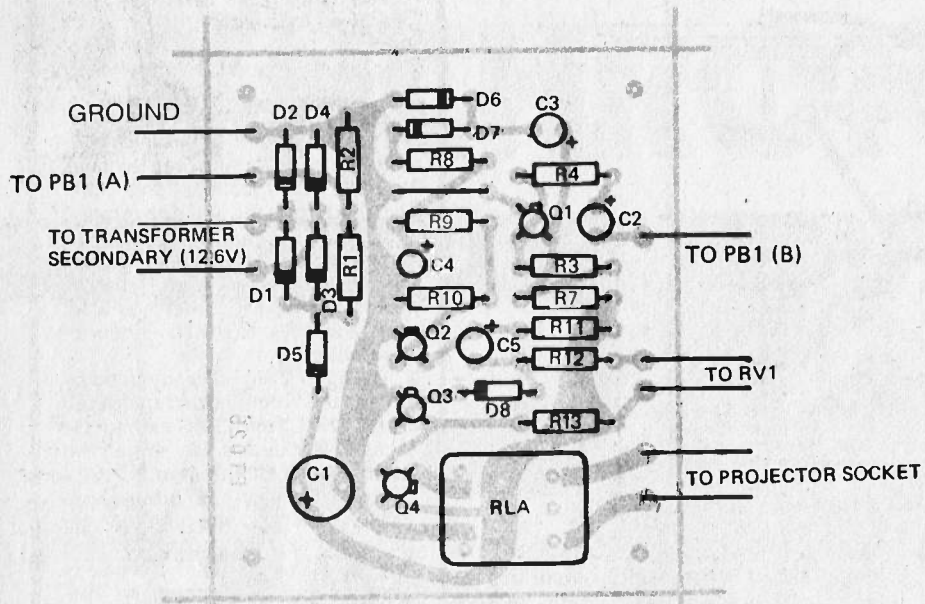


Fig. 3. How the components are assembled on the printed circuit board.

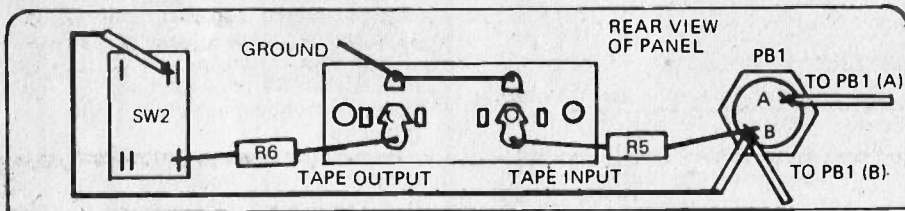


Fig. 4. This drawing shows components and wiring on the front panel of the unit.

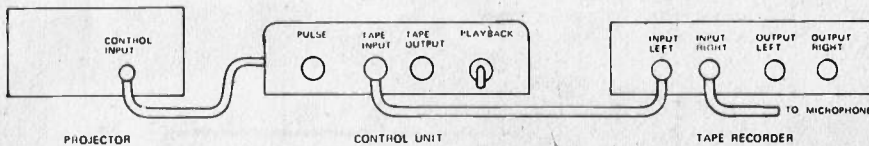


Fig. 6. Interconnections — checking and recording.

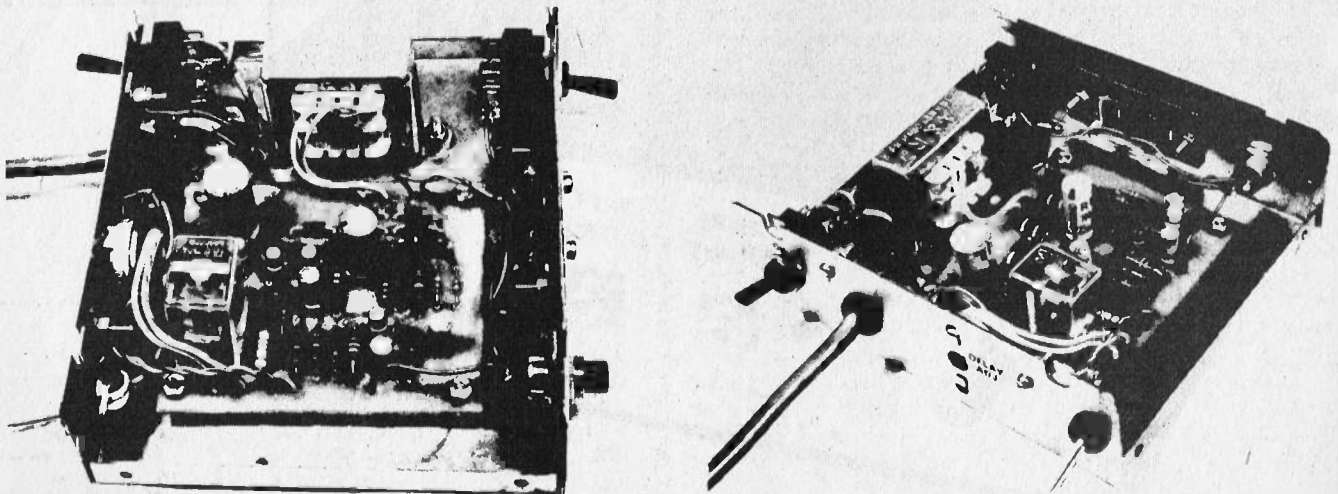


Fig. 5. The printed circuit board and remaining components assembled within the case.

connected to the tape recorder (Input Channel 1) in the normal way. The output of the tape recorder is left disconnected at this stage.

Load the slides into the magazine of the projector in the order in which they will be shown.

Switch on all three units. Slides can now be changed by pressing the 'pulse' button on the front of the control unit. It will be necessary to press this button for about one second. The time period is not critical providing it is long enough for the slide to change.

Internal circuitry — controlled by RV1 — ensures that only one slide is changed at a time, this feature is lacking on many proprietary units. If more than one slide is changed — or a slide does not change at all — adjust potentiometer RV1 until satisfactory operation is obtained.

## OPERATION

Once the unit has been checked out for satisfactory operation it is ready to use.

A minimum period of about five seconds must be allowed between slide changes to enable the control unit to reset.

Move the first slide in the required sequence into position, start the tape recorder, and record the required commentary, changing the slide whenever required by actuating the button on the control unit. Stop the tape recorder when the last slide has been shown.

Figure 7 shows how the units are interconnected for replay. As can be seen the relay output lead of the control unit is still connected to the external control socket of the slide projector, but the output from Channel 2 of the tape recorder (from preamplifier or speaker output sockets) is now connected to the tape output socket of the control unit. The input to the tape recorder Channel 2 is left disconnected.

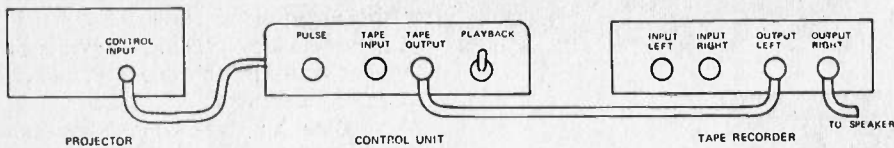


Fig. 7. Interconnections — replay.



Fig. 8. The relay is soldered directly onto the printed circuit board. The two centre pins of the change-over contacts are commoned — as shown here.

## PARTS LIST

R1	— resistor	10k	1/2 Watt	5%
R2	— resistor	100ohm	1/2 Watt	5%
R3	— resistor	680k	1/2 Watt	5%
R4	— resistor	1k	1/2 Watt	5%
R5	— resistor	100k	1/2 Watt	5%
R6	— resistor	10k	1/2 Watt	5%
R7	— resistor	1k	1/2 Watt	5%
R8-R12	— resistor	10k	1/2 Watt	5%
R13	— resistor	2.7k	1/2 Watt	5%
C1	— capacitor	330µF	25V electrolytic	
C2	— capacitor	10µF	25V electrolytic	
C3	— capacitor	10µF	25V electrolytic	
C4	— capacitor	100µF	25V electrolytic	
C5	— capacitor	10µF	25V electrolytic	
Q1-Q4	— transistors	2N2222		
D1-D5	— silicon diodes	IN4001	or equivalent	
D6-D8	— silicon diodes	IN914	or equivalent	
RLA	— miniature relay	430 ohm coil (or equivalent)		
T1	— mains transformer	— 12.6V, 150 mA		
PC board	—	ET 026		
SW1	— double pole on/off switch			
SW2	— single pole on/off switch			
PB1	— push button switch	— press to make RCA sockets, case, 3 wire line cord and plug, plug for projector etc.		

Flick the replay switch SW2 to the off position and move the first slide into position. Now start the tape recorder and switch the replay switch into the on position as soon as the commentary starts. The slides will now be changed automatically at the prerecorded times.

The 'pulse' button on the control unit may still be used to override the control unit at any time.

The replay switch must be in the off position when stopping, starting or rewinding the tape as any signal from the tape recorder will initiate a slide change.

# AUTHORS!

OK, all you budding authors, we know you're out there. ETI, as you may have noticed is the only Canadian magazine for the electronics hobbyist and enthusiast. Now, we like to think of you all frantically rushing about buying components for, and building, our projects. But we know you won't all do that — it would be very boring if you did, because some of you are doing your own things, designing your own projects, and sometimes, getting them to work.

So, if you've built something interesting, and it works, perhaps you would like to see it as an ETI project. We even pay you for the privilege of seeing your pride and joy in print. Or, perhaps you haven't built anything you feel worthy of the accolade, but you could write an interesting feature article.

Either way we'd like to hear from you. This is your magazine in many ways — and by the way, if you've just designed a computer-controlled hi-fi based on three chips, please telephone!

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# LIQUID CRYSTAL DISPLAYS

BY ROBIN C. H. MOORSHEAD B.Sc.

AS DAY FOLLOWS NIGHT, there are certain patterns of change in the physical world which we hold to be always true. Perhaps one of the earliest that we learn is that matter exists in three states, solid (crystalline), liquid or gas. The particular state a substance exists in depends on temperature. At low temperatures substances tend to be solid, at higher temperatures liquid, and yet higher, gaseous. Further more, the transition between the states is clear and precise, for example, ice changes to water at 0°C, there is no gradual transition.

This pattern of change is explained by the "Kinetic theory." This theory is based on several assumptions: That matter consists of minute, more or less spherical particles which are held together by "cohesive forces" which are spread evenly over their surface. In the solid (crystalline) state the particles are tightly bound by the cohesive forces and are perfectly ordered like bricks in a wall. As the temperature increases, the particles begin to vibrate and the cohesive forces weaken so the particles can move about but are still attached to one another:



Fig. 1

At higher temperatures the cohesive forces are vanishingly small and the (gas) particles fly about at random.

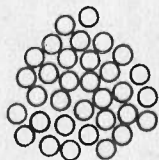


Fig. 2

Simple materials which fit into this description have another property, that their physical characteristics are the same from whichever direction they are approached. This is termed "Isotropic." Examples of isotropic materials are glass, steel or water. Their electrical resistance, refractive index and strength are the

same from whichever direction we measure them.

## Against the grain

However, by no means all materials are isotropic, wood for example is much stronger across the grain than with the grain, graphite has a higher electrical resistance when measured through it's "plate" structure than when it is measured along the plates. Such materials as these are termed "Anisotropic."

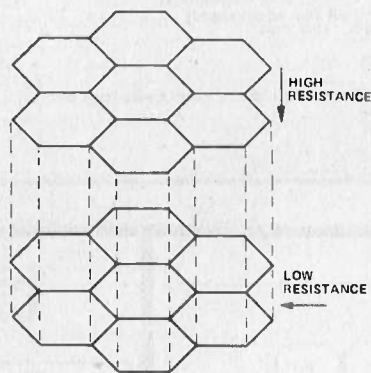


Fig. 3

It would be surprising if wood and graphite were isotropic, since they are constructed of rods (cellulose fibres) and plates (the graphite). In the same way we would not expect roof slates to fall into a box in a random arrangement, they will have a strong tendency to fall flat and so order themselves into an anisotropic arrangement.

## Rods and plates

In exactly the same way many of the large molecules found in organic chemistry have rod- or plate-like shapes and have anisotropic crystal structures. The tendency towards ordered arrangements in these substances is so great, that when they melt they retain a degree of order until the temperature is considerably increased. As a result the liquid has anisotropic properties, some flowing in a gliding stepwise fashion, or interfering with

the passage of light. When this happens the substance is said to possess a liquid crystalline phase (sometimes termed a mesomorphic or paracrystalline state).

So we have:

	Increasing temperature
	→
For an isotropic material:	solid → liquid → gas
For an anisotropic material:	solid → liquid → isotropic → gas
	crystal      liquid

It is of interest to note that this property has been well known since 1890, and some 0.6% (15,000-20,000) of organic chemicals show this behaviour.

## Nematic and smectic

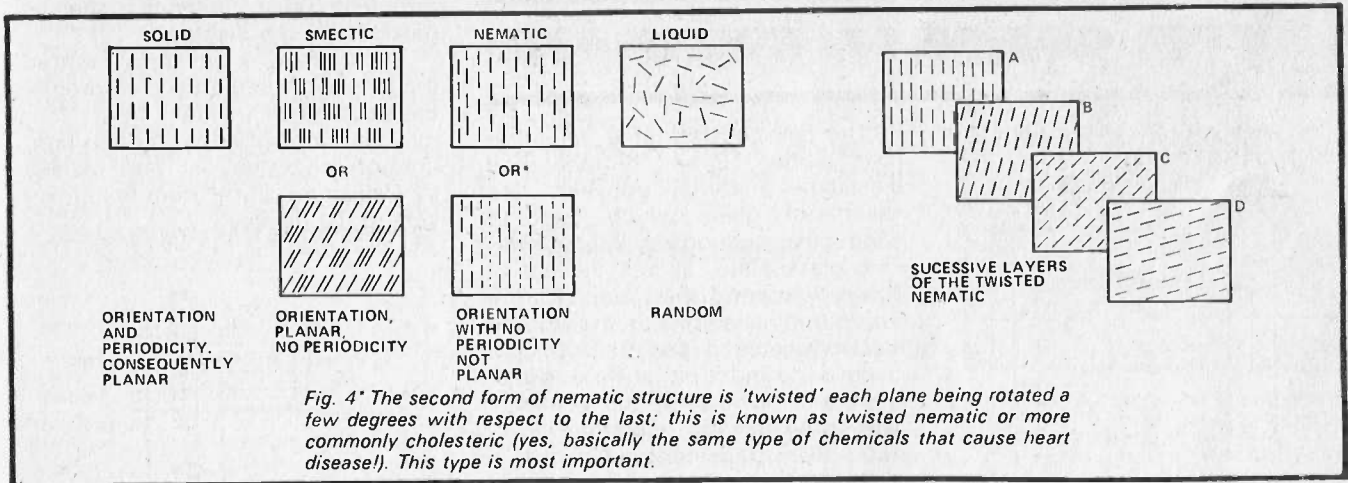
Liquid crystals fall into two main categories: Nematic (from the Greek thread) and Smectic (from the Greek for soap).

Smectic liquid crystals have many interesting properties but have found little practical application, so they will not enter into the article any further.

The nematic liquid crystals have many applications and form the substance of this article. There are several types of nematic materials. The difference in these types is shown in fig. 4.

Some nematic liquid crystals possess properties which cause them to interfere with the passage of light in an applied electric field, or with changing temperature. They are of great interest in modern electronic displays for several reasons:

- (1) The power consumption of such displays is extremely small, between 2μA and 0.2μA per segment of a 7-segment display, about 10μW per Cm<sup>2</sup> of display, where as a similar LED display consumes 500 mW.
- (2) They are made of the commonest elements, carbon, hydrogen, oxygen, nitrogen, rather than the more expensive elements



such as gallium, germanium, etc.

(3) Since they do not emit light themselves, but interfere with the passage of incident light, they cannot be "washed out" by strong incident light.

(4) They are compatible with PMOS circuits.

There are, needless to say, disadvantages as well:

(1) Since they are passive, i.e. they do not emit light, they cannot be read in the dark, however, this can be overcome by providing background illumination. This increases power consumption; the power consumed however does not have to pass through the addressing circuit, as it does in LED displays.

(2) Since they are operating in a phase between solid and liquid their temperature range is limited, at a maximum between  $-20^{\circ}\text{C}$  and  $100^{\circ}\text{C}$ , but more typically  $0^{\circ}\text{C}$  to  $60^{\circ}\text{C}$ .

Below this temperature the display freezes, above the maximum the liquid is isotropic and no display is visible. Furthermore, the response time near the freezing point is rather slow, in the order of 0.2-second rise time and 0.6-second fall time. Freezing or liquifying the display does no permanent damage, but temperatures in excess of  $150^{\circ}\text{C}$  may cause irreversible damage. There is no doubt that future development will broaden this temperature range considerably.

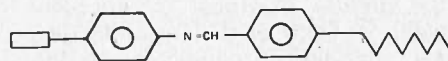
(3) The lifetime is still limited, but provided conditions are ideal it is now well in excess of 100,000 hours. Future development of materials with higher purity, and chemical stability will improve this a great deal.

Stability may be affected by several factors. Firstly, certain liquid crystalline materials undergo irreversible chemical changes under d.c. conditions, it is critical that such

display have no d.c. components whatsoever in the addressing circuit, secondly chemical changes are caused by impurities. Thirdly, certain liquid crystalline materials are effected by ultra violet light.

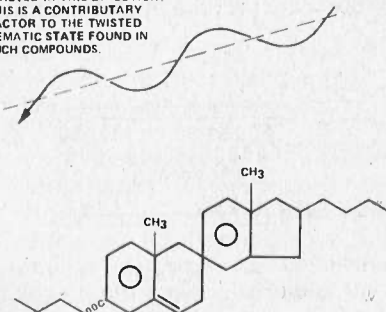
### Chemistry

We have no intention of discussing the detailed chemistry of the materials used — it is quite complex — and most names are longer than those found in the small print on toothpaste tubes. However, an outline of the structure of a typical nematic and a typical cholesteric material are included for comparison:



*Fig. 5. A 'Shiffs' Base. This has a fairly straight structure about seven times as long as it is broad.*

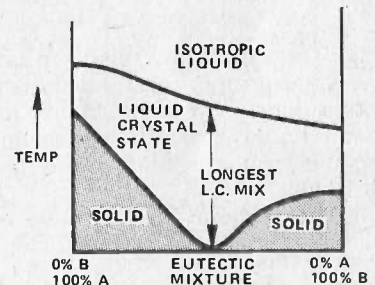
TWISTED IN THIS DIRECTION. THIS IS A CONTRIBUTORY FACTOR TO THE TWISTED NEMATIC STATE FOUND IN SUCH COMPOUNDS.



*Fig. 6. A cholesterol ester. The molecule is about 8-10 times longer than it is broad.*

The actual material used in a display is not usually pure, it is more frequently a mixture of two or more nematics. This has the advantage of increasing the liquid range by the creation of a "Eutectic" mixture.

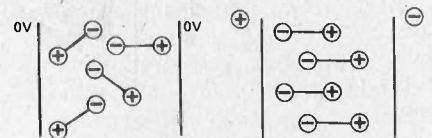
The anisotropic properties that materials suitable for display pur-



poses must include are:

(1) The refractive index is different as the material is viewed from different aspects, i.e. the light is bent more as it passes through the material in one direction than another.

(2) The molecule must possess a dipole. This is an uneven distribution of charge on the molecule, which causes it to align in an electric field thus:



*Fig. 8.*

A large proportion of organic molecules possess such dipoles. The dipole on the materials used in liquid crystalline displays have two components, one along the long axis ( $\epsilon_{ll}$ ) and one perpendicular ( $\epsilon_{\perp}$ ) to it.

If the dipole along the long axis A is greater than dipole perpendicular to it, it is said to possess positive dielectric anisotropy. If the dipole is greater on the perpendicular axis



# LIQUID CRYSTALLINE DISPLAYS

it is said to possess negative dielectric anisotropy.

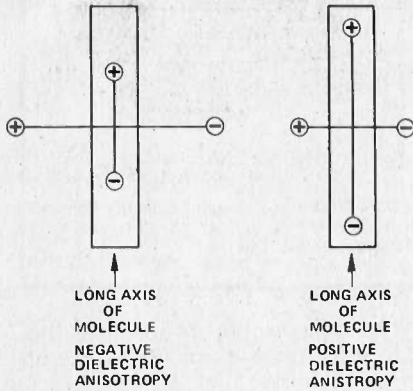


Fig. 9.

(3) The material also must possess anisotropic conductivity (as graphite does). The conductivity in nematic liquid crystals is greater along the long axis than perpendicular to it.

(4) The material should have a resistivity of the order of  $10^9 \Omega \text{ Cm}$ .

## Display construction

The displays work in two different ways, but the construction of the cells are similar, the differences are

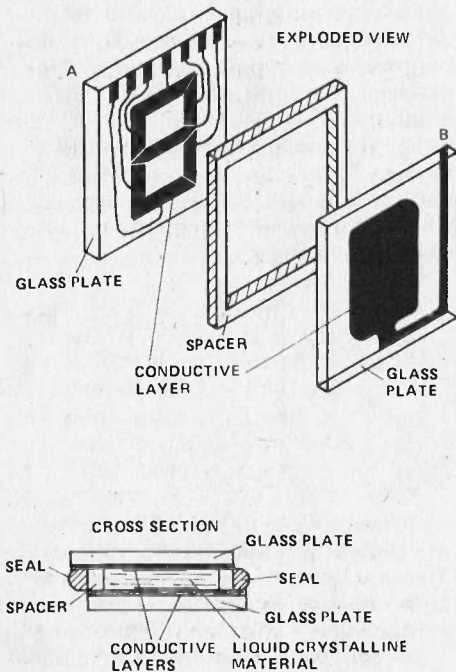


Fig. 10.

mainly in the filters on the back and faces of the display and of the type of background.

The cell consists of a very thin layer (about  $12 \mu\text{m}$ ) of the liquid crystalline material between two sheets of glass which have a conductive coating on their inside. One glass plate (a) has the actual seven-segment display etched on it. The other plate (b) has a common electrode etched on it. This conductive coating is either tin oxide, or a mixture of tin and indium oxides. This provides an electrode with about 90% transmission of light.

This conductive coat is further treated so that the molecules align themselves with the surface while an electric field is not applied.

This provides a more or less translucent display. When an electric field is applied, the molecules move so as to align their dipoles with the electric field. This causes changes in the optical properties of the liquid crystal material which appears as the display.

There are two principle techniques used here, dynamic scattering and polarization modes.

## Dynamic scattering:

In this mode the liquid crystalline material is chosen such that it has negative dielectric anisotropy, with the greater electrical conductivity along its long axis. The molecules are normally perpendicular to the surface when an a.c. field is applied the molecules, in clusters, move to re-align their dipoles with the field. The re-alignment of the dipole is in opposition to the conductivity and the liquid becomes

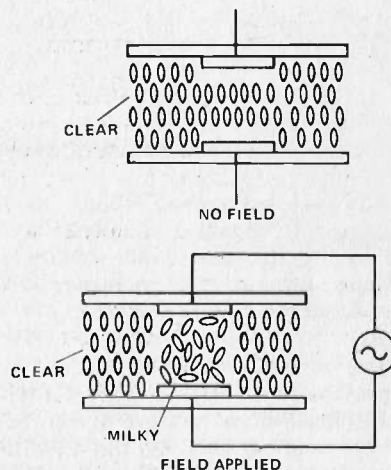


Fig. 11.

turbulent. This turbulence is seen as milkiness in the display.

Since there is no light emitted the display must be used to modify the passage of incident light. This may be done either by passing light through the display, or more usually by reflecting light from a mirror behind the display.

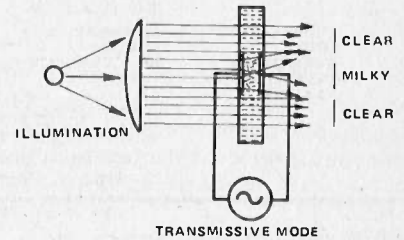


Fig. 12.

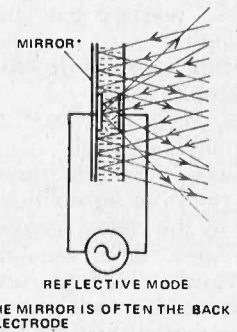


Fig. 13.

The transmissive cell will appear to glow where the segments are switched on. The reflective cell will appear misty where the segments are switched on. These displays have the shortcoming of a rather low "contrast ratio." That is, the apparent difference between the switched on and switched off display is not very great.

## Polarization modes

The display is constructed in basically the same way as the dynamic scattering cell. The difference lies in the type of liquid crystalline material. The material used is one which assumed a twisted nematic structure, and has positive dielectric anisotropy (the major component of its dipole along its long axis).

In this case the inside faces of the cell are coated so that the molecules are parallel to them and aligned in a particular direction when no electric field is applied.

The cell thickness is designed so that there is a complete  $90^\circ$  turn of molecules between the top and

bottom faces. The twisted nematic has the property that it twists light that passes through it. Polaroid filters are fitted above and below the cell so that light is polarized as it enters, and is twisted through 90° existing through a filter opposed at 90° to the first. The light is then reflected off a mirror and returns via the same pathway.

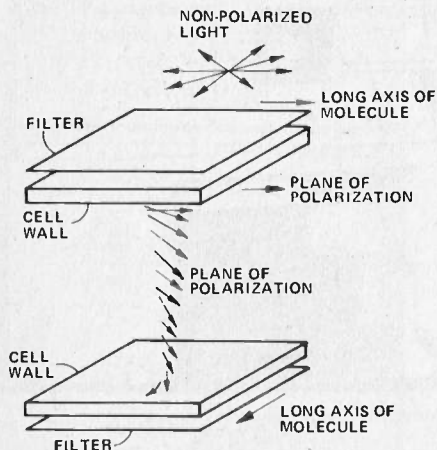


Fig. 14.

In this state the cell is clear. When an electric field is applied the molecules re-orientate to lie perpendicular to the faces of the cell and no longer twist the light. The light is now polarized as it enters the cell, and without being twisted, meets the second filter which is at right angles to the first and so does not pass the light. Hence that portion of the display with the field applied appears black (since no light is reflected).

If you have not seen this effect before take two pairs of polaroid sun glasses, look at a source of light with one in front of the other, thus:



Fig. 15.

Held in this way light, although polarized, is free to pass through the second filter since the plane of polarization is the same for both lenses. If one lens is now rotated through 90° thus:

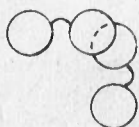


Fig. 16.

No light passes since the light polarized by the first lens will not pass through the second.

The effect of having the "crossed polaroids" in the cell causes almost total extinction of reflected light and consequently a high contrast ratio, an almost completely black and white display. This is many times better than the dynamic scattering cells.

### Addressing technique:

The cells are normally operated under a.c. conditions (although some cholesteric cells may operate under d.c.

The technique commonly used is to have d.c. pulses of identical amplitude, one applied to the back, the other to the display segment via an exclusive — or gate. In the off state the two signals are in phase, in the on state they are out of phase.

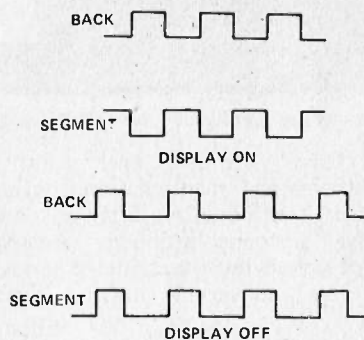


Fig. 17.

This technique has limitations due to the large number of both circuits and connections, however this has been overcome by putting the circuit on the glass of the display using thick film techniques!

Alternatives to this form of drive are to use multiplexed addressing, or m.o.s. shift register memory.

### Other uses of liquid crystals:

The use of liquid crystal is not restricted to electrical displays.

#### Temperature measurement:

Certain nematic liquid crystals (cholesteric) change colour over the whole range of the spectrum (red to violet) as their temperature changes. Furthermore the colour change is over a very narrow temperature range, usually 2° or 3°C. The temperature at which this happens and the range over which the change takes place can be adjusted by use of mixtures of different cholesterics.

A set of 10 or 12 of such cells in a row, the following one starting to show colour at 2°C higher temperature than the previous one, forms a useful thermometer working over a fairly restricted range. They have



Liquid crystal displays have made big inroads into the watch market but this may only be the beginning of the story.

found application as living room and refrigerator thermometers.

Perhaps a more important application is using liquid crystals which have a very narrow range over which they change colour (0.5°C). They have found application in medicine since they can resolve differences of 0.05°C.

Assuming the liquid crystal is set to show colour at normal skin temperature any local deviation from the correct temperature will show as a different colour. This has applications in detecting cancers, since they tend to be hotter than normal body heat. They can also be used to see areas of poor blood flow, or where allergic reactions are taking place, since they are slightly hotter or colder than the normal body temperature.

Cells with extremely low temperature resolution can even detect field intensity patterns of microwaves and ultrasonic sound fields due to local heating effects.

As might be expected there are also cells which change colour with applied electric field. This would appear to have interesting prospects for the future.

Other interesting possibilities which occur include the "memory effect". Certain cholesterics take hours, or some cases weeks, to return to their clear liquid crystalline state after they have been scattered by an applied electric field. The clear state can be restored by applying a different electric field.

Clearly liquid crystal technology has an enormous amount to offer a wide variety of fields — electronics, medicine and others. We are likely to see further interesting developments in the next few years as this technology takes over, and improves on existing display techniques. How about an alpha numeric display with independently variable colour segments? ●



# introduction to computers

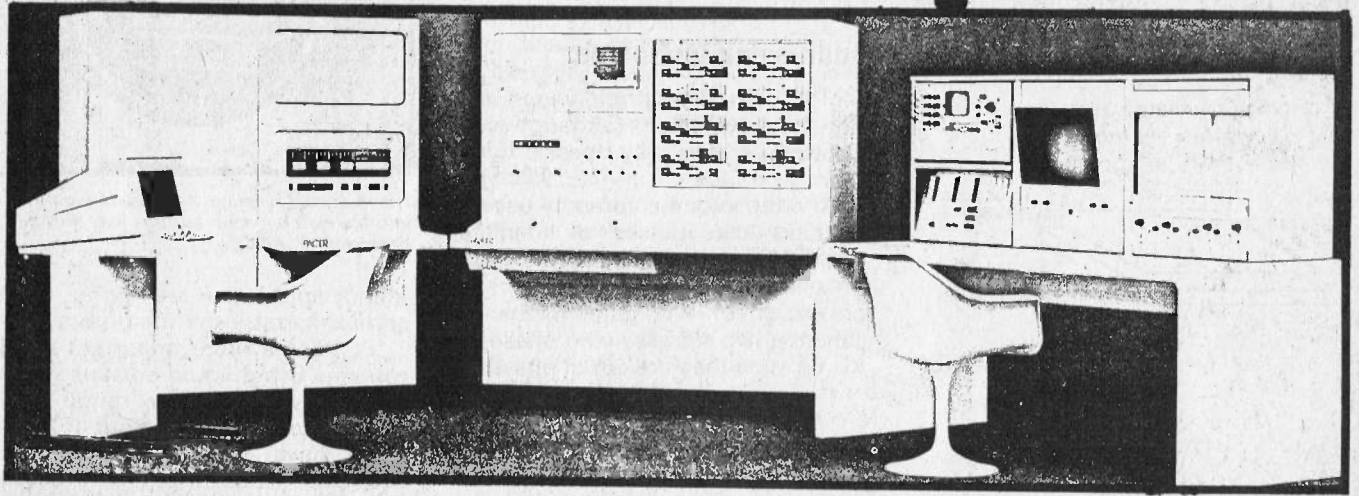


Fig. 1. Here a digital computer and an analogue computer are combined — the result is known as a hybrid computer.

IN THE LIGHT of growing interest in microcomputers and computing techniques in general many readers require some basic grounding in digital computers. What follows is necessarily an introduction only — computers are now extremely sophisticated in design and the manufacturing methods very specialised. It is, however, quite important that the operation of computers be understood by electronic craftsmen at a general systems level. This general article will introduce the philosophies, the hardware and the operation of digital computers from a technical rather than user-only viewpoint. (Analogue computers are still valuable in some applications but in general, machine computing is now mainly done digitally).

## WHAT IS A COMPUTER?

Regardless of whether a computer is digital or analogue in operation its role is to perform various kinds of mathematical operations. The analogue machine cannot perform logic operations: (unless joined with a digital computer, in which case it is known as a hybrid computer — as shown in Fig. 1) its use is generally restricted to what are called linear mathematical problems in which signals vary continuously and information is transferred as levels not as digital codes. Analogue computers can be very good at such operations, often better than a digital computer of similar cost. The digital machine, on the other hand, (a general purpose installation is shown in Fig. 2) can

perform almost any kind of mathematical manipulation, however special techniques are often needed to solve analogue problems. Analogue type signals must be sampled and each sample converted into a digital equivalent before they can be processed in digital machines: this is where the digital machine in certain applications may be less efficient than the analogue alternative.

As well as performing arithmetical operations (called scientific computing) the digital machine can be instructed to process or sort discrete data in digitally encoded form (called data processing or DP, for short). Typical computer data processing operations are the sorting of numerical

data — for example to see how many people have heights of various chosen values, or the booking of airline seats. Mixed working, where scientific calculation and data-processing are both involved, occurs for example, in costing out a building estimate, raising a stock value for a business, or producing pay-slips.

Digital computers may also calculate tables by automatically incrementing the input data between preset limits. For example the computer could be asked to generate and print the sines of all angles between  $10^\circ$  and  $90^\circ$  at  $1^\circ$  intervals.

We pause now to note that we call such machines computers *not* calculators. The term calculator has

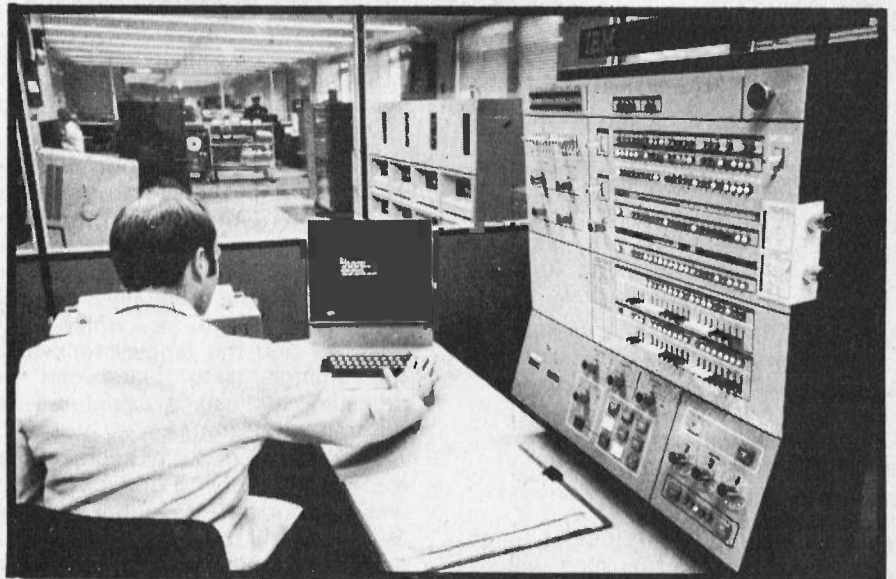


Fig. 2. General purpose digital computer, this centre is used by Lloyds Bank.

traditionally been used to describe machines which perform a fixed set of mathematical calculations. The term computer on the other hand, is reserved for those machines which may be reconfigured by a set of programme instructions to perform any particular task. However such distinction between the roles of calculator and computer is becoming increasingly difficult to make. Some computers are now dedicated to performing calculator like tasks and some calculators are now so flexible that they can be programmed to perform a variety of tasks.

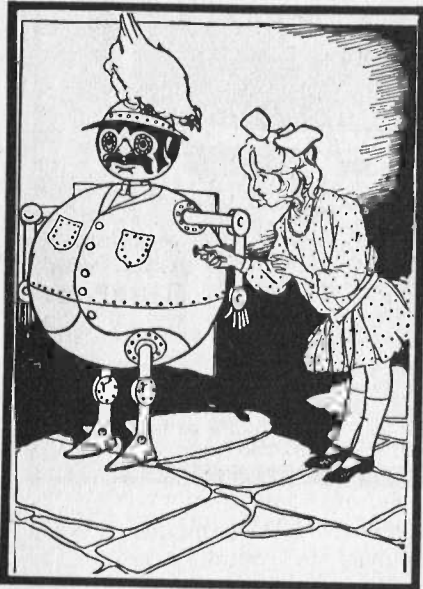


Fig. 3. As yet, computers can only do what they are programmed to do.

In the 1950s, when powerful electronic computers were emerging, the popular concept was of a machine that would soon have thinking powers of its own — and its own will and imagination — as depicted in Fig. 3. Although we must concede such is probably possible one day — no one has yet gained an inkling into how this extra facility could be realised. Computers are merely machine slaves that, if working internally as the designer thinks and intends, will perform as commanded. The operator informs the machine of its job via the programme presented to it. Where the computer has valuable merit is in its ability to perform calculations and process numerical data at rates vastly greater than a human mind, with rarely an error, and for hours on end if need be. It is a tool and no more. To say the computer accidentally sent the \$1,000,000 bill to Bill Blogs is entirely incorrect. The programmer or the machine did not perform as hoped through one or the other being defective in the instructions given or the way they were obeyed.

As well as computers that operate

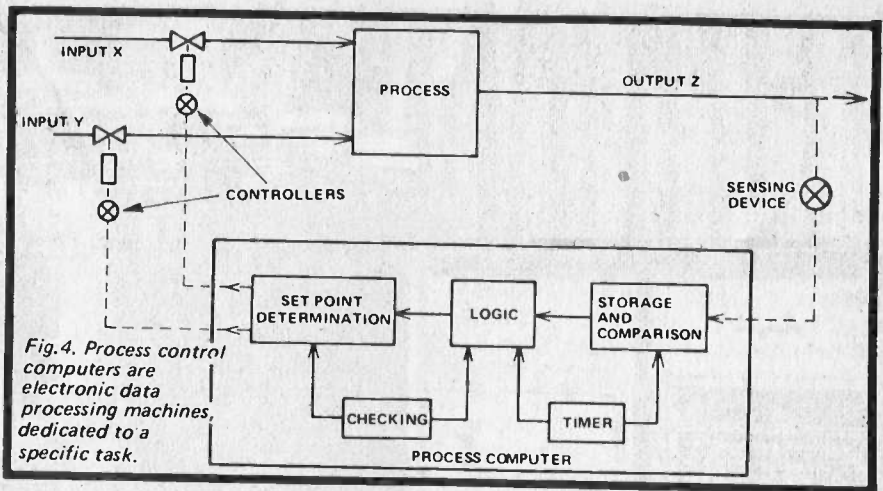


Fig. 4. Process control computers are electronic data processing machines, dedicated to a specific task.

only when the operator gives instructions there is also the dedicated machine that, once set internally to compute or process in a predetermined way, becomes part of a process. It helps control by working at the same rate as signals are generated in the process — real time working. Process-control computers, as these are called, operate on data and perform calculations as part of many feedback loops in, say, a chemical plant. Figure 4 shows this use in a diagrammatic form. Other names variously used to describe this use are in-line, on-line, direct-digital-control (DDC) or just plain computer control. Wherever automation of extensive complex process is necessary a computer will usually be found — waste-water

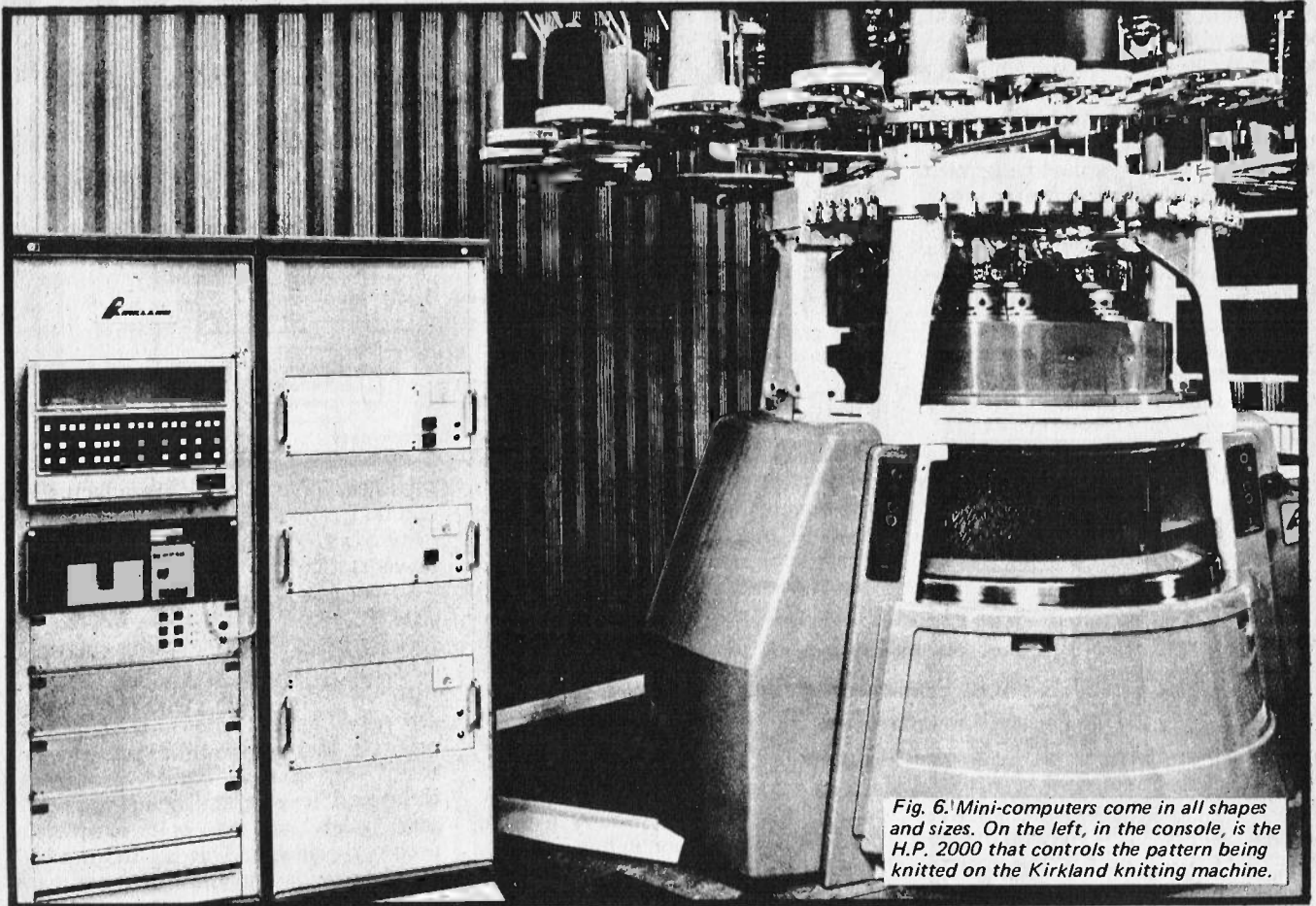
treatment plants, paper manufacture, natural gas and electricity distribution networks, satellite control and power-station plant operation are but a few of thousands of in-line applications. Computers are far more useful in this task than human operators — see Fig. 5.

On-line operation (although not generally agreed upon) is a term probably best reserved for cases where each of many input terminals connected to a central computer can gain access to the unit when it becomes available. This is also known as time-sharing and is used where the signal processing rate need not match the process. The computers used in banking often operate in a time-sharing mode — bank branches.

	Machine	Man
<b>Speed</b>	Much superior	Lag 1 sec.
<b>Power</b>	Consistent at any level	1500W for about 10 sec, 350 W for a few minutes, 150 W for continuous work over a day.
<b>Consistency</b>	Ideal for routine, repetition, precision	Not reliable — should be monitored by machine.
<b>Complex activities</b>	Multi-channel	Single channel.
<b>Memory</b>	Best for literal reproduction and short-term storage	Large store multiple access. Better for principles and strategies.
<b>Reasoning</b>	Good deductive	Good inductive.
<b>Computation</b>	Fast, accurate — poor at error correction	Slow, subject to error
<b>Input sensitivity</b>	Some outside human senses, e.g. radioactivity	Good at error correction.
	Insensitive to extraneous	Wide range (10 <sup>12</sup> ) and variety of stimuli dealt with by one unit, e.g. eye deals with relative location, movement and colour.
	Poor for pattern detection	Affected by heat, cold, noise and vibration.
<b>Overload reliability</b>	Sudden breakdown	Good at pattern detection. Can detect signals in high noise levels.
<b>Intelligence</b>	None	Graceful degradation. Can deal with unpredicted and unpredictable.
<b>Manipulative abilities</b>	Specific	Can anticipate. Great versatility.

Fig. 5. Fitt's list summarizes the relative advantages of man versus machine control.





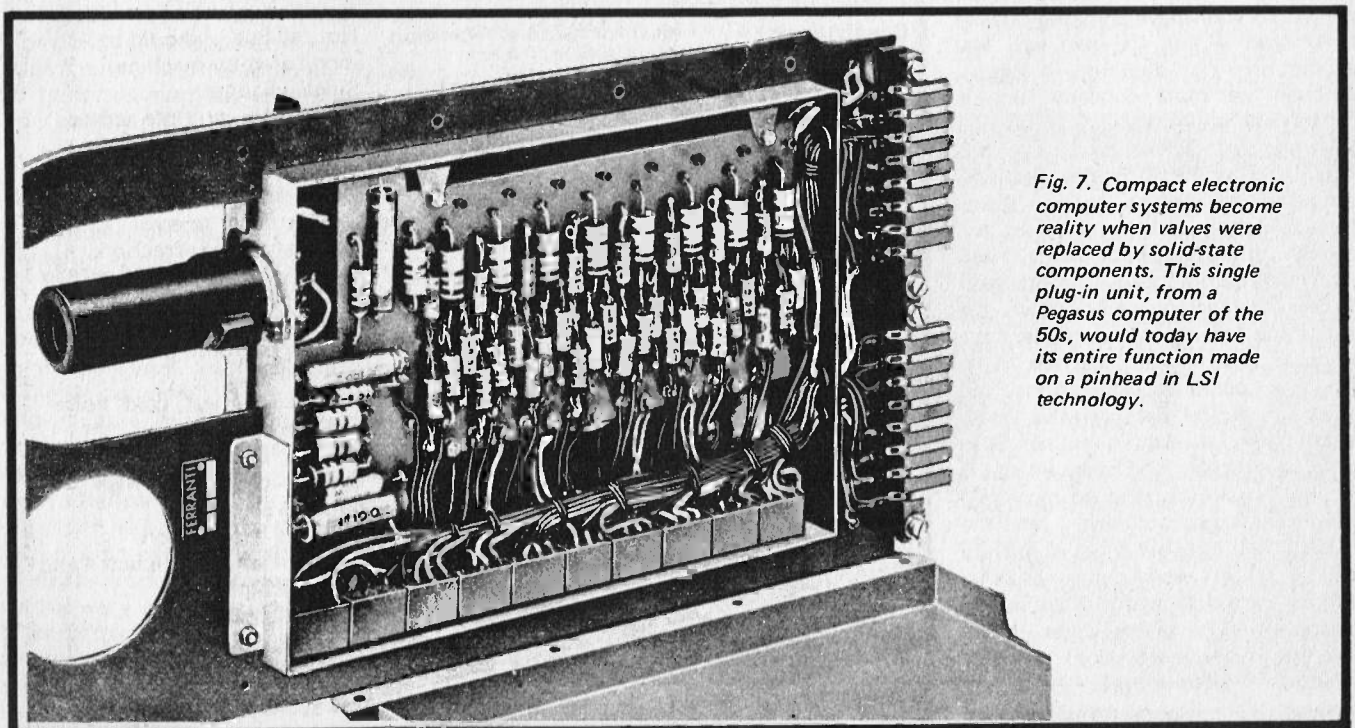
*Fig. 6. Mini-computers come in all shapes and sizes. On the left, in the console, is the H.P. 2000 that controls the pattern being knitted on the Kirkland knitting machine.*

can gain access to the central account records — a short wait may be necessary. When the computer works on diverse problems at the will of the operator and is not used for any dedicated purpose it is said to be off-line. Originally electronic computers were

huge — several rooms filled with racks of valve electronic circuits. In the mid-sixties manufacturing techniques and designs were such that a new style of less versatile but compact computer was marketed — the so-called minicomputer. Figure 6 shows but one

kind of mini-computer system employed to control a process by providing instructions as needed. (It is not used in closed-loop as this process does not feed data back to the computer).

We do not use the word "generation"



*Fig. 7. Compact electronic computer systems become reality when valves were replaced by solid-state components. This single plug-in unit, from a Pegasus computer of the 50s, would today have its entire function made on a pinhead in LSI technology.*

in connection with the minicomputer because that term is used in computer jargon in two distinct ways. It may describe the hardware used — first generation computers use thermionic valves and ordinary cable wiring, such as shown in Fig. 7, second generation machines use discrete transistor circuits on printed-circuit boards, third generation machines use integrated-circuitry and the most recent fourth generation computers use large-scale-integration LSI manufacturing methods — A fifth generation computer is yet to emerge as an accepted concept. The other use of "generation" is in describing the system interconnections — the philosophy of system hardware interconnection and style, and capacity of the store involved.

## A HISTORY OF COMPUTING MACHINES

Intertwined with the development of machine operated logic, was the gradual increase in sophistication of computing machine systems.

Earliest devices were simple calculators based on mechanical concepts. They performed simple addition, subtraction and sometimes multiplication and division, doing this without the ability to store or hold values other than inputs and computed output.

Space does not permit extensive description of this history — see the reading list for that. Figure 8 shows the style of the first calculating machine of the "modern" kind. This performed arithmetic addition and subtraction only, by mechanically manipulating interconnected counting wheels and was probably made by Pascal in 1642. In 1671 Leibniz modified the same mechanism (see Fig. 8) to obtain multiplier action, producing his own design calculator much later — in 1694. Because mechanism manufacture at that time was crude indeed — all parts were individually hand-crafted — the Leibniz machine was not reliable even though the concepts involved were sound. Improvements in mechanical manufacture had to occur before a routinely useful gear and crank calculator could be built (by de Colmar in 1820). Thus, through these and many other gradual improvements to method and manufacture, the scene was set for grander ideas.

A major advance was made by Babbage. Charles Babbage was born in Devon, England. In 1792, he became a Professor of Mathematics at Cambridge University and had a consuming passion for mechanical machines that could perform far more

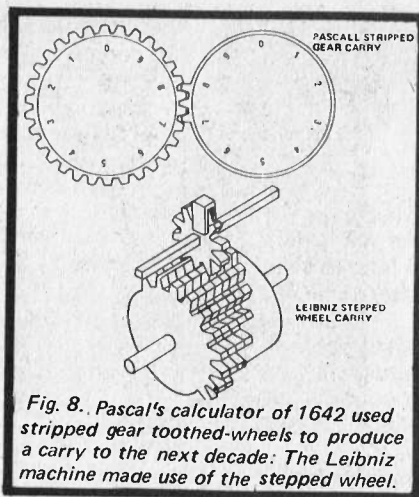


Fig. 8. Pascal's calculator of 1642 used stripped gear toothed-wheels to produce a carry to the next decade: The Leibniz machine made use of the stepped wheel.

advanced mathematical operations than any previous apparatus. His first machine, shown in Fig. 9, was devised to solve differential equations by calculating differences. This was his "Difference Engine" of about 1812. In 1833 he conceived a second, quite different general-purpose engine — the so-called "Great Calculating Engine". In principle, it could do any

mathematical operation by following instructions programmed into it by the operators. It could also make decisions, on what to do next, that were based on its just calculated results.

Babbage used punched-cards for input information (a reasonably logical choice in view of the many repetitive industrial processes using this control medium at that time), a memory (which he called "the store"), a number processing section (called the mill), a means of transferring results to and from the store, and automatic output (as cast type ready to print). It was a grand machine having ability to store 1000 fifty-digit numbers in its store. It even had overflow indication.

The intended power supply was steam. Sadly, Babbage's engines were not proven in practice in his time; those built were either not completed or proved too unreliable. Manufacturing methods were still incapable of maintaining the tolerances needed — it was a classical example of a concept waiting for the requisite technology.

Complicated mathematical equation solving in the 19th and very early 20th century was performed on other kinds

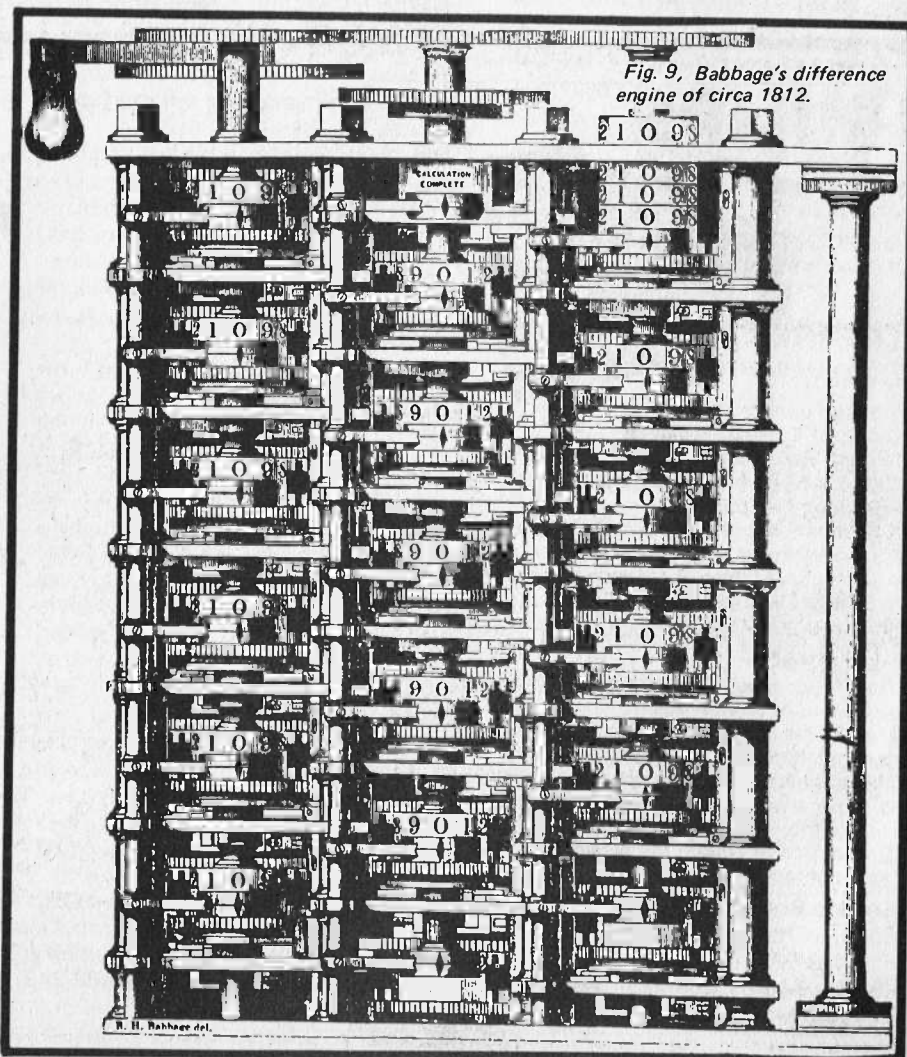


Fig. 9. Babbage's difference engine of circa 1812.



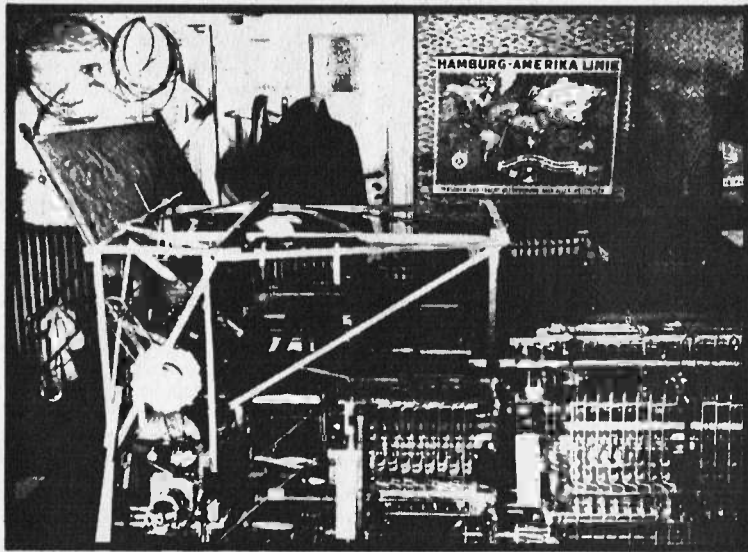


Fig. 10. This relay-switched digital calculator was built by Zuse in Germany in 1936. (This photograph has been included because of its historical interest — unfortunately the original print is of border-line quality).

of special purpose mechanical calculating devices. The planimeter, which determines area under a curve, was devised in 1814, the mechanical ball-and-disk integrator was devised in 1876 (by Lord Kelvin's brother). With these and other basic mechanical-function solving ideas, Lord Kelvin and others put systems together that carried out specialised calculations. Kelvin produced a tidal amplitude and phase predictor for sea-tide forecasting around 1874. Later in 1898 Michelson (of speed of light fame) worked with Stratton to produce a mechanical harmonic analyser.

Special-purpose mechanical calculators were still in use in the 1940s. During World War II, for instance, gun crews fed data concerning range, direction and wind strength into computers by which the correct aiming information for the gun was computed.

Today a few equipments still perform simple operations by mechanical means for in applications where electrical power is not available and the inputs not in electrical form it may be more economic to use mechanical methods.

With the advent of electronic amplification at the turn of this century electronic circuitry gradually replaced mechanical mathematical functions. This was feasible because of the superior speed of calculation, reduced manufacturing tolerances and greater reliability of electronics. The swing to electronics was intensified by the need to process an ever increasing amount of data that arises in, for example, more complex equation solving, census taking, or warfare.

Hollerith devised the punched-card sorting machine to help handle the U.S. census data. This device won an 1890 competition organised by the U.S. Government.

Electric computers using the same basic system that we use today became reality around 1936 when Zuse, in Germany, built the relay-switched digital calculator (shown in Fig. 10). This machine featured automatic computing, binary arithmetic, floating decimal point and punched-tape programming. In 1937 the USA's IBM Corporation began development of a machine called the Automatic Sequence-Controlled Calculator, or, locally, just Mark I.

The trend toward total electronic working continued. ENIAC, generally recognised as the first all-electronic computer, had 18 000 valves and could operate at 500 additions per second. This was followed, after many other developments, by the first production computer — the Remington Rand UNIVAC I. It has been estimated that all computers installed in the U.S. in 1955 could do just 250 000 additions per second. Just one low-cost mini can do that today.

In 1959 a U.S. refinery installed the first process-control computer system and in 1960 a large steel corporation in U.S. was the first to use a computer to carry out inventories, handle orders and control production. Airline booking by computer began in 1964.

Integrated circuits (in the third generation machines) came into use in 1964 via the IBM 360 system and by 1970, in the U.S. alone, roughly 1 000 000 people were employed in making and using digital computers. Single chip, fourth generation

machines came to reality around 1972 with the use of LSI. Today pocket scientific calculators containing over 30,000 transistors in LSI form can be purchased for about \$40. In 1974 the world market for small calculators was estimated to be 40 million! The cost of modern computers is now governed by the cost of the peripheral bits and pieces rather than the processing unit itself — the cost of the electronic components is now just a minor part of the whole.

#### Further reading

"A Computer Perspective", C. and R. Eames, Harvard University Press, Massachusetts, 1973. (This is a definitive work on the development of data processing equipment from 1800 to 1940).

"Electronic Computers -- Made Simple", H. Jacobowitz and L. Basford, W.H. Allen, London, 1967. (Although out of date with respect to certain aspects of hardware this provides a valuable basis for technical understanding of both analogue and digital computers. It also explains the arithmetical operations).

"Introducing Computers", M. Laver, HMSO, London, 1973. (A version compiled for users with a little technical knowledge. It discusses programming procedures).

"Computers at work" J.O.E. Clark, Bantam Books, London 1973 (A most useful book on where computers are used).

"Electronic Computers", S.H. Hollingdale and G.C. Tootill, Penguin Book A524, Harmondsworth, 1965. (A fine layman's summary of analogue and digital computers including a lengthy chapter on what sort of jobs computers do).

Computer programming is covered in many texts and booklets. One example is:

"Elements of Computer Programming", K.P. Swallow and W.T. Price; Holt, Rinehart and Wilson, New York, 1965.

ALGOL language began to emerge in 1958 as a step toward a universal computer language for scientific working. COBOL is the commercial counterpart. Relevant books are:

"Basic ALGOL", W.R. Broderick and J.P. Barker, IPC Electrical and Electronic Press, 1970.

"A Guide to COBOL Programming", D. McCracken, Wiley, New York, 1970.

# ETI DATA SHEET

## MC14490 HEX BOUNCE ELIMINATOR

MOTOROLA

The MC14490 is constructed with complementary MOS enhancement mode devices, and is used for the elimination of extraneous level changes that result when interfacing with mechanical contacts. The digital contact bounce eliminator circuit takes an input signal from a bouncing contact and generates a clean digital signal four clock periods after the input has stabilized. The bounce eliminator circuit will remove bounce on both the "make" and the "break" of a contact closure. The clock for operation of the MC14490 is derived from an internal R-C oscillator which requires only an external capacitor to adjust for the desired operating frequency (bounce delay). The clock may also be driven from an external clock source or the oscillator of another MC14490.

### CHARACTERISTICS

The single most important characteristic of the MC14490 is that it works with a single signal lead as an input, making it directly compatible with mechanical contacts.

The circuit has a built in pullup resistor on each input. The worst case value of the pullup resistor is used to calculate the contact wetting current. If more contact current is required, an external resistor may be connected between  $V_{DD}$  and the input.

Because of the built in pullup resistors, the inputs cannot be driven with a single standard CMOS gate when  $V_{DD}$  is below 5V. At this voltage, the input should be driven with paralleled standard gates or by the MC14049 or MC14050 buffers.

The clock input circuit (pin 7) has Schmitt trigger shaping such that proper clocking will occur even with very slow clock edges, eliminating any need for clock preshaping. In addition, other MC14490 oscillator inputs can be driven from a single oscillator output buffered by an MC14050.

The MC14490 is TTL compatible on both the inputs and the outputs. When  $V_{DD}$  is at 4.5V, the buffered outputs can sink 1.6 mA at 0.4V. The inputs can be driven with TTL as a result of the internal input pullup resistors.

### OPERATION

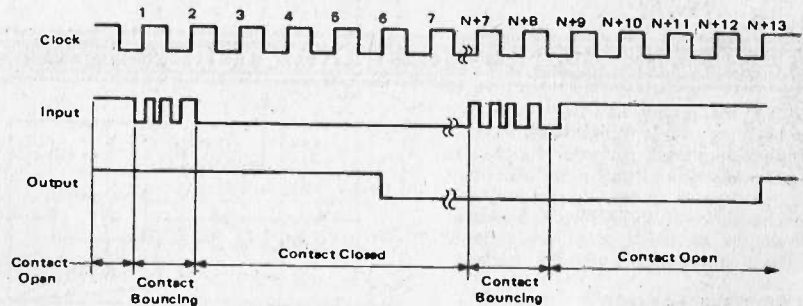
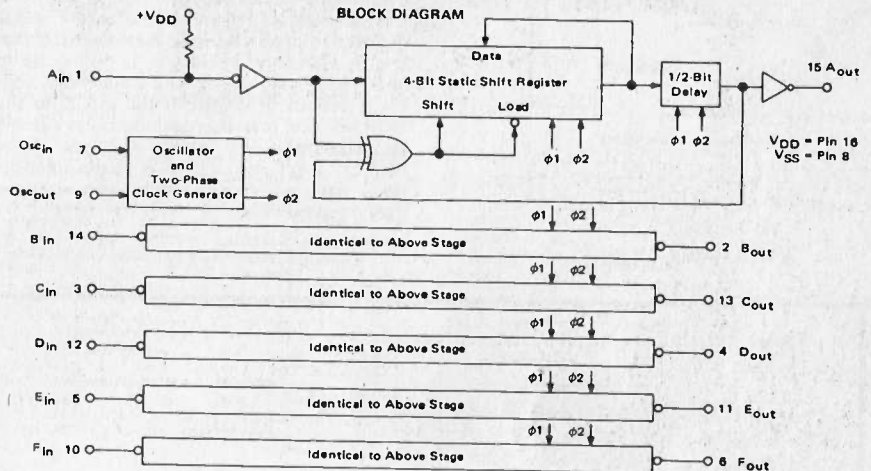
To understand the operation, we assume all bits of the shift register are loaded with 1's and the output is at a 1 or high level.

At clock edge 1 the input has gone low and a 0 (low level) has been loaded into the first bit or storage location of the shift register. Just after the positive edge of clock 1 in input signal has bounced back to a logic 1. This causes the shift register to be reset to all 1's in all four bits — thus starting the timing sequence over again.

During clock edges 3 to 6 the input signal has stayed low. Thus a logic 0 has been shifted into all four shift register bits and, as shown, the output goes to a 0 during the positive edge of clock pulse 6.

It should be noted that there is a  $3\frac{1}{2}$  to  $4\frac{1}{2}$  clock period delay between the clean input signal and output signal. In this example there is a delay of 3.8 clock periods from the beginning of the clean input signal.

After some time period of N clock periods, the contact is opened and at N+7, a 1 is loaded into the first bit. Just after N+7, when the input bounces low, all bits are reset to 0. At N+8 nothing happens because the



input and output are low and all bits of the shift register are 0. At time N+9 and thereafter the input signal is a high (1) clean signal. At N+13 the output goes high (1) as a result of four 1's being shifted into the shift register.

Assuming the input signal is long enough to be clocked through the Bounce Eliminator, the output signal will be no longer or shorter than the clean input signal plus or minus one clock period.

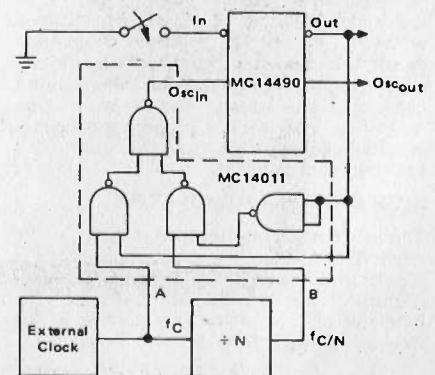
### CLOCKING

The only requirement on the clock frequency in order to obtain a bounce free output signal is that four clock periods do not occur while the input signal is in a false state.

If the user has an available clock signal of the proper frequency, it may be used by connecting it to the oscillator input (pin 7). However, if an external clock is not available the user can place a small capacitor across the oscillator input and output pins in order to start up an internal clock source. The clock signal at the oscillator output pin may then be used to clock other MC14490 Bounce Eliminator packages. With the use of the MC14490, a large number of signals can be cleaned up, with the requirement of only one small capacitor external to the Hex Bounce Eliminator packages.

### ASYMMETRICAL TIMING

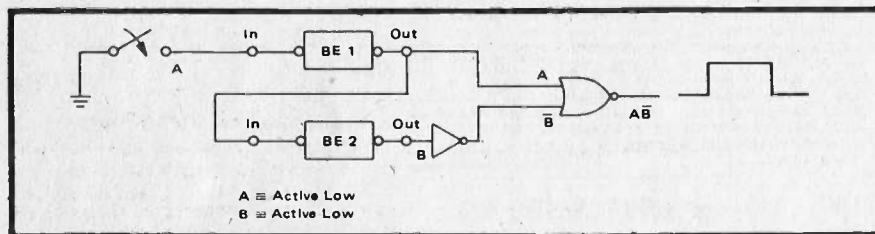
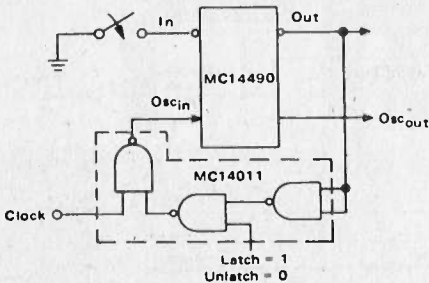
In applications where different leading and trailing edge delays are required (such as a fast attack/slow release timer.) Clocks of different frequencies can be gated into the MC14490. In order to produce a slow attack/fast release circuit leads A and B should be interchanged. The clock out lead can then be used to feed clock signals to the other MC14490 packages where the asymmetrical input/output timing is required.





**LATCHED OUTPUT**

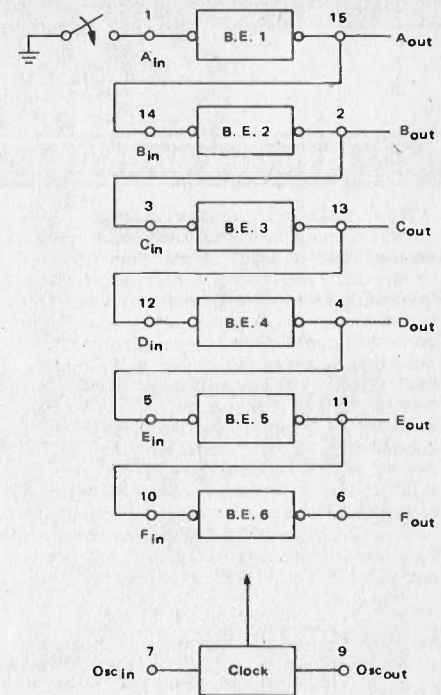
The contents of the Bounce Eliminator can be latched by using several extra gates. If the latch lead is high the clock will be stopped when the output goes low. This will hold the output low even though the input has returned to the high state. Any time the clock is stopped the outputs will be representative of the input signal four clock periods earlier.



**MULTIPLE TIMING SIGNALS**

Bounce Eliminator circuits can be connected in series. In this configuration each output is delayed by four clock periods relative to its respective input. This configuration may be used to generate multiple timing signals such as a delay line, for programming other timing operations.

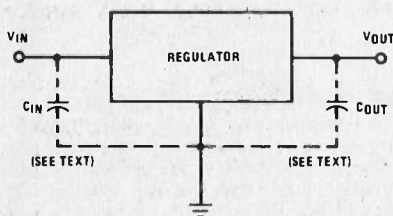
One application of the above is where it is required to have a single pulse output for a single operation (make) of the push button or relay contact. This only requires the series connection of two Bounce Eliminator circuits, one inverter, and one NOR gate in order to generate the signal AB. The signal AB is four clock periods in length. If the inputs to the NOR gate are interchanged the pulse AB will be generated upon release or break of the contact. With the use of a few additional parts many different pulses and waveshapes may be generated.



**THREE TERMINAL VOLTAGE REGULATORS**

Voltage regulator use can be expanded beyond that of the simple three-terminal fixed voltage regulator. Some of the circuits which are practical and useful are described in this section. Pertinent equations are included rather than providing fixed component values as the circuits are equally applicable to all regulators within a family.

**POSITIVE REGULATORS**

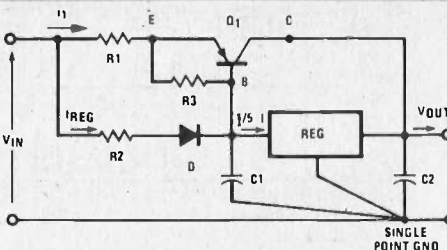


**FIGURE 1 Basic Regulator Connection**

If the regulator is located more than two inches from the supply filter capacitor, a supply bypass capacitor is required to maintain stability (much as is the case with op-amps). This should be a 0.22 μF or larger disc ceramic, 2 μF or larger solid tantalum, or 25 μF or larger aluminium electrolytic capacitor. Transient response of all the regulators is improved when output capacitors are added. To minimize high frequency noise, an 0.1 μF output capacitor is recommended on the LM78LXX and LM309 series.

**HIGH CURRENT REGULATOR**

This current circuit takes advantage of the internal current limiting characteristics of the regulator to provide short-circuit current protection for the booster as well. The regulator and Q<sub>1</sub> share load current in the ratio set between R<sub>2</sub> and R<sub>1</sub> if V<sub>O</sub> = V<sub>REG(Q1)</sub>.



**FIGURE 2 High Current Regulator with Short Circuit Limit During Output Shorts.**

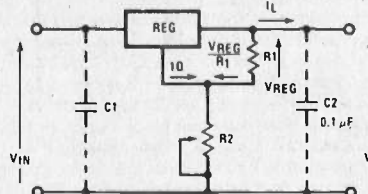
$$I_1 = \frac{R_2}{R_1} I_{REG}$$

During output shorts

$$I_{1(SC)} = \frac{R_2}{R_1} I_{REG(SC)}$$

If the regulator and Q<sub>1</sub> have the same thermal resistance θ<sub>JC</sub> and the pass transistor heat sink has R<sub>2</sub>/R<sub>1</sub> times the capacity of the regulator heat sink, the thermal protection (shutdown) of the regulator will also be extended to Q<sub>1</sub>.

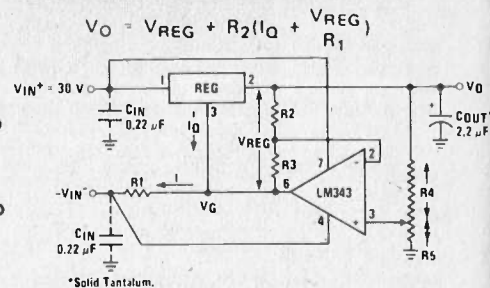
**ADJUSTABLE OUTPUT VOLTAGE**



**FIGURE 3 Adjustable V<sub>OUT</sub>**

A fraction of the regulator current V<sub>REG</sub>/R<sub>1</sub> is used to raise the ground pin of the regulator, and provide through voltage drop across R<sub>2</sub>, an adjustable output voltage.

**NATIONAL**



**FIGURE 4 Variable Output Voltage of 0.5 - 28V**

A wide range of output voltages can be obtained with the circuit of Figure 4. A 0.5- to 20-volt supply can be built using a 30-volt supply and a conventional op-amp, such as the LM143. If

$$R_2 + R_3 = R_4 + R_5 = R, \text{ and } R_2/R_3 = 1/10,$$

$$\text{then } V_O = V_{REG} \left( \frac{R_2}{R_4} \right) = V_{REG} \left( \frac{1}{11} \right) \left( \frac{R_4 + R_5}{R_4} \right)$$

Since V<sub>O</sub> is inversely proportional to R<sub>4</sub>, low output voltages can be very accurately set. The required R<sub>1</sub> is

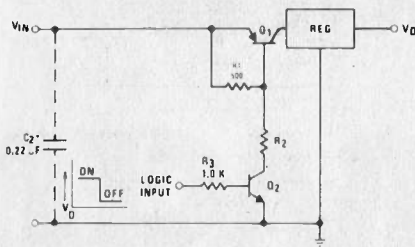
$$R_1 = \frac{V_{IN}}{I_Q}$$

The V<sub>O(MAX)</sub> is dependent on V<sub>IN</sub> and V<sub>dropout</sub>, provided that the amplifier can source the current required to raise V<sub>G</sub> to V<sub>O</sub> - V<sub>REG</sub>.

**Example:**

- V<sup>-</sup><sub>IN</sub> = -15 V    R<sub>1</sub> = 2K2
- V<sup>+</sup><sub>IN</sub> = +30 V    R<sub>2</sub> = 910R
- V<sub>O</sub> = 0.5-28 V    R<sub>3</sub> = 9K1
- LM340K-05    R<sub>4</sub> + R<sub>5</sub> = 10K

## ELECTRONIC SHUTDOWN



\* Required if regulator far from power supply filter

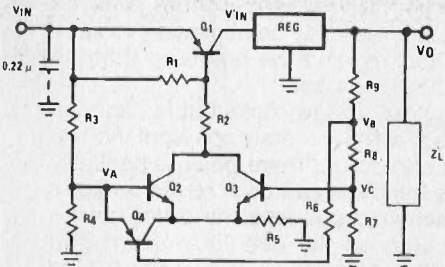
**FIGURE 5 Electronic Shutdown Circuit**

Electronic shutdown in three-terminal regulators is done by simply opening the input circuit using a transistor switch.  $Q_1$  operates as the switch which is driven by  $Q_2$ . The control voltage  $V_C$  can be TTL compatible with the use of  $R_3 = 1K$ .  $R_1$  is a biasing resistor, and  $R_2$  can be calculated as

$$R_2 = \frac{V_{IN} - 1V}{I_0} \beta_{SAT}(Q1)$$

Figure 6 illustrates a short-circuit-dependent power shutdown circuit with reduced heat sink requirements under short-circuit conditions.

When the power is first applied,  $Q_2$  turns ON and saturates  $Q_1$ . The regulator output ramps up to turn  $Q_3$  ON, which turns  $Q_2$  OFF ( $V_C$  should be  $> V_A$ ), thus maintaining  $Q_1$  in the ON state.



**FIGURE 6 Output Electronic Shutdown on High Voltage Regulator**

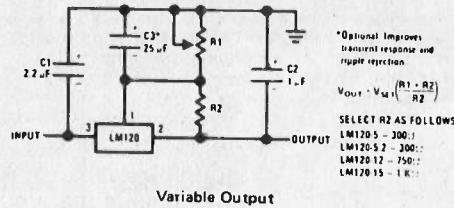
When the output is shorted,  $Q_3$  turns OFF,  $Q_4$  turns ON to clamp  $Q_2$  OFF.  $Q_1$  loses base drive and so opens to isolate the regulator from  $V_{IN}$ . When the short circuit is removed,  $Q_4$  loses some base drive and enables  $Q_2$  to re-start the regulator.  $Q_1$  always operates as a switch and needs no heat sinking.  $Q_2$  and  $Q_3$  need not be matched.  $Q_4$  may be any small signal PNP transistor. The entire circuit (less regulator) fits easily on a one-inch square PC board.

### Example: LM340K-24

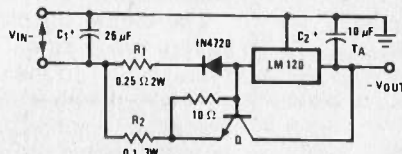
$V_{IN} = 36V$   
 $V_0 = 24V$   
 $I_0 = 1A$   
 $V_A = 2.5V$   
 $V_B = 8V$   
 $V_C = 4.8V$   
 $Q_1 = TIP 32$   
 $Q_2 = 2N4141$   
 $Q_3 = 2N4141$   
 $Q_4 = 2N2906$   
 $R_1 = 500R$   
 $R_2 = 250R, 2W$   
 $R_3 = 3K3$   
 $R_4 = 240R$   
 $R_5 = 62R$   
 $R_6 = 2K$   
 $R_7 = 1K$   
 $R_8 = 680R$   
 $R_9 = 3K3$

## NEGATIVE REGULATORS

All the applications circuits for positive regulators can be used with the polarities inverted for the negative regulator LM320/345 series (e.g., reverse the sense of the diodes, replace PNP's with NPN's etc., etc.).



Variable Output

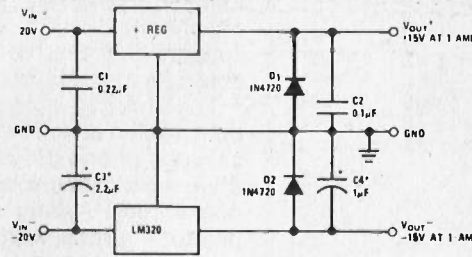


(d) High Current Regulator

$Q = 2N3055$  (for 5 A)  
 or TIP31 (for less than 2-3 A)

**FIGURE 7 Negative Regulator Circuits**

## BASIC DUAL POWER SUPPLY



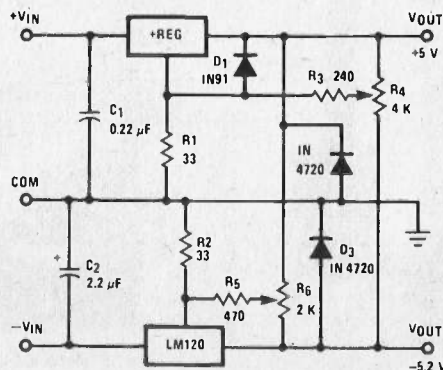
\*Solid tantalum

Note: C1 and C2 required if regulators are located far from power supply filter.

**FIGURE 8 Dual Power Supply**

A positive regulator can be connected with an LM320 to form a non-tracking dual power supply. Each regulator exhibits line and load regulation consistent with their specifications as individual devices. Protective diodes  $D_1$ ,  $D_2$  allow the regulators to start under common load. They should be rated at the regulator short circuit current.

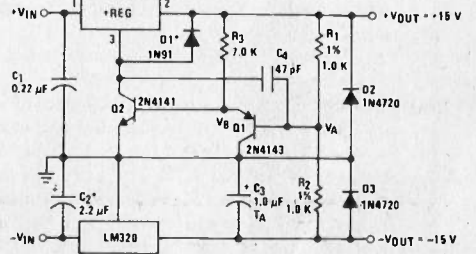
**FIGURE 9 Trimmed Dual Supply**



## TRIMMED DUAL SUPPLY

Figure 8 may be modified to obtain a dual supply trimmed to a closer output tolerance. The trimming potentiometers are connected across the outputs so positive or negative trimming currents are available to set the voltage across the  $R_1$  ( $R_2$ ) resistors.  $R_3$ ,  $R_5$  are included to linearize the adjustment and to prevent shorting the regulator ground pin to opposite polarity output voltages.

## Tracking Dual Supply



\* Solid Tantalum

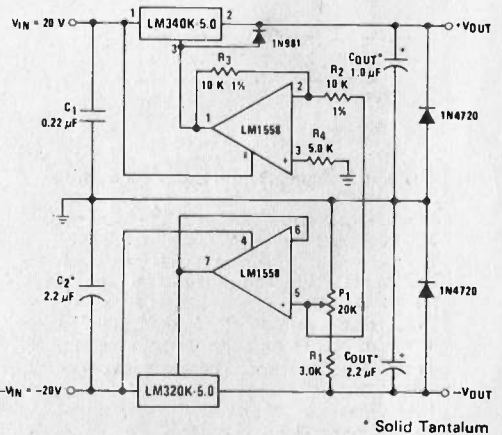
**FIGURE 10 Tracking Dual Supply**

A tracking supply can be built as in Figure 10 where the positive regulator tracks the negative regulator.  $V_A$  is a virtual ground under steady state conditions.  $Q_2$  conducts the quiescent current of the positive regulator.

If  $-V_{OUT}$  falls,  $V_A$  follows forward biasing collectorbase junction of  $Q_1$ .  $V_A$  falls, thus raising the collector voltage of  $Q_2$  and  $+V_{OUT}$  to restore  $V_A$  to desired voltage. Germanium diode  $D_1$  may be needed to start the positive regulator with a high differential load.

**Example:** +15V, 1A tracking dual supply: LM340T-05, LM320T-15. The 340 will track the LM320 within 100 mV.  $D_1, D_3$ : IN4720.

## VARIABLE TRACKING DUAL SUPPLY



\* Solid Tantalum

**FIGURE 11 Variable Tracking Dual Supply  $\pm 5.0V - \pm @ 18V$**

The ground pins of the negative regulator and the positive regulators are controlled by means of a voltage follower and an inverter, respectively. The positive regulator tracks the negative to within 50mV over the entire output range if  $R_2$  is matched to  $R_3$  within one per cent.



# —SHORT CIRCUITS—

## INJECTOR/TRACER

THIS PROJECT IS an opportunity to present both a novel circuit and a useful test instrument. It is straightforward to build, and uses such easy to find components that you could probably start construction yesterday.

The signal injector part of the unit generates a 1V square wave signal at about 1kHz, and is connected through SK1 to the probe tip.

The input to the tracer sections is via SK2. This signal is amplified, volume controlled by RV1, and the earphone output appears at SK3.

### CONSTRUCTION

Step one of construction was to slim down our aluminum box to one inch, simply done by trimming  $\frac{3}{8}$  inch off each half, then the control slot was cut. The next problem was squeezing the guts into the box. But it can be done!

The main trick is to support the Veroboard on the phone sockets — mount them in their holes and epoxy the board to them. However, remember that the control is to be attached to the board. Hence it may be necessary to stick spacers between the sockets and the board so that the control protrudes at the right place.

The injector probe is made detachable and is constructed as follows. Take the metal caps from the two shielded phono plugs and solder them back to back. By filing the plastic probe handle it can be screwed into one of the caps. A plug screws back into the other cap — presto — probe with plug on the handle to insert into socket on box! Naturally we leave it as an exercise for the reader to figure out how to wire it up. A look at the first picture shows that we incorporated the ground lead into the probe unit by inserting the lead through a hole bored in the handle.

The tracer probe can be connected to "IN" by a length of thin co-ax.

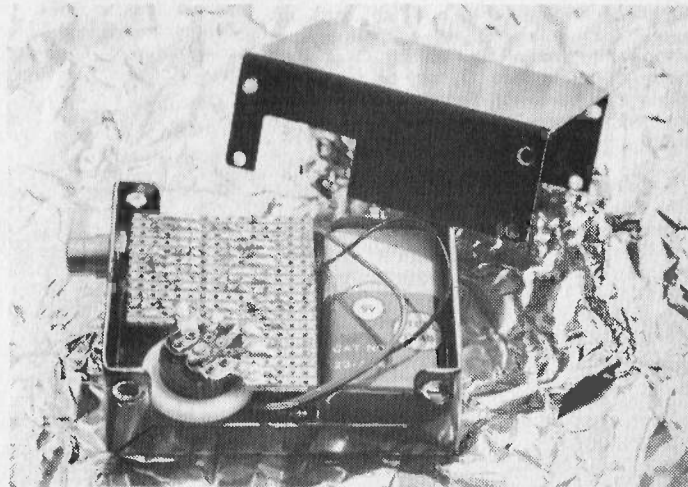


Fig. 1. View of board and parts mounted inside box.



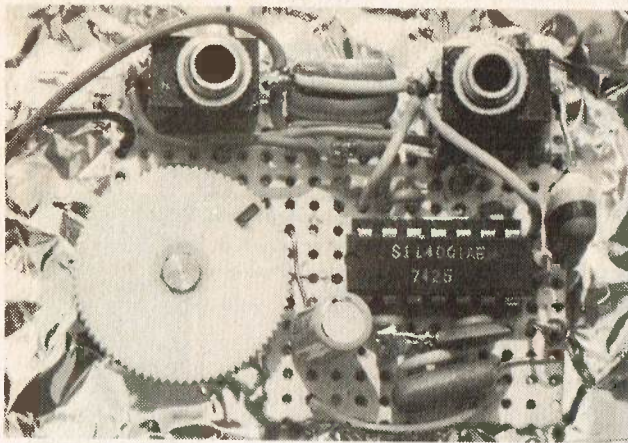


Fig. 2 Layout of components on board — top view.

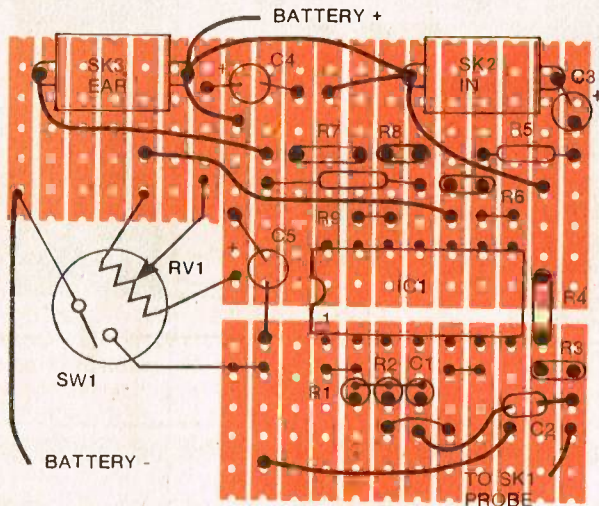


Fig. 3. Again — top view of Veroboard showing components and connections. Note foils cut — see also Fig. 1.

## COMPONENT NOTES

The voltage ratings for C2 and C3 should be chosen high enough for the applications expected, since these are the capacitors connected to the outside equipment.

Our volume control with switch was liberated from an expired transistor radio, and this is one source of supply. Most are a suitable size, electrically and mechanically, and are audio taper as desired.

## How it works

The injector is the familiar CMOS oscillator configuration we all know and love, with period approximately equal to  $1.4 \times C1 \times R2$  seconds. The values are given for 1kHz operation. Resistors R3 and R4 divide the output to 1V.

Whereas the oscillator employs the gates in their digital mode, in the tracer they are used in linear fashion by applying negative feedback from output to input. Hence they are used in much the same way as op-amps.

It should be noted that this circuit uses positive ground. This does not affect the tracer input, or injector output, which are capacitively coupled, but it offers an advantage at the earphone output. Because of the construction of the jack, one side of the earphone must be connected to ground via the case. If a negative ground had been used (see Fig. 7) the earphone would have been driven by two P-channel transistors in series. Use of a positive ground allows the phone to be driven by the two n-channel transistors which are arranged in parallel and are thus able to handle more current. Result — better volume.

## Parts List

IC1	CD4001AE	CAPACITORS	
RESISTORS		C1	7n ceramic
R1	200k	C2	0u1 ceramic
R2	100k	C3	10u electrolytic
R3	8k2	C4	10u/15V electrolytic
R4	1k	C5	50u/15V electrolytic
R5,7	10k		
R6,8	470k		
R9	500R		
RV1	10k miniature audio with switch and knob	MISCELLANEOUS	
		Box (2¼ x 2½ x 1½), high impedance earphone, plugs, probes, ground clips, IC socket, 9V battery and clip, Veroboard (0.1 inch grid) etc.	
SOCKETS			
SK1	phono jack		
SK2,3	miniature phone jacks (see pictures)		

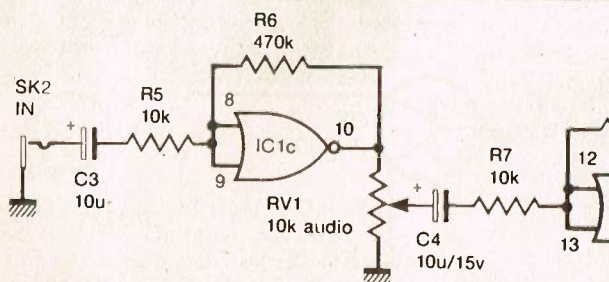


Fig. 4 Tracer circuit diagram.

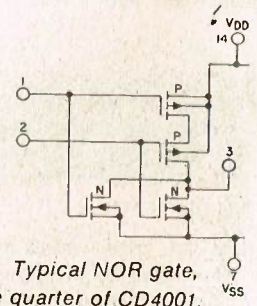


Fig. 7. Typical NOR gate, one quarter of CD4001.

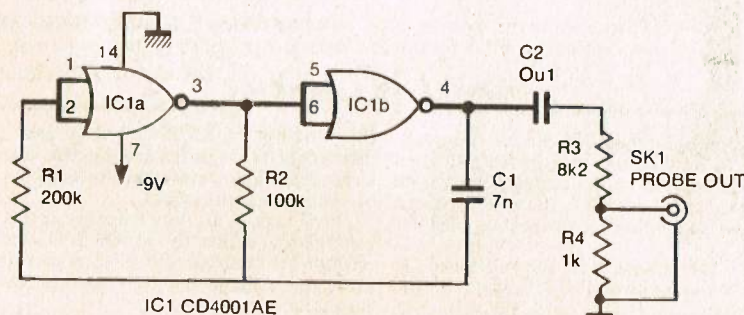


Fig. 5. Injector circuit diagram.

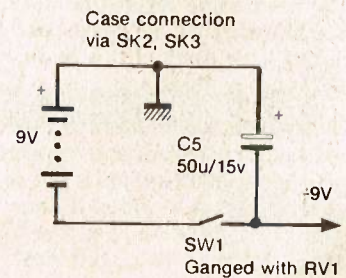


Fig. 6. Battery and switch connections.



# Short Circuits

# METRONOME

THE TRADITIONAL metronome is well-known to those who have learnt the piano for beating out the time - these mostly operate by clockwork.

A variable beat with a far greater range than the mechanical types is very easily produced electronically, especially if a unijunction transistor is used as a relaxation oscillator.

In our circuit we have opted for a tantalum capacitor for C1; an electrolytic can be used but due to the enormous tolerance spreads (usually +100% to -50%) the range can be very different from that of our prototype.

A volume control is hardly necessary but we have included a preset control which can be adjusted from outside the box which can be used to attenuate the level considerably: a low volume is almost essential when using an ear-phone.

RV1 sets the 'beat' and can be log or lin but a log type wired as reverse log gives a smooth calibration over the range which varies from 30 beats per minute to 400 beats per minute. Calibration can easily be done using a watch.

The normal nominal impedance of small speakers is 8 ohms and that is what we have used but higher impedance types will work.

Construction is very straightforward. We have used a small pcb but there's nothing to prevent other constructional methods from being used.

## USES

The use of a metronome for a musician is well-known but there are other applications. People learning to touch-type now sometimes use a regular beat to improve performance.

There are other areas where a metronome may be of use - in curing stammering. We know of someone who was helped enormously by the use of a metronome set at the fairly critical frequency of 50 beats per minute. We have marked this as an asterisk on our calibration.

However we have checked with a qualified speech therapist and it seems that this use of a metronome is not so widely recognised as an aid as it once was. What they would say was that 'In some cases, it could help, but not always.'

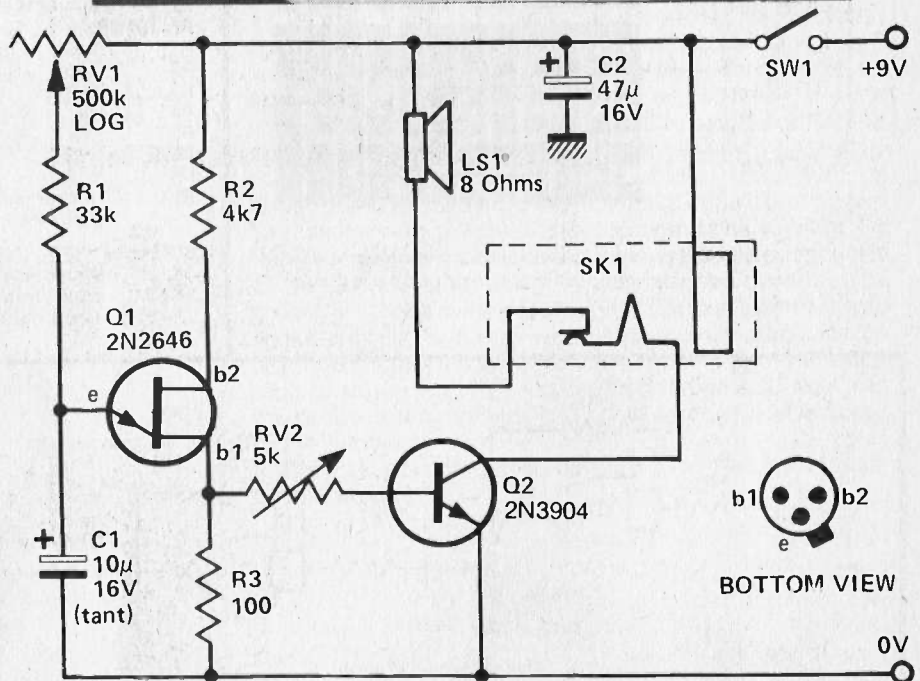


Fig 1. Circuit diagram for the metronome. SK1 switches off the L.S. upon insertion of the earpiece. The connection diagram is for the 2N2646.

## How it works

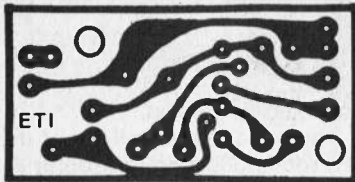
The circuit makes use of the special properties of a unijunction transistor, Q1. When voltage is applied to the circuit, C1 charges up through RV1 and R1, the rate at which it charges depending on the setting of RV1.

When the voltage is at the emitter of Q1 reaches a certain level, this effectively shorts out the two bases. This raises the voltage at

the junction of R3/RV2 briefly and C1 is discharged through R3 enabling the cycle to start again. The waveform across R3 appears as a series of short spikes.

RV2 acts as a crude volume control as it passes these spikes to Q2 which is switched on and off in sympathy in turn passing the burst of voltage to the speaker or the earphone.

# Short Circuits



## Parts List

RESISTORS all 1/2 W, 5%

R1 33 k  
R2 4k7  
R3 100

CAPACITORS

C1 10μ 16 V tantalum electrolytic  
C2 47μ 16 V electrolytic

SEMICONDUCTORS

Q1 2N2646 unijunction  
Q2 2N3904 or similar

POTENTIOMETERS

RV1 500 k log rotary  
RV2 5 k lin trim type

SWITCH

SW1 On-off rocker switch

SOCKET

SK1 3.5mm panel jacket socket

SPEAKER

LS1 8 Ω (2 1/2" - 2 3/4") type

CASE

Norman P.B.1 or similar  
(4 1/2" x 3" x 1 1/2" / 115mm x 75mm x 35mm)

MISCELLANEOUS

9V battery, battery clip, knob, nuts, bolts, etc, pcb as pattern, wire, 8Ω earpiece with 3.5mm plug.

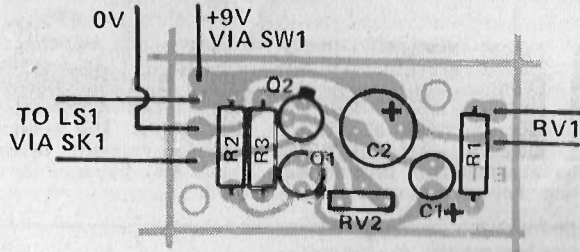
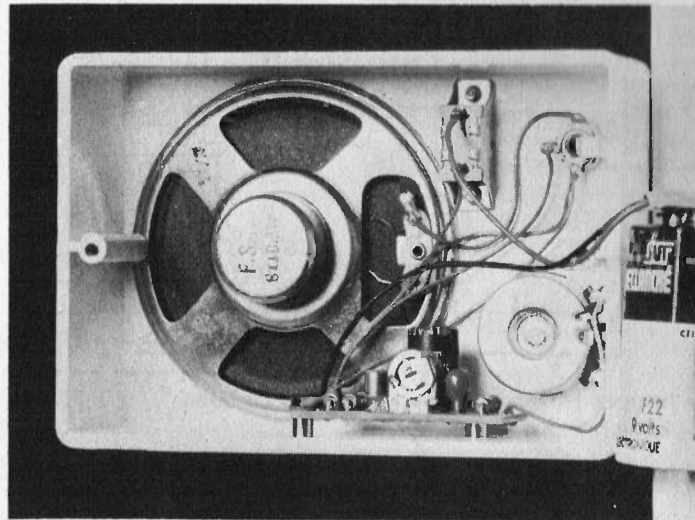


Fig 2. Overlay for the metronome. RV2 is mounted vertically to allow adjustment. Take care with the semiconductor connections.



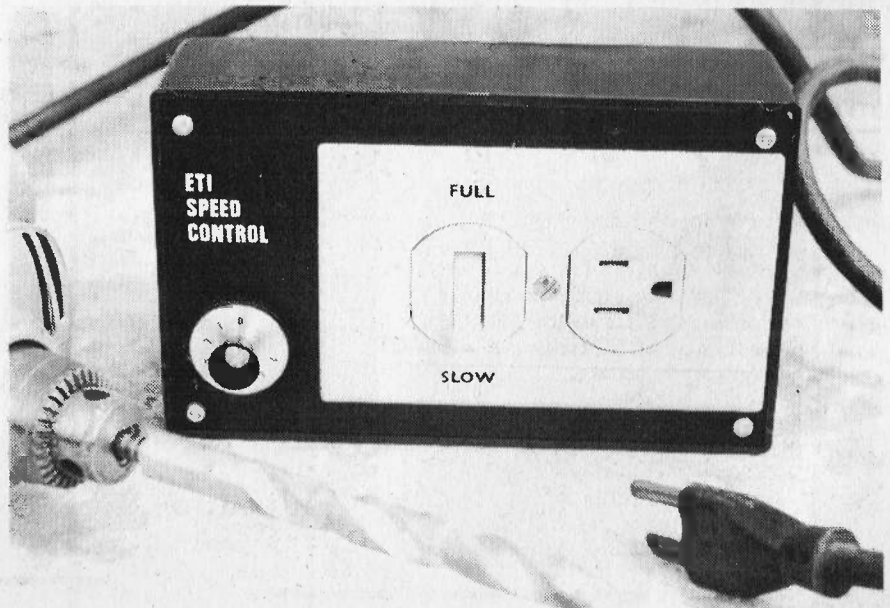
RV2, the preset volume control can be clearly seen on the pcb. A hole is drilled in the back panel to allow this to be adjusted by screwdriver when need be, which is surely infrequently. The rate control down on the right works most effectively if a log control wired in 'reverse log' is employed.

# DRILL SPEED

# CONTROLLER

IF YOU'VE EVER HAD TO USE your drill for anything but holes in aluminium panels, you will know how useful a speed controller is! Masonry bits need a very slow speed to be effective (they work at high speed, but not for very long); wood drills need a medium speed (too fast and the wood bursts into flames!); metalwork usually needs the full speed but better control can be obtained with the exact speed for the drill/bit combination.

The circuit used is not the most sophisticated available but it is reliable and cheap. As line voltages are involved in all parts of the circuit, extreme care should be taken, when constructing, to make sure nothing can come





# How it works

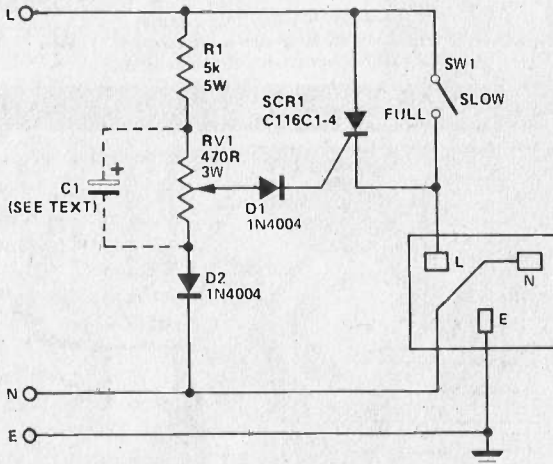
The silicon-controlled rectifier conducts in one direction only, and then only when it has a voltage at its gate. This triggering signal is provided by the voltage from RV1 wiper rising enough to forward bias D2. Hence RV1 provides the trigger at different parts of the A.C. cycle, so turning on the SCR for different amounts of time according to its setting - hey presto: speed control!

As the back EMF from the motor tends to reverse bias D2, this affects the trigger point as well. In fact at low speeds the motor back EMF is lower, and so the gate voltage is higher, providing earlier triggering - more power. This to some extent compensates for excessive loading of the drill. Switch SW1 bypasses the SCR to give full speed.

# Short Circuits

loose or touch anything it shouldn't. Also all exposed metalwork *must* be connected to ground.

Because of the simplicity of the circuit, some juddering may occur at low speed. Inserting capacitor C1 across RV1 will reduce this effect, however, the torque will be slightly reduced. The value of C1 can be from 1uF to 4uF (63 VWG at least).



Circuit Diagram — Drill Speed Controller

## CONSTRUCTION

We used a PCB as this ensures that the parts can't move around (very dangerous at line voltage), also the SCR uses it as a small heatsink.

If C1 is used, make sure it's positive side is connected to R1 (point X on PCB overlay), otherwise it will self-destruct!

SCR1 is bolted to the PCB and must make electrical contact with the copper side, which also acts as a heat-sink. Because of this, the PCB *must* be mounted on insulating pillars. ●

## Parts List

### RESISTORS:

R1 5k 5W wire wound  
RV1 470R 3W wire wound

### CAPACITOR:

C1 See text

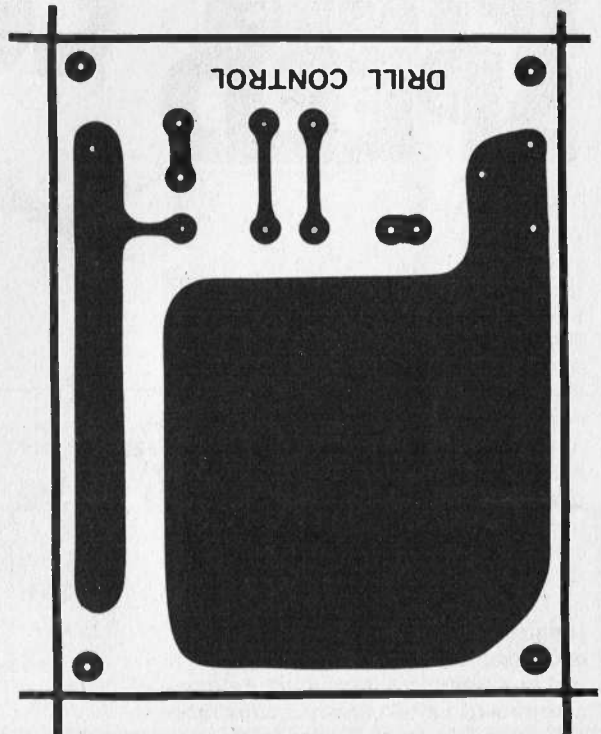
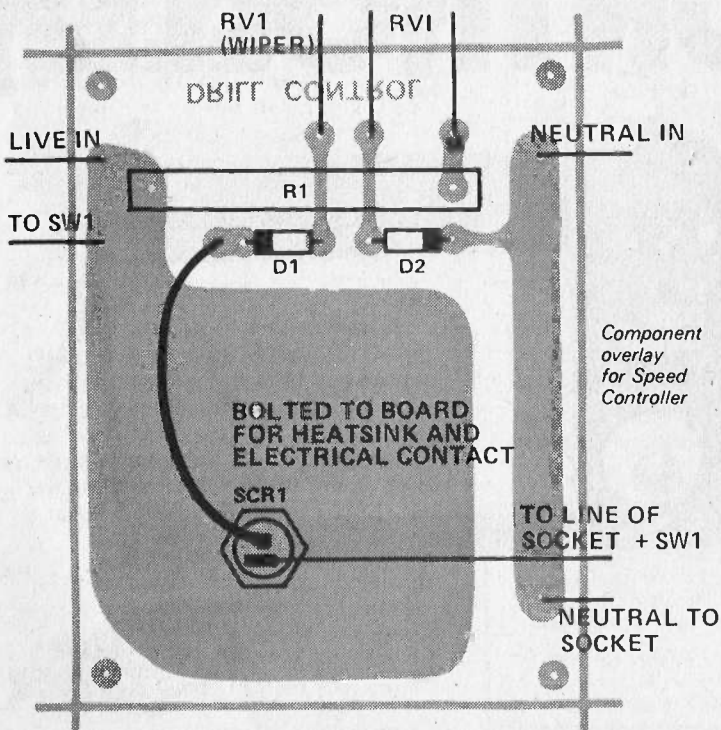
### SEMICONDUCTORS:

D1, D2 1N4004  
SCR1 C116C1-4

### MISCELLANEOUS:

SW1 Single pole on/off  
Case 6 x 3½ x 2in.  
155 x 94 x 50mm.  
A.C. receptacle with switch  
3-pin plug and line cord  
PC board, spacers, nuts, bolts, etc.  
Cable grommet, clip, knob.

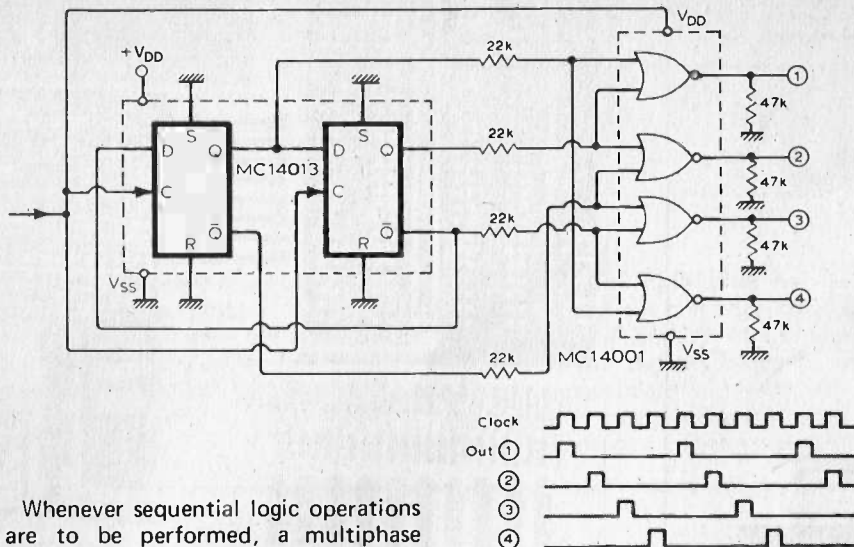
Speed Controller — Foil Pattern — shown full size.



# tech-tips

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## MULTIPHASE CLOCK GENERATOR

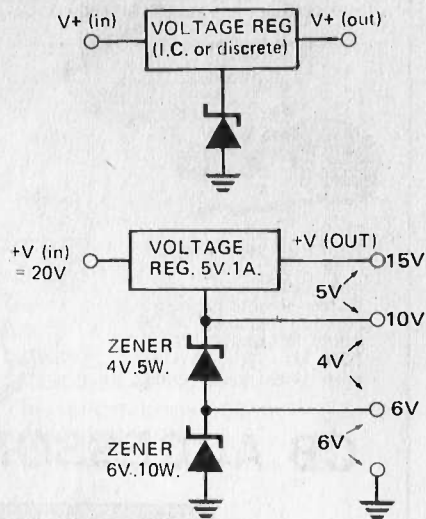


Whenever sequential logic operations are to be performed, a multiphase clock generator is often required. The circuit shown, which uses only two CMOS ICs, was designed by Michel Burri of Motorola's Geneva applications laboratories. It will produce a pulse on each of the four output lines in turn. These pulses do not overlap one another.

Operation of the circuit is self-evident from an examination of

the schematic; however, it is interesting to note that the power supply of the MC14001 is derived from the clock input. The maximum operating speed of this circuit is about 1 MHz.

## ZENER BOOSTS OUTPUT VOLTAGE OF REGULATOR



In this circuit the zener diode raises all voltages — with respect to ground by the zener voltage, i.e.

$V_{in}(\max) \approx \text{voltage regulator } V_{in}(\max) + \text{zener voltage}$

$V_{in}(\text{working min}) \approx \text{voltage regulator } V_{in}(\min) + \text{zener voltage}$

$V_{out} = \text{voltage regulator } V_{out} + \text{zener voltage}$

As the voltage regulator dissipates all excess power while the zener merely clamps the output voltage above its own voltage, a low wattage zener (250 mW) should be adequate — unless lower voltage taps are used, as in the second example in which the total output is one amp.

For other value zeners, wattages can be worked out by the formula  $W = \text{zener voltage} \times \text{current}$ .

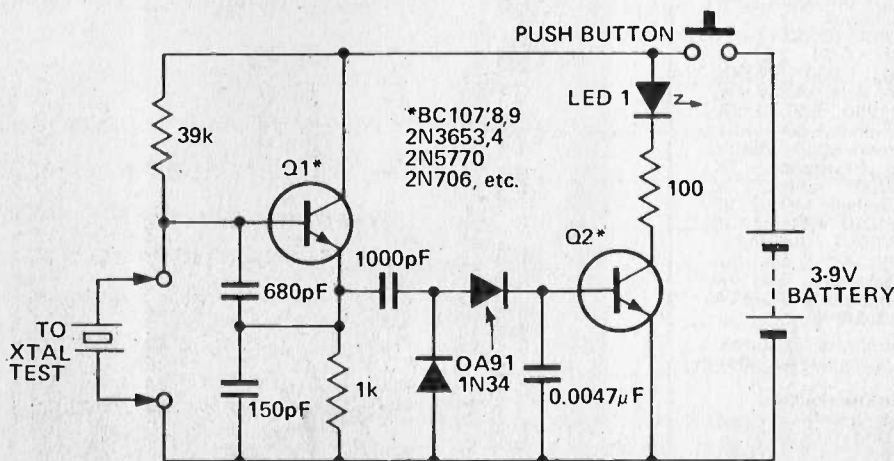
## COLOUR CODING COMPONENTS

The resistor colour code can be extended for use in codifying all manner of other components.

Zener diodes for example can be thus coded once their parameters have been established. Similarly it assists when building a unit to mark the leads of transformers, coils transistors etc with short lengths of coloured insulating spaghetti. If for example one has a centre-tapped transformer then — from the top of the winding inwards — the code could be top = brown, centre = red, bottom = orange.

With a transistor base (B) = 2 = red; collector (C) = 3 = orange; emitter (E) = 5 = green. Just follow a numerical sequence equating numbers with letters of the alphabet.

## CRYSTAL CHECKER



For checking fundamental HF crystals on a 'Go-No-Go' basis, the above circuit works quite well. An untuned Colpitts oscillator drives a voltage multiplier rectifier and a

current amplifier. If the crystal oscillates, Q2 conducts and the LED lights.

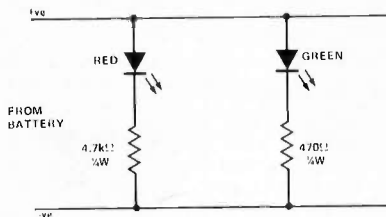


# tech-tips

## MANY BATTERY TESTERS . . . MAKE LIGHT WORK

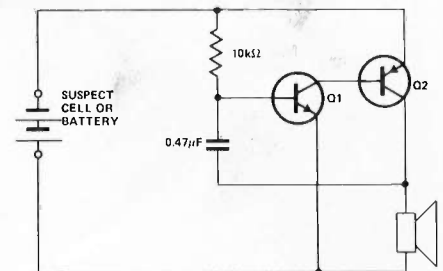
This tester is intended for use with 9V batteries. It can be connected to the battery via an appropriate clip, or a clip stolen from a deceased battery. With some ingenuity (and epoxy) the entire tester could be built onto the clip itself, but check that polarity first!

The tester uses two small LEDs, one red, one green. Due to the fact that green LEDs need more current to operate, only a battery in good condition will illuminate both LEDs. A medium condition battery will only illuminate the red LED, while a faint red glow indicates a trip to your battery supplier.

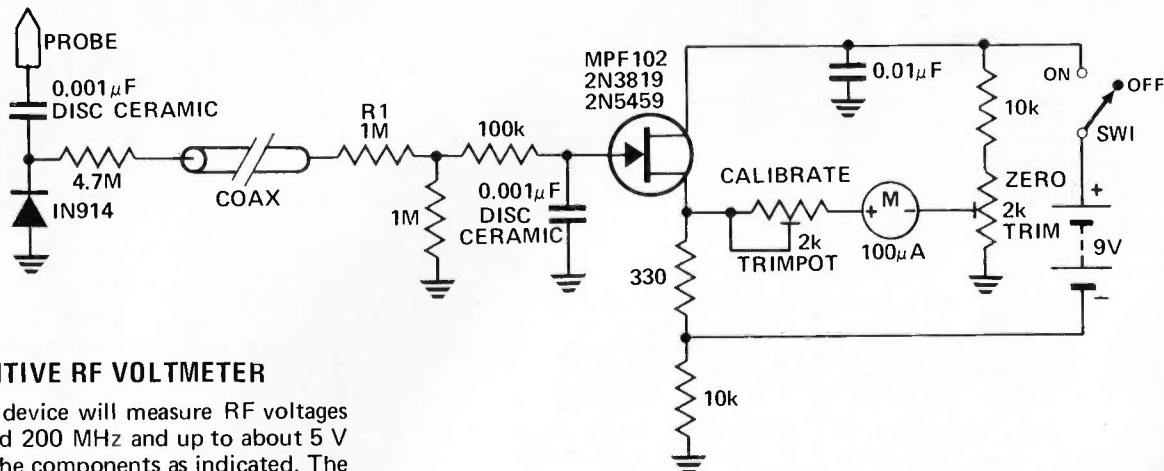


## BASED ON SOUND PRINCIPLE

This device tests the condition of dry cells. The circuit consists of a simple oscillator whose output frequency is relatively independent of supply voltage, but varies greatly with changes in supply impedance. Thus, with the



component values shown, a fresh battery or cell will give a note of about 500Hz, whereas an exhausted cell will give a note above 1kHz. The device has been tested with battery voltages between 1.5V and 14V, using a 2N2923 as Q1, and a 2N2706 as Q2. The unit is undamaged by reversed supply potentials.

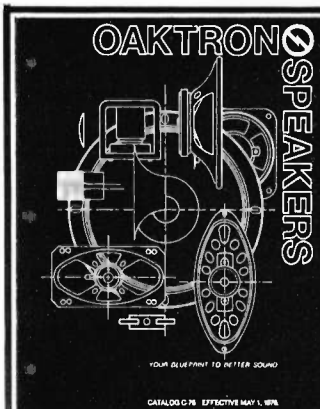


## SENSITIVE RF VOLTMETER

This device will measure RF voltages beyond 200 MHz and up to about 5 V with the components as indicated. The diode etc should be mounted in a remote probe, close to the probe tip. Sensitivity is excellent and voltages less than 1 V peak can be easily measured. The unit can be calibrated by connecting input to a known level

of RF voltage, such as a calibrated signal generator and setting the calibrate control. The output indicates in RMS. As it is it reads about 2 V

RMS full scale. This can be increased to 20 V or more by increasing R1 to 20 M (two 10 M in series). The 100 µA meter could be a multimeter if desired.



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