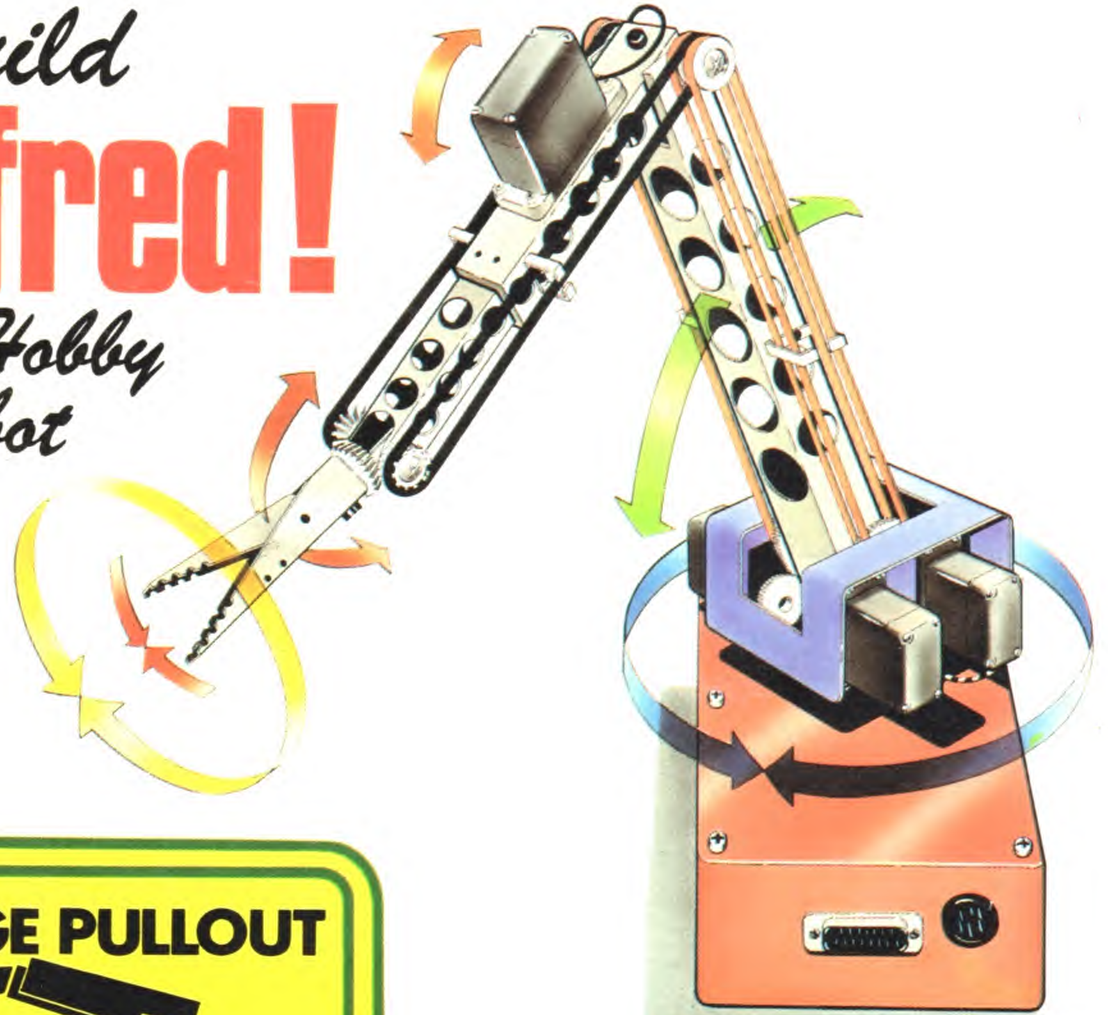
EVERYDAY

# ELECTRONICS

## and computer PROJECTS

NOVEMBER 1984 90p



## *Build* Alfred! *the Hobby Robot*

16 PAGE PULLOUT

## robotics

SUPPLEMENT

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# THE SKYS THE LIMIT AT

# LEISURE TRONICS

## THERE'S SO MUCH WAITING FOR YOU, IT'S IMPOSSIBLE TO CRAM IT ALL IN THIS SPACE:

• satellite tracking and receiving equipment (impress the neighbourhood with your space-age dish) • robots – bits and pieces, kits, computers, instructions (no more washing-up?) • electronic music (instruments, synthesisers, keyboard, amps, midis) (Look out, ELO) • home recording equipment (what about your own studio?) • amateur radio (your club is there and Practical Wireless has a set-up that's bound to intrigue you) • computers (with a wide range of games, books etc) • components (special offers galore) • tools and test instruments • disco and light show equipment (dazzle 'em with your brilliance) • radio controls for models, etc, etc, etc... • demos • prizes

CANCELLED

**SEMINARS** You want to know what's the very latest – in technique and equipment – on electronic music. **"Electronic Music Maker"** is running seminars on Thursday/Friday a.m.

**ROBOTS** How to build them. Where to get the parts. The Micros? Programming? Software? **"Your Robot"** will tell you in down to earth language on Saturday/Sunday.

**'HOME RECORDING STUDIO'** are also running seminars, so if your want to start building, here's how on Thursday/Friday.

**LIMITED ACCOMMODATION AT SEMINARS, SO MAKE SURE YOU GET THERE EARLY**

**LOOK WHO'S SPONSORING**

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YOUR ROBOT

– and they will all be there with advice and guidance.

EE

How much will this cost you? £1.00 only if you fill in this coupon and hand it in at the Registration Desk. £2.00 without the coupon.

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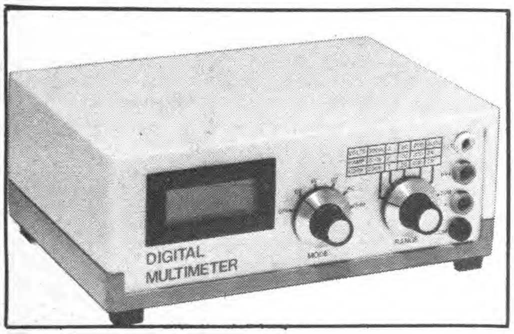
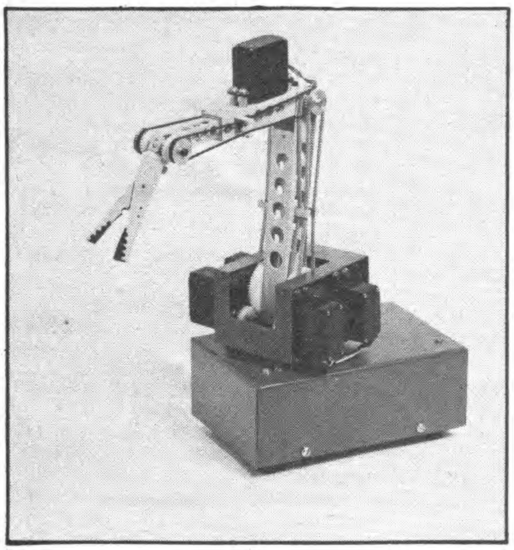
**Leisuretronics is at the Royal Horticultural Hall, London, Nov. 8,9,10,11, 1984 Thursday, Friday and Saturday 10 a.m. to 6 p.m., Sunday 10 a.m. to 4 p.m.**

# EVERYDAY ELECTRONICS and computer PROJECTS

**VOL. 13 No. 11 NOVEMBER 1984**

PROJECTS . . . THEORY . . . NEWS . . .
COMMENT . . . POPULAR FEATURES . . .





## PROJECTS



## SERIES



## FEATURES



## SPECIAL SUPPLEMENT



***Our December 1984 issue will be published on Friday, November 16. See page 683 for details.***

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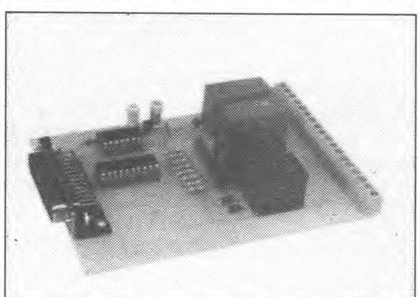
Adjustable 1-30V Power supply with pre-setable current limit from 1mA-2A 41-01600 37.46



*Centronics Interface*

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Adjustable PSU from 5-12V with current protection, 1 amp max output 41-01504 6.45

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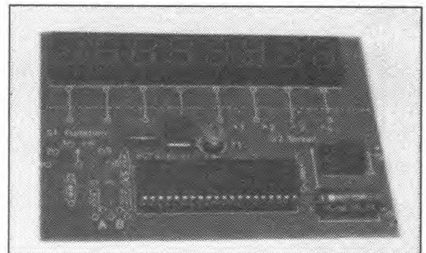
1-30 volt adjustable PSU with protected output up to 1.5 Amps 41-01402 10.45

3 DIGIT LED DVM
DVM to read up to 99.9 volts or configured as an ammeter to read up to 9.99 amps 41-01403 17.00



*10MHz DFM*

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2M CONVERTER
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DATA & PRICES

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| C | 1.2V | 1.2AH | 01-12024 | 2.35 | 1.99 |
| D | 1.2V | 1.2AH | 01-12044 | 2.00 | 2.00 |
| PP3 | 8.4V | 110mAH | 01-84054 | 3.70 | 3.50 |

**CH/4/50**

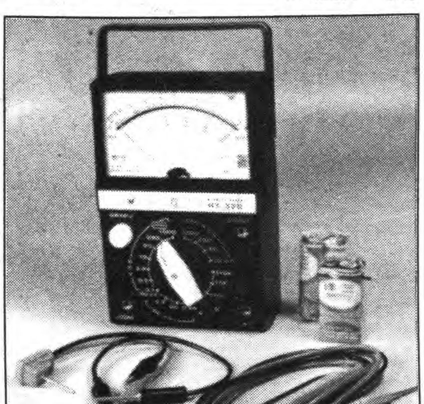
To recharge up to 4 AA size NiCads.
Size; 112 x 71 x 37mm 01-00409 4.95

**CH1/22**

To charge PP3 type NiCads.
Size; 70 x 50 x 32mm 01-00159 4.30

**CH8/RX**

Will recharge AA, C, D and PP3 size cells with automatic voltage selection. Will recharge following combinations: 4xD, 4xAA, 4xC, 2xPP3, 2xD + 2xC, 2xD + 2xAA. 2xD + 1xPP3, 2xC + 2xAA, 2xC + 1xPP3, 2xAA + 1xPP3. Charge rate: 11mA for PP3, 45mA for AA size, 120mA for C and D size, for 16 hrs. Power: 240V 50Hz. Output Voltage: 2.9V for AA, C and D size, 11.0V for PP3 size. Weight: 0.475kg. Size: 199 x 109 x 55mm. 01-02204 9.45



## HT320

High quality, high specification meter at a reasonable price. In addition to the usual ranges, facilities are provided for measuring transistor parameters such as Iceo and Hfe.
Meter movement fully protected against overloads. 3-colour mirrored scale in robust case. Supplied complete with comprehensive instructions, test leads, transistor test leads and batteries (2 x HP-7, 1 x PP3).
DC Volts: 0.1V, 0.5V, 2.5V, 10V, 50V, 250V, 1kV (20kΩ/V). AC Volts: 10V, 50V, 250V, 1kV (18kΩcV). DC current: 50μA, 2.5mA, 25mA, 250mA. Resistance: 2k, 20k, 2M, 20Mz. AF Output: −10dB to +22dB for 10VAC (0dB/0.775V, 600Ω). Leakage (Iceo) 15μA, 15mA, 150mA. Hfe: 0-1000 (Lc/Tb). Weight: 410gms. 56-83201 14.00

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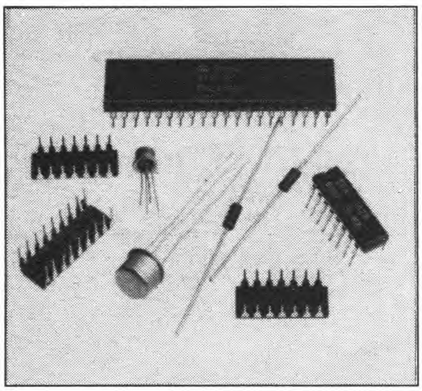

## Linear ICs

| | | Stock No. | Price |
|---|---|---|---|
| LF351 | Bi-FET op amp | 61-03510 | 0.49 |
| LF353 | Dual version of LF351 | 61-03530 | 0.81 |
| LM380N | IW AF power amp | 61-00380 | 1.45 |
| LM381 | Stereo pre-amp IC | 61-00381 | 3.27 |
| NE544 | 14 pin DIL servo driver IC | 61-00544 | 1.80 |
| NE555N | Multi-purpose low cost timer | 61-05550 | 0.21 |
| uA741CN | DIL low cost op-amp | 61-07411 | 0.42 |
| TDA1062 | RF ocillator and mixer system for 1-200MHz | 61-01062 | 1.95 |
| TDA1083 | Portable radio AM/FM audio in one IC | 61-01083 | 1.95 |
| HA1388 | 18W PA from 14V | 61-01388 | 2.75 |
| MC1496P | Double balanced mixer/ modulator | 61-01496 | 1.25 |
| TDA2002 | 8W into 2 ohms power amp | 61-02002 | 1.25 |
| ULN2283 | 1W max 3-12V power amp | 61-02283 | 1.00 |
| CA3089 | FM IF amp, detector, mute, AFC, AGC system | 61-03089 | 2.84 |
| CA3130E | BIMOS op amp | 61-31300 | 0.80 |
| CA3140E | BIMOS version of 741 | 61-31400 | 0.46 |
| MC3359 | Low current dual conversion NBFM IF and det | 61-03859 | 2.95 |
| LM3900 | Quad norton amp | 61-39000 | 1.20 |
| LM3909N | 8-pin DIL LED flasher | 61-39090 | 0.68 |
| KB4412 | Two balanced mixers IF amp with AGC for AM/SSB | 61-04412 | 1.95 |
| ICM7555 | Low power CMOS version of 55 timer | 61-75550 | 0.98 |
| HA11225 | Low noise FM IF | 61-11225 | 1.45 |
| HA12017 | 83dB S/N phono preamp 0.001% THD | 61-12017 | 0.80 |
| MC14412 | 300 baud MODEM controller (Euro/US specs) | 61-14412 | 6.85 |

## Selected Lines

| | | | |
|---|---|---|---|
| PB2720 | 80dB Piezo Buzzer | 43-27201 | 0.55 |
| 10M15A | 10.7 Filter | 20-10152 | 2.10 |
| 10M08AA | 10.695 Filter | 20-11152 | 3.49 |
| FC177 | LCD Freq. Meter | 39-17700 | 20.00 |
| CM161 | Min LCD Clock | 40-80161 | 8.25 |
| BBC to Centronics Cable | | 03-10019 | 7.25 |
| Dragon to Centronics Connect Cable | | 03-10017 | 7.25 |
| C12 Computer Cassette Tape | | 21-00012 | 0.55 |
| 8 x 0.3" | IC socket | 28-00800 | 0.12 |
| 14 x 0.3" | IC socket | 28-14000 | 0.13 |
| 16 x 0.3" | IC socket | 28-16000 | 0.13 |
| 6V | KUIT-A Relay | 46-80000 | 0.48 |
| 9V | KUIT-A Relay | 46-80001 | 0.48 |
| 12V | KUIT-A Relay | 46-80002 | 0.48 |
| CX120P | COAX Relay | 46-90120 | 11.96 |
| CX520D | COAX Relay | 46-90520 | 26.98 |
| CX540D | COAX Relay (BNC) | 46-90540 | 26.98 |

## Books

| | | |
|---|---|---|
| Beginners Guide to Amateur Radio | 02-11262 | 4.50 |
| Beginners Guide to Electronics | 02-04134 | 4.50 |
| Active Filter Cookbook | 02-21168 | 12.70 |
| CMOS Cookbook | 02-21398 | 11.85 |
| TTL Cookbook | 02-10358 | 11.00 |
| Design of Active Filters | 02-21539 | 10.15 |
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| 55 Timer Applications Sourcebook | 02-21538 | 6.40 |
| Television Engineers Pocket Book 7th Ed | 02-21313 | 8.50 |
| Electronics Pocket Book | 02-21309 | 7.50 |
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| More Electronic Projects in the Home | 02-21307 | 3.80 |
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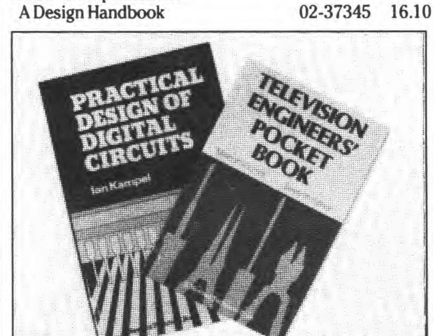
| Z8000 Microprocessor: A Design Handbook | 02-37345 | 16.10 |




| | | |
|---|---|---|
| 68000: Principles and Programming | 02-21853 | 12.70 |
| 8085A Cookbook | 02-21697 | 13.55 |
| Handbook of Electronic Tables Formulas | 02-21532 | 11.00 |
| Popular Circuits: Ready Reference | 02-04585 | 13.95 |
| Semiconductor Data Book 11th Edition | 02-04797 | 9.00 |

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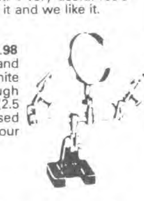

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EVERYDAY ELECTRONICS and computer PROJECTS

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EVERYDAY ELECTRONICS EDITORIAL
WESTOVER HOUSE
WEST QUAY ROAD, POOLE, DORSET BH15 1JG
Phone: Poole (0202) 671191
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## FAULT FINDING

FAULT finding is probably the one part of electronics that is very difficult to put over successfully in a magazine article. It is an area where interaction is necessary for a successful conclusion, e.g., instructions like "If the test reading at point X is Y then change R1" are fine, and you can give a number of options for Y, but what if your reading is none of them, where do you go then? What we can do in the magazine is cover the basic processes involved; this will aid readers with some understanding of circuit operation.

Our new series on *Fault Finding* in this issue does just that. If, however, you know no theory and want to fault find on your video recorder, then we really cannot help you very much. After all, would you expect to be able to diagnose and correct a car engine that would not start if you did not know that it required petrol, sparks and valve operation at the right time and in the right amounts?

## EXPERIENCE

Part of the art of fault finding is experience and a good TV serviceman will know what faults to expect from which sets before he takes the back off—precisely why I do not try to repair my TV when it goes wrong. I once stated in an editorial in our sister publication *Practical Electronics* that "fault finding is a peculiar skill, usually practised better by the humble repairman than by the honors-degree-engineer". I was taken to task by a reader who maligned me for using the term "repairman" rather than service engineer but, that aside, the statement is true and few design engineers would waste time looking for faults on equipment they are not familiar with.

Of course, when it comes to constructional projects, the fault finding is more problematical since it is possible that your newly constructed item has never worked and there are likely to be errors in construction, poor joints or even missing components. At least if the equipment has failed in service you can look for overheated parts or broken leads, etc., and you know everything was there and connected correctly in the first place.

However, good fault finding can be accomplished with practise. The application of a logical approach together with some thought and common sense will go a long way; but do not expect to be able to mend any item without some understanding of basic electronics. Like everything else if you are going to be successful, you must do your homework first.

Mike Kenward

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# ALFRED

## ALAN GREEN

## PART ONE

It has been said that robotics technology is currently where computer technology was twenty to thirty years ago. Certainly if one imagines the kind of intelligent robots that will undoubtedly one day turn the wheels of manufacturing industry, then the programmable arms of today would indeed compare with the cumbersome "adding machines" of long ago. Even operating on the familiar programmed sequence of instructions principle it will be some time yet before robots are flexible enough, and cheap enough, to be considered for routine domestic chores such as vacuum cleaning or mowing the lawn.

The benefits afforded automation by robots as they exist today can best be understood by looking at the automobile industry. Although a motor vehicle is a large body it is an assembly of components the majority of which weigh only a few kilograms. These small components spend most of their time waiting to be transferred to the next stage along the production line. When applied properly, robots speed up the process from raw material to finished item and trim manufacturing costs dramatically, for they will work ceaselessly at a pace which would ultimately deteriorate the human worker.

### CREATURE OF THREE DIMENSIONS OBEY ME

Although we live in a three-dimensional world, it is only now in man's history that we are widely able to store information in three or more dimensions in computer, as opposed to storing it on two-dimensional pieces of paper. After generations of living with two dimensions we suddenly find ourselves in the midst, not only of machines that can *think* in three dimensions (even if they have trouble displaying it), but robotic machines which behave *physically* to order in three dimensions. Those orders, or instructions need to relate to positions in three-dimensional space, and take account of errors of a volumetric nature which are introduced by a confounding array of sources. All this creates a conceptual hurdle for the human mind—certainly for those who grew up with paper as the storage medium.

*Alfred* joins the swelling ranks of the little robots which are materialising to teach we *early* human beings the concepts which we must grasp if we are one day to take their services for granted. Alfred is a robot trainer kit.

### X, Y, Z IN A CUBE

How do we define a position in a cube of space and record that position on a two-dimensional piece of paper, or VDU screen? The co-ordinates X, Y and Z are used, and if you look at the facing surface of a cube (thinking of it as a sheet of paper) then you can calibrate it from left to right (x axis), from top to bottom (y axis), and through its depth (z axis). See Fig. 1.1. Three numbers will then adequately define a position within that cube. Fig. 1.2 illustrates some of the conventional solutions to accessing positions in space, although robots of numerous alternative designs exist for accessing awkward positions and manipulating irregular objects.

As a robot training kit Alfred is intended to facilitate an understanding of these concepts. He is designed to work with the BBC microcomputer, or any other micro with an 8-bit user I/O port. Alfred will not only teach the student or hobbyist about the spatial aspects of moving a robot arm but also the techniques of computerised control. He was originally conceived as a tool for the education market yet is in a price range (£170 + VAT) which places him squarely within reach of the individual enthusiast.

***This is it!***
***The arm that won't cost a leg too!***
***And what Alfred can't do, you wouldn't want to witness.***

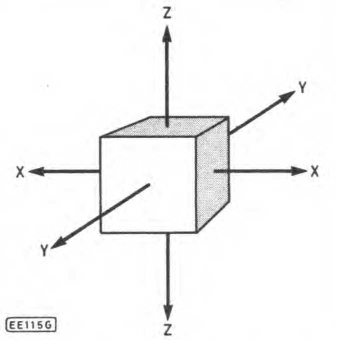



Fig. 1.1. Any position in a volume of space may be defined by the calibrated axes x, y and z.

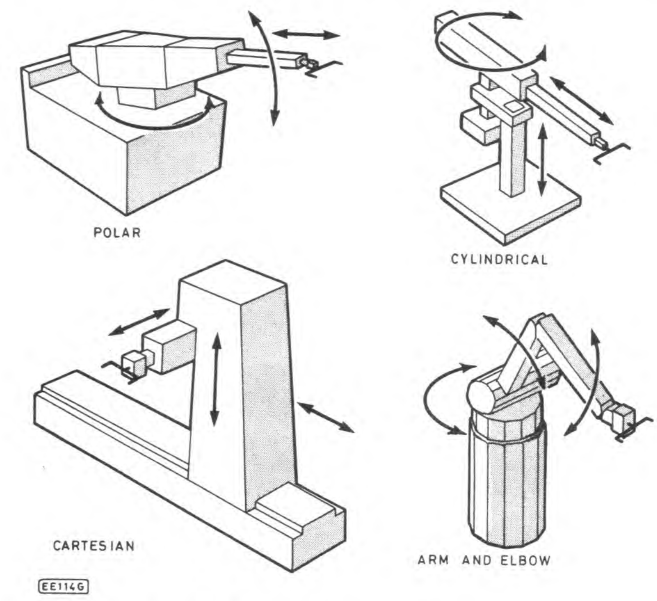



Fig. 1.2. Various robot arm designs.

Alfred will accommodate a number of departures from his basic configuration, a few of these being; an alternative gripper, various sensors including a full solid state vision system, and a mobile base, details of which will be published in EVERYDAY ELECTRONICS. The modular construction of the robot allows experimentation with his mechanical articulations—individual parts being readily available from *Robot City Technology Ltd.*

Alfred comprises three main sections:

**1) Arm**
**2) Carriage**
**3) Base**

The arm is made of plastic and supports one servomotor which activates the gripper. The gripper jaws are held open by a spring, and closed by the servomotor when the cord connected to one of the jaws is wound onto a bobbin. The gripper has a payload of 170 grams—a figure which would be de-rated by the presence of sensors or other fixtures at the gripper end of the arm. The arm has a maximum reach of 380mm.

The carriage comprises five servomotors which transmit their power through the arm via toothed drive belts. These belts may be adjusted to the correct tension by rotating simple U-bars on the arm to minimise hysteresis. The entire transmission system is exposed so that the student may inspect it whilst in motion. The servomotors incorporate D-to-A conversion electronics, and whilst they may resemble standard radio control units, they are in fact substantially reinforced to give much increased torque for robotics use.

The base unit houses the printed circuit board containing the interface and driver circuits for the six servomotors. Alfred requires an unregulated mains power supply producing 9–12 volts d.c. at 2·5 amperes.

Alfred's basic anatomy is described in Fig. 1.3, in which the angular scope of all his joints are indicated. Fig. 1.4 shows in simple block diagram form the channels of his mechanical linkages, and Fig. 1.6 illustrates the general interface architecture.

## CONSTRUCTION OF THE ARM

Construction of the base, carriage and electronics will be described in Part Two of the series. This month we look at assembly of the arm itself. The forearm section has the appearance of having a telescopic action, but is, in fact, a single rigid piece, the lower end of which is the elbow swivel joint. Fig. 1.5 shows how this is assembled. The two outer toothed drive pulleys (double-width) are free spinning idlers and are present merely to transfer drives from the lower belt section to the upper. The single-width inner pulley on the right-hand side is integral to the spindle (and therefore locked to the arm) so that when this pulley is driven it operates the elbow. The spindle is locked by a long screw threaded through the plastic arm itself.

The wrist construction can be studied in Fig. 1.7. This is controlled by two pulleys which, if driven in unison will cause the wrist to move the gripper upwards or downwards, but any *differential* in their operation will cause roll (rotating motion) in the gripper. This differential action makes the wrist's mechanical linkage independent of the positions of other joints.

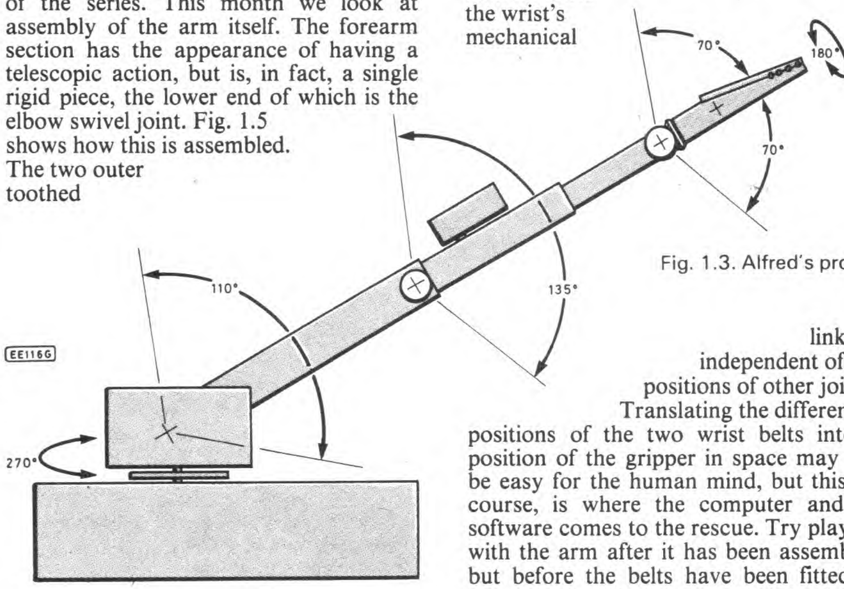



Fig. 1.3. Alfred's profile.

Translating the differential positions of the two wrist belts into a position of the gripper in space may not be easy for the human mind, but this, of course, is where the computer and its software comes to the rescue. Try playing with the arm after it has been assembled but before the belts have been fitted, it helps to appreciate the wrist mechanics.

There are two combined bevel gear/pulley units, each of which has a bush inserted into it. A screw, acting as a spindle, passes through the bevel gear/pulley unit and threads into the alloy U-piece of the gripper. The bevel gear/pulley on the opposite side is assembled as a mirror image. The alloy U-piece is bridged by two pillars which act as a cord guide (to be explained later) and which should be ignored for the moment.

The gripper servomotor is mounted on the forearm by four screws, so that its output spindle projects into the hollow of

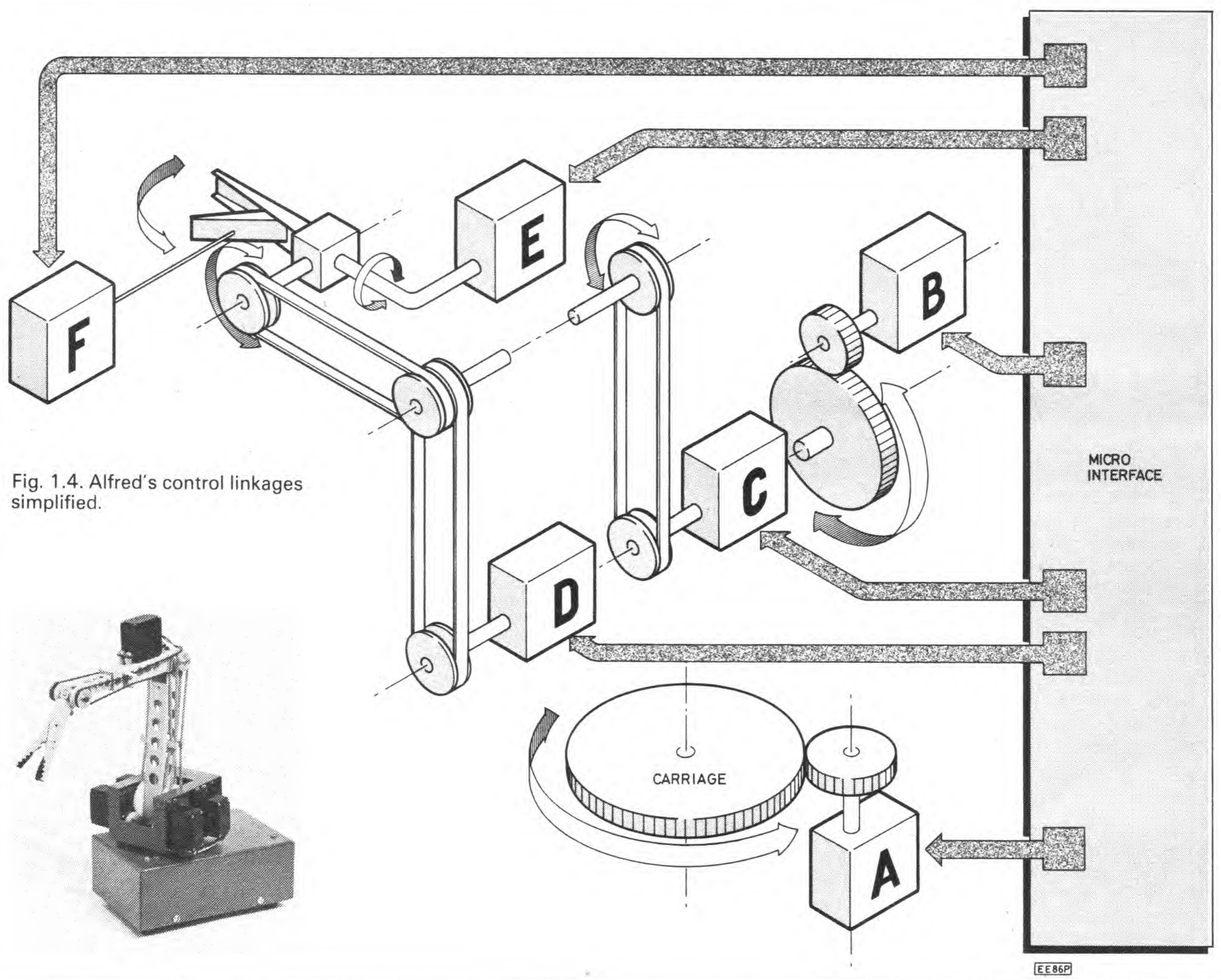



Fig. 1.4. Alfred's control linkages simplified.

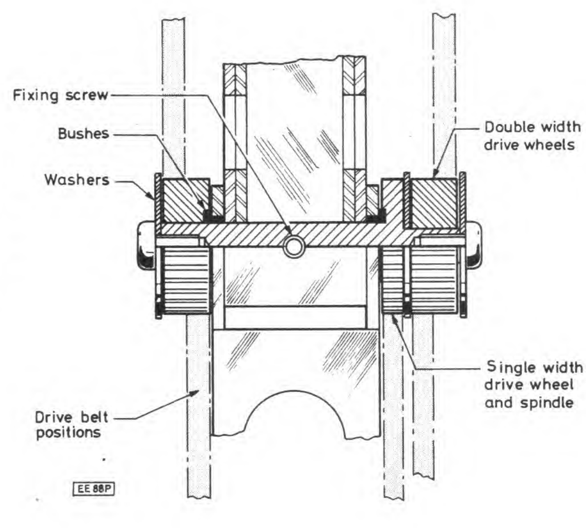
the arm. On its drive spindle is fitted a bobbin which winds and unwinds cord. Once the gripper is mounted, cord from the bobbin is threaded along the hollow of the arm and between the two guide bars of the alloy U-piece. It should continue until it emerges between the two jaws of the gripper, where it is passed around the bronze guide bar and secured to the opposite jaw by way of a "fishing weight" arrangement (the lead is squeezed around the cord using a pair of pliers). Fig. 1.8 illustrates the assembly of this system and how it works. Foam rubber pads are glued to the gripper jaws.

Finally, at the bottom of the arm use two countersunk screws to mount the 40mm diameter gearwheel which transmits the elevational drive to the arm.

## ACCURACY

Figures are occasionally quoted for accuracy in small trainer robots, but it is felt that these, at best, should only be regarded as a guide. Alfred promulgates no such figures even though his positional characteristics are at least as respectable as any other robot in his class, because he

Fig. 1.5. Partially cut away view of the elbow joint. The single-width drive wheel and spindle forms a single component which takes the screw on the right-hand side.



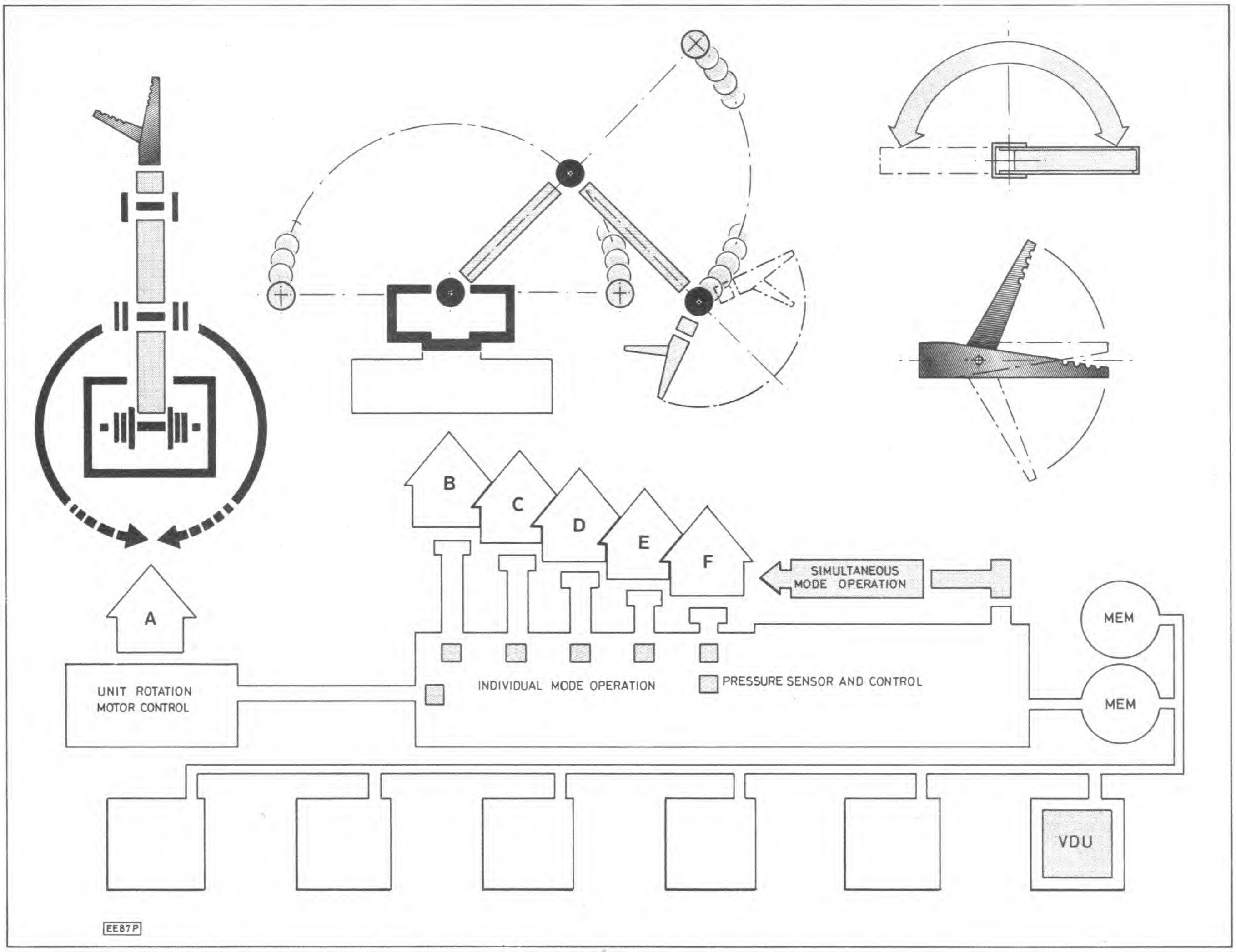



Fig. 1.6. Interface architecture and movements.

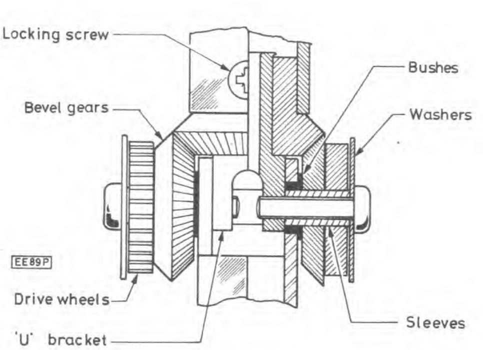



Fig. 1.7. Partially cut away view of the wrist. This is a differential arrangement that is controlled by two drive wheels to provide roll and pitch.

knows the variables involved—one of the aspect of robotics he likes to teach.

The factors affecting the "accuracy" of position in a volume of space that a robot arm can achieve insist on a more suitable term; *positional uncertaintly*. The difference (albeit it small) between where an arm goes to and where it was instructed to go to will be caused by such things as: whether or not the arm is in an extended position or retracted position; the weight of the payload; lost motion in the arm's mechanics; flexing of its structure; the accuracy of its position sensors and A-to-D converters, etc. In addition to these effects there are variations due to environmental temperature, and wear of the arm itself. Repeatability of position of the arm will depend upon the path taken each time. Uncertainty of position may be expressed mathematically using techniques which, unfortunately, transcend the scope of this magazine, but the reader looking at robotics in a serious light will appreciate that this aspect cannot be treated glibly.

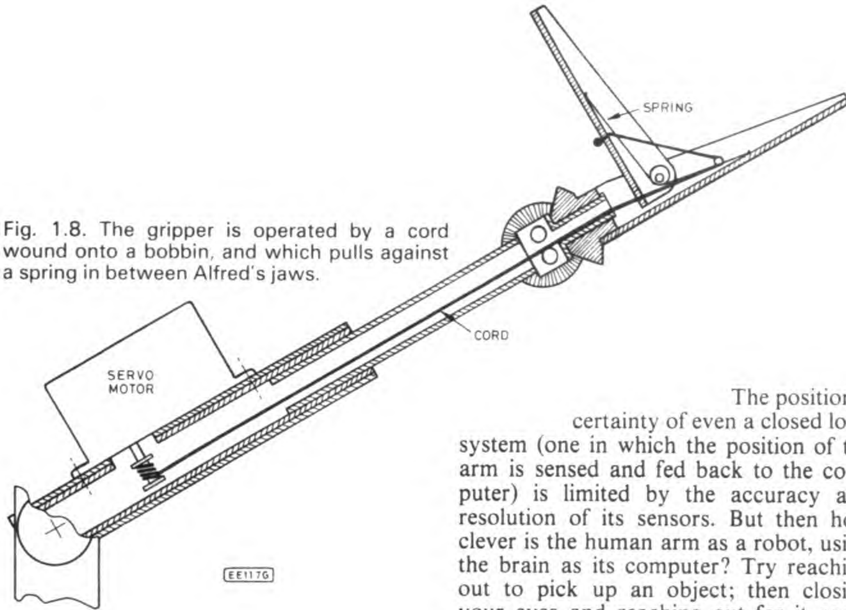


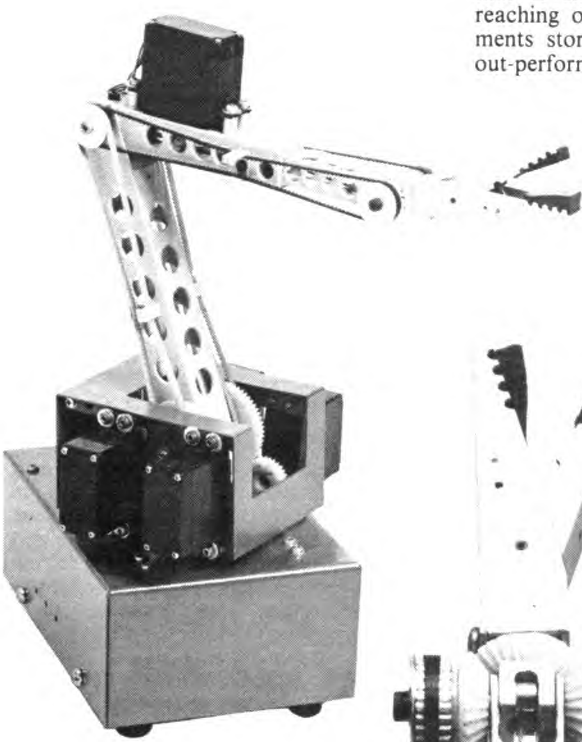

Fig. 1.8. The gripper is operated by a cord wound onto a bobbin, and which pulls against a spring in between Alfred's jaws.

The positional certainty of even a closed loop system (one in which the position of the arm is sensed and fed back to the computer) is limited by the accuracy and resolution of its sensors. But then how clever is the human arm as a robot, using the brain as its computer? Try reaching out to pick up an object; then closing your eyes and reaching out for it again from memory. You will soon discover that a simple robot arm like Alfred reaching out for the object from movements stored in computer memory can out-perform you. What *nature* knows is that the precision of any kind of actuator (your arm) becomes less critical when used with sophisticated sensors (your eyes) and a really clever computer (your brain).

As computers become more powerful and feedback systems such as solid state vision become higher in resolution the mechanics of robots will undoubtedly become less demanding, but all this is entering into the realm of artificial intelligence.

The world of robotics is engaging and rewarding, and the software available for Alfred enables the experimenter to explore both the practicalities and the theory. A *Learn Mode* allows control of Alfred directly from the keyboard, with movements committed to computer memory so that they may be repeated. Movements and pauses may be stored in this simulated pendant mode of operation. The software allows all motors to be turned off, instantly and simultaneously, thus providing a useful safety feature, or "panic button". There is also control of other features through four spare bits in the interface hardware. Software will be featured more fully in Part Three.

**NEXT MONTH:** Construction details of the carriage, base and p.c.b. will be given, and a description of the electronics.



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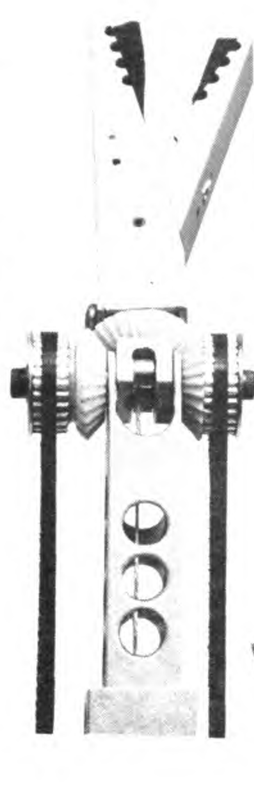

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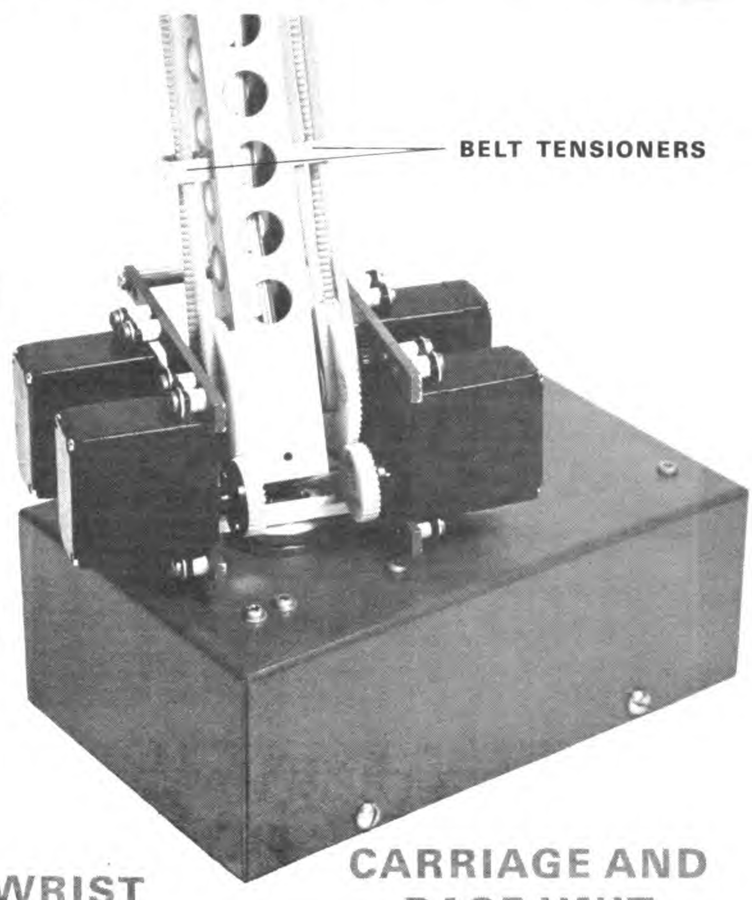
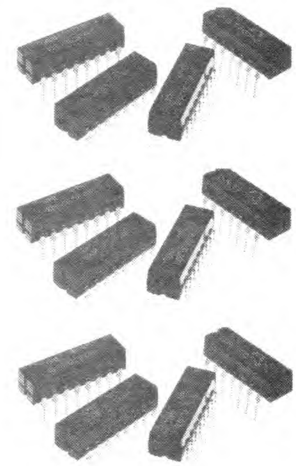



CARRIAGE AND BASE UNIT

# DIGITAL ELECTRONICS

D.W. CRABTREE B Sc Tech Eng (CEI)

## PART TWO



In the last article I described the rules of Boolean Algebra and the formation of expressions which would lead to the design of circuits to carry out the required functions. A description of the logic gates and packages used in circuitry was given and some initial design techniques were employed.

This month we will look at how expressions and circuits can sometimes be minimised in order to limit the number of gates and/or packages used.

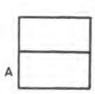
## KARNAUGH MAPS

Karnaugh Maps are a method of mapping out all the inputs and outputs of a system on a chart, or a series of charts, to the effect that the input/output relationships can easily be seen. From these relationships it is then possible to obtain the minimised logic expressions for the functions.

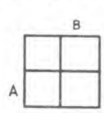
The Karnaugh Map is a series of squares in a symmetrical shape. Each variable in the expression can, obviously, have two states, either "0" or "1", hence the number of squares depends upon the number of variables and is determined by the equation below, which is a function of the two possible states for each variable.

No. of squares = $2^n$ where 2 is raised to the power n and n is the number of variables. Hence for three variables, there will be $2^n$ or $2^3$ or eight squares.

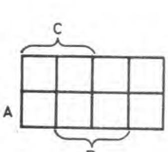
The map formats are shown below:



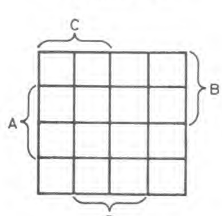

One variable




Two variables

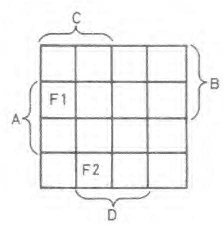



Three variables

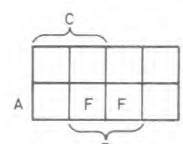



Four variables

In each case, it is seen that, where the variable is shown, this represents the "true" function (where the input is a "1"). Where the variable is not shown, then this is the "false" function, where the input is a "0". Therefore, in the example below, an output F1 is obtained when there is an input of the form $A.B.C.\bar{D}$ and there is an output F2 when there is an input of the form $\bar{A}.\bar{B}.C.D$.



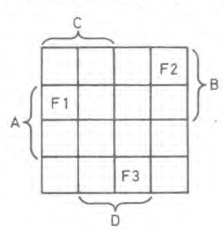

For example, suppose we have a function A.B in a Karnaugh map for three variables, A, B and C. We can draw in the function as being A.B.C and $A.B.\bar{C}$, since both imply A.B alone. Shown thus:




This rule always applies when the function uses less than the total possible number of variables.

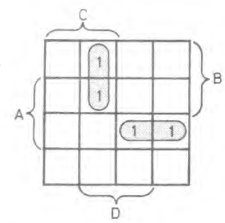
Now, since Karnaugh maps are important and of great use to a digital electronics designer, let us spend a little time doing some exercises.

**Exercise (1):** Give the input arrangements required to give the outputs F1, F2 and F3 in the Karnaugh map below:




**Exercise (2):** Draw, in a Karnaugh map, the positions of the functions F4, F5 and F6 whose input arrangements are $A.\bar{B}.C.D$, $\bar{A}.B.\bar{C}.D$ and $A.B.C$ respectively.

Now, so far, we have only looked at individual functions within the Karnaugh map. We can combine these functions to give an overall output function that includes all the required input arrangements. Let us consider the Karnaugh map below:



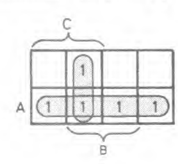

Instead of writing F1, F2, F3, etc., as we have written before, we now show an output as a "1" when we have the required input arrangement. (A "0" indicates no output.) Squares in the map that contain a "1" and are horizontally or vertically adjacent can then be combined. Thus, in the example shown, we have the function $F = A.\bar{B}.\bar{C} + B.C.D$. That is, we have an output from the function with an input of either $A.\bar{B}.\bar{C}$ or B.C.D.

## MINIMISATION USING KARNAUGH MAPS

Suppose we have a 3-input function:

$$F = A.\bar{B}.\bar{C} + A.B.\bar{C} + A.\bar{B}.C + \bar{A}.B.C + A.B.C$$

If we draw a Karnaugh map and plot each of the sub-functions with a "1", we will see that we can use these maps to minimise functions. We can see how the function minimises to F = A + B.C.



## DeMORGANS' RULES

Logic expressions can be written in "sum of product" form, for example, as in F1 = A.B + B.C + A.B.C, or in "product of sums" form, for example, as in F2 = (A + B + C).(B + C + D) or in any combination of both, for example, as in F3 = (A + B.C).(A.B) + B.C.D.

Sometimes it is convenient to put expressions into one form only and generally it is better to do so. Using DeMorgans' Rules, together with the rules shown in the first article in this series, we have a way to change the form in which an expression is written, but without actually altering the function of the expression.

If we have a function, say F = A.B, we can rewrite the expression by negating it (i.e.: making it the "not" function) and changing each term underneath the "bar". Hence:

$$F = A.B = \overline{\bar{A} + \bar{B}}$$

Note that A becomes $\bar{A}$, B becomes $\bar{B}$, . becomes + and the whole expression has a Not bar above it.

This works for any number of variables. Remember that if there is already a bar above the expression, then another bar will "cancel" out both bars.

$$F = \overline{A + B} = \overline{\overline{\overline{\bar{A}.\bar{B}}}} = \bar{A}.\bar{B}$$

The rule is: Put a bar above everything and change each term below. Example:

$$F = \overline{A.\bar{B} + B.\bar{A}}$$
$$= \overline{\overline{\overline{A.\bar{B}.B.\bar{A}}}}$$
$$= \overline{A.\bar{B}.B.\bar{A}}$$
$$= (\overline{\overline{\bar{A} + B}}).(\overline{\overline{\bar{B} + A}})$$
$$= (\bar{A} + B).(\bar{B} + A)$$

This may seem to be quite a lot but if you follow the working through, you should see that it becomes really simple to understand. With practice it becomes very easy to do. Using these rules and the rules already taught we can then more simply minimise such expressions.

**Exercise (3):** Put into Sum of Products form, using DeMorgans' Rules:

$$F1 = \overline{A.\bar{B}.\overline{(A.B.C)}}$$

**Exercise (4):** Put into Product of Sums form, using DeMorgans' Rules:

$$F2 = \overline{A.B + \bar{A}.C + A.(\bar{B} + C)}$$

## STATIC HAZARDS

So far we have discussed inputs as being in a "steady state" condition, that is they assume either a "0" or a "1". However we are also concerned with the transient conditions, when the inputs are changing from a "0" to a "1" or from a "1" to a "0". Consider the following:

Let

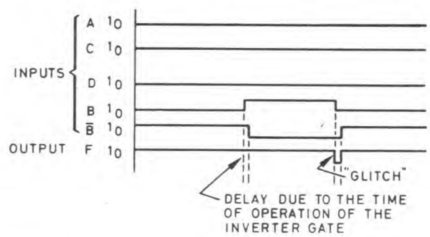
$$F = A.\bar{B}.C + A.B.\bar{D}$$

Now, if A = 1
C = 1
and D = 0

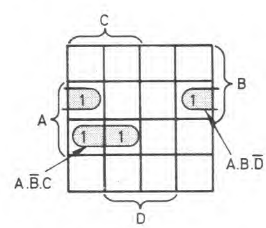
the function F is equivalent to:

$$F = 1.\bar{B}.1 + 1.B.1$$

Hence: F gives an output regardless of whether B is a "1" or a "0". However, what happens if B is, say, a high "1"? Then $\bar{B}$, which is probably derived by putting B through an inverter, must be a low "0". Now if B suddenly goes to a "0", $\bar{B}$ must go to a "1", but this must be a certain limited time after B changes, due to the response time of the inverter. Therefore, for that same time, both B and $\bar{B}$ will both be a "0". This produces what is known as a "glitch", which is a transient or sharp spike on the output. This glitch will also be noticeable on the power supplies and may upset a complete system. The condition described is known as a "static hazard" and is to be avoided at all costs. The waveforms below, for the example quoted, emphasise the problem:



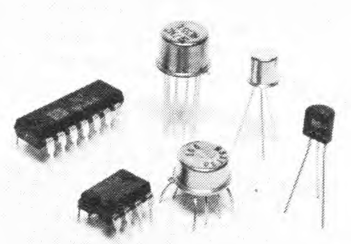

How do we get round the problem? Let us look at the function in the example, on a Karnaugh map.




$$F = A.\bar{B}.C + A.B.\bar{D}$$

Now the two sub-functions are shown on the Karnaugh map and are separate from each other. The presence of a static hazard can easily be seen by looking for horizontally or vertically adjacent non-overlapping "loops". The static hazard is then eliminated by introducing a redundant term which links the loops. In this case, A.C.$\bar{D}$ is added. So our function becomes:

$$F = A.\bar{B}.C + A.B.\bar{D} + A.C.\bar{D}$$

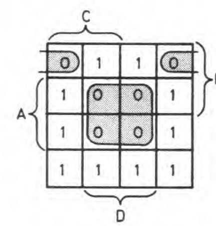


## MAPPING OF ZEROES

Now, so far, we have only looked at the "1"s on a Karnaugh map and built up an expression using those. It sometimes becomes easier, and/or cheaper, to map the "zeroes" or "0"s on the map and then design the circuit via the use of the $\bar{F}$ function. Let us look at the following example:

$$F = A.C.\bar{D} + \bar{B}.C.\bar{D} + \bar{B}.\bar{C}.\bar{D} + \bar{A}.\bar{B} + A.\bar{C}.\bar{D} + \bar{A}.B.D$$

Mapping gives:




Now this involves quite a few gates to create this function. Let us see what the function would look like if the "0"s were to be considered instead. We would have: $\bar{F}$ = A.D + $\bar{A}$.B.$\bar{D}$. This is so much easier, and F is then merely $\bar{F}$ passed through an inverter. Thus a considerable saving in gates is achieved.

## USE OF "DON'T CARE" CONDITION

Sometimes in a switching network, a certain combination of inputs quite literally cannot occur. In those cases we "don't care" how that input combination would affect the output. But this "don't care" condition can be used on occasions to minimise the logic design. For example, supposing states 7, 8 and 9 need to be decoded, from a binary coded decimal counter, for outputting purposes. Now if we look at the truth table for this we see:

| | D | C | B | A | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | |
| 1 | 0 | 0 | 0 | 1 | |
| 2 | 0 | 0 | 1 | 0 | |
| 3 | 0 | 0 | 1 | 1 | |
| 4 | 0 | 1 | 0 | 0 | |
| 5 | 0 | 1 | 0 | 1 | |
| 6 | 0 | 1 | 1 | 0 | |
| 7 | 0 | 1 | 1 | 1 | Output required |
| 8 | 1 | 0 | 0 | 0 | |
| 9 | 1 | 0 | 0 | 1 | |
| 10 | 1 | 0 | 1 | 0 | Can't happen. (Don't care) |
| 11 | 1 | 0 | 1 | 1 | |
| 12 | 1 | 1 | 0 | 0 | |
| 13 | 1 | 1 | 0 | 1 | |
| 14 | 1 | 1 | 1 | 0 | |
| 15 | 1 | 1 | 1 | 1 | |

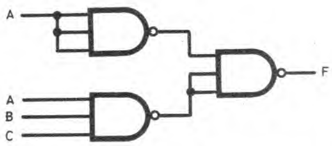
Now, we want an output on 7, 8 or 9. Therefore:

$$F = A.B.C.\bar{D} + \bar{A}.\bar{B}.\bar{C}.D + A.\bar{B}.\bar{C}.D$$

We could create a circuit using the above, but it is easier to incorporate the "don't care" conditions as well as 7, 8 and 9. So, mapping the expression, together with "don't cares" (marked an "X"), we get:

| | | | |
|---|---|---|---|
| | X | X | |
| 1 | X | X | |
| | X | 1 | |
| | X | 1 | |

Thus we get F = D + A.B.C. Hence the circuit is very simple to both design and produce:




The circuit uses only one 3-input Nand gate package.

## EXCLUSIVE-OR FUNCTION

Suppose we have a function thus:

$$F = A.\bar{B} + \bar{A}.B$$

If this function is mapped we get the basic identity known as the "Exclusive-OR" function.

| | |
|---|---|
| 0 | 1 |
| 1 | 0 |

Note that there are no static hazards (since no vertically or horizontally adjacent functions) and no minimisation is possible. This Exclusive-OR identity is available as a package of gates. The symbol for the gate is as shown below.


$(\bar{A}.B + A.\bar{B})$

There is only an output from the gate when the inputs are *different*, never when they are the same.

Note also that if $A \oplus B = \bar{A}.B + A.\bar{B}$

then $A \oplus B = \bar{A}.B + A.B$

when both inputs are the same.

Consider also the following:

$$F1 = A \oplus B \oplus C$$

Let $F2 = (\bar{A}.B + A.\bar{B})$

Now

$F1 = A \oplus B \oplus C$
$= (\bar{A}.B + A.\bar{B}) \oplus C$
$= F2 \oplus C$
$= (\overline{F2}.C + F2.\bar{C})$
$= (\bar{A}.B + A.\bar{B}).\bar{C} + (\bar{A}.\bar{B} + A.B).C$
$= A.\bar{B}.\bar{C} + \bar{A}.B.\bar{C} + \bar{A}.\bar{B}.C + A.B.C$

Mapping this gives:

| | | | |
|---|---|---|---|
| 1 | 0 | 1 | 0 |
| 0 | 1 | 0 | 1 |

This is typical Exclusive-OR mapping.

Similarly, if we consider four functions, we get:

| | | | |
|---|---|---|---|
| 0 | 1 | 0 | 1 |
| 1 | 0 | 1 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 1 | 0 |

Again, this is typically Exclusive-OR.

If this pattern is recognised when mapping out functions, it can be used to save gates by using Exclusive-OR gates as well as other gates. Example:

Let $F = \bar{A}.B.\bar{C}.\bar{D} + A.\bar{B}.\bar{C}.\bar{D} + A.B.C.\bar{D} + \bar{A}.B.C.D + A.B.\bar{C}.D$

Mapping this gives:

| | | | |
|---|---|---|---|
| 0 | 1 | 0 | 1 |
| 1 | 0 | 1 | 0 |
| 0 | 0 | 0 | 1 |
| 0 | 0 | 0 | 0 |

To produce a circuit for this, would mean using 5 packages, 12 gates.

Now:

| | | | |
|---|---|---|---|
| 0 | 1 | 0 | 1 |
| 1 | 0 | 1 | 0 |
| 0 | 0 | 0 | 1 |
| 0 | 0 | 0 | 0 |

≡

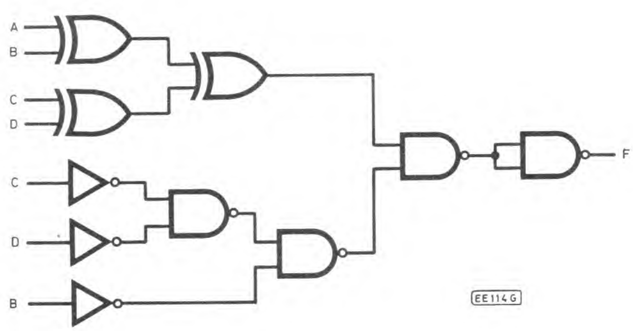
| | | | |
|---|---|---|---|
| 0 | 1 | 0 | 1 |
| 1 | 0 | 1 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 1 | 0 |

| | | | |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 1 |
| 0 | 0 | 0 | 1 |

Therefore $F = (A \oplus B \oplus C \oplus D).(B + \bar{C}.\bar{D})$

Implementing this directly, using Exclusive-OR gates, gives the circuit shown:

This requires 3 packages (10 gates) only, compared with the 5 packages that would otherwise have been used. Hence a great saving in gates results.




**Exercise (1) Answers:**
$F1 = A.B.C.\bar{D}$
$F2 = \bar{A}.B.\bar{C}.\bar{D}$
$F3 = \bar{A}.\bar{B}.\bar{C}.D$

**Exercise (2) Answer:** Note that F6 has two positions because A.B.C is equivalent to A.B.C.D and A.B.C.$\bar{D}$.

| | | | |
|---|---|---|---|
| | | F5 | |
| F6 | F6 | | |
| | F4 | | |
| | | | |

**Exercise (3) Answer:**
$F1 = \overline{A.\bar{B}.\overline{(A.B.C)}}$
$= \overline{A.\bar{B}.(\bar{A} + \bar{B} + \bar{C})}$
$= \overline{\overline{\bar{A} + B + A.B.C}}$
$= \bar{A} + B + A.B.C$

**Exercise (4) Answer:**
$F2 = \overline{A.B + \bar{A}.C + A.(\overline{B.C})}$
$= \overline{\overline{(\bar{A} + \bar{B}).(A + \bar{C}).(\bar{A} + B.C)}}$
$= (\bar{A} + B).(A + \bar{C}).(\bar{A} + B + C)$

*In the next article in this series, we will break away from the use of individual SSI (Small Scale Integration) gates/chips and show how circuits, complex or simple, may be designed using LSI (Large Scale Integration) and MSI (Medium Scale Integration) chips, with an overall saving in packaging and on-board wiring, together with ease of design.*

# FLUID DETECTOR

I. A. DUNCOMBE

ONE of the consequences of owning a tropical aquarium is the constant fear that it may spring a leak, the effect of which is well known to many people, much to their cost. It was this thought, and the overheard lamentation of a customer in a local pet shop, which prompted the design of this simple alarm system.

There have been many previously published designs for water or fluid level detectors, and each one has its own advantages and disadvantages. The i.c. used in the present design seemed perfect for the job, and it was no surprise to see that an enterprising manufacturer had come up with a single i.c.; in the past it had taken two or three transistors and associated components to do the same task.

## PRINCIPLES

The basic principle of any fluid sensor is well known and is shown in Fig. 1.

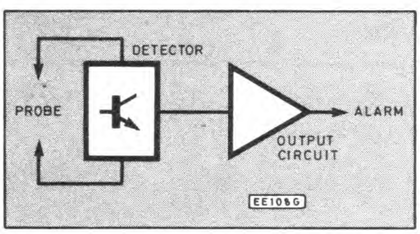



Fig. 1. Fluid Detector principle.

Here, the detector, often a single transistor, is biased in such a way that it will either turn on or off, depending on the resistance between the two probes. In most designs the biasing arrangements of the transistor is such that it will switch when the fluid between the probes is water. If the same circuit is used to sense the level of other fluids, for example coffee, the transistor may not be able to switch (either on or off).

A further disadvantage of using such a simple circuit, is the effect of polarisation of the probes because of the d.c. current normally used in such designs. The i.c. used in the present design eliminates this problem and also provides additional advantages.

## BLOCK DIAGRAM

It is worth considering the internal design of the i.c. before describing the full circuit.

A simplified diagram of the internal structure of the i.c. is shown in Fig. 2.

An internal regulator is employed in the i.c., and this enables a wide range of operating supplies. Typically this range is from 6V to an absolute *maximum* of 28V. The oscillator serves a dual purpose, to provide the a.c. signal between the probes, and to provide an audio alarm signal.

The a.c. signal is applied via the reference resistor $R_{ref}$ to one side of the probe, the other probe connection being to ground. The detector is also connected to the same probe and monitors the resistance of the fluid. An equivalent electrical circuit is shown in Fig. 3. As can be seen from this circuit, if the resistance of the fluid should rise, i.e. the level falls, the potential at the detector input will also rise. As the detector is directly connected to the buffer amplifier this will in turn switch the transistor at a rate determined by the timing capacitor Tc. The result will be an audio output from a loudspeaker.

The value of the internal reference resistor is approximately 13k. This means that any fluid with a resistance greater than 13k will automatically sound the alarm as soon as the complete unit is turned on. To counter this, an external reference resistor can be added which may be varied to suit different resistances of different fluids.

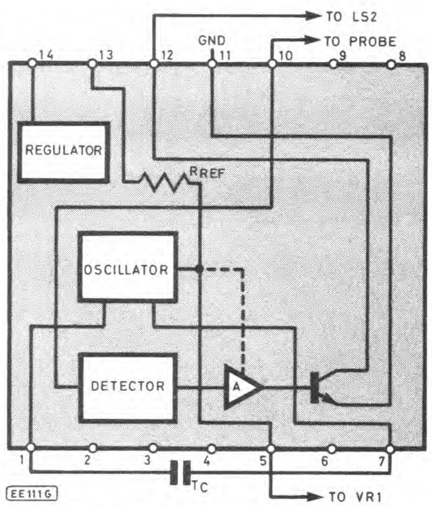



Fig. 2. Block diagram of LM1830.

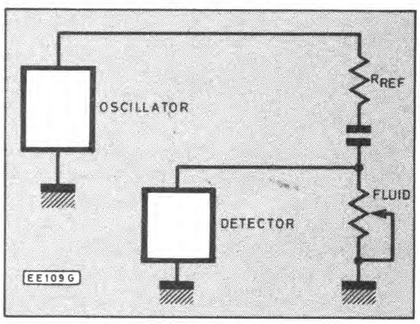
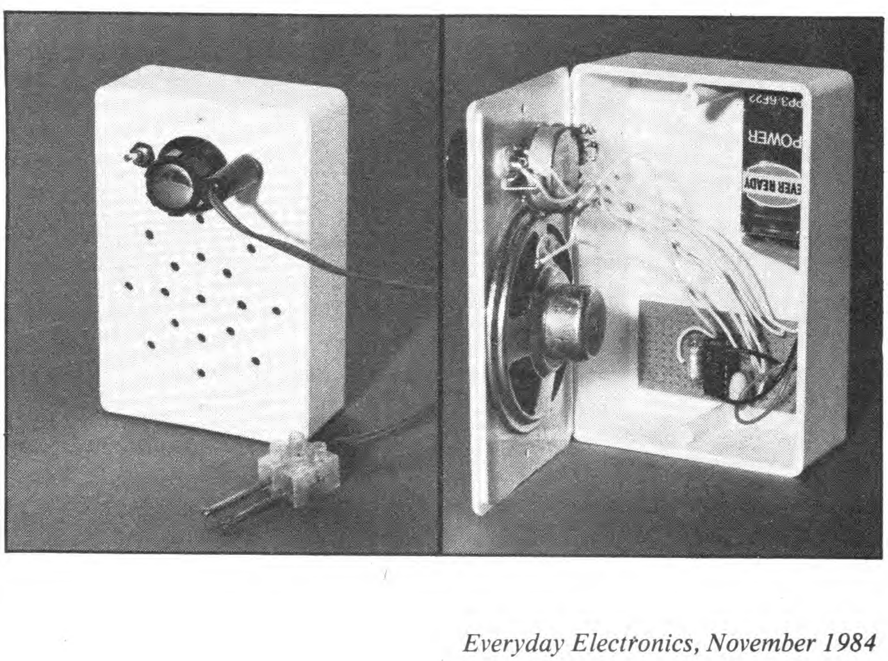



Fig. 3. Equivalent circuit.



## CIRCUIT DESCRIPTION

The full circuit for the Fluid Detector is shown in Fig. 4. The supply for the i.c. is a standard PP3 9V battery, although a simple mains operated power supply could be used. The current taken by the circuit is approximately 2mA, this value remaining constant when the alarm sounds.

Capacitor C1 is the oscillator timing capacitor and with the value shown, the frequency is 850Hz. The value may be altered as required to give different output frequencies. The second capacitor C2, provides d.c. blocking and only allows the a.c. signal from the oscillator to pass to the probe. The variable resistor is the resistivity control, and is used to adjust for different fluid resistances.

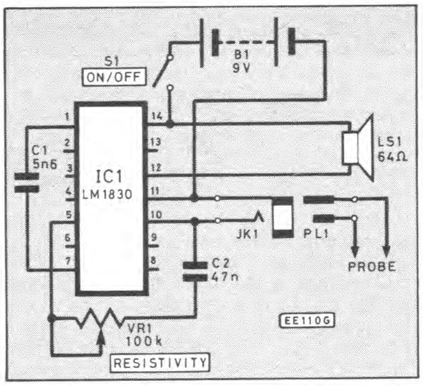



Fig. 4. Circuit diagram of the Fluid Detector.

# CONSTRUCTION

## ASSEMBLY

The Fluid Detector is very simple to construct, and all the details are shown in Fig. 5, and the photographs.

Apart from the usual breaks under the i.c., there is only one other break to be made in the copper strips. A symmetrical pattern of $\frac{3}{16}$in holes is drilled in the top of the plastic box to suit the loudspeaker. The loudspeaker can conveniently be mounted using a clear adhesive. Be sure that no adhesive is allowed to come into contact with the cone.

The positions of the holes for the jack socket, switch and potentiometer will depend to a large extent on the dimensions of the loudspeaker and the case employed. A relatively large diameter loudspeaker should be used so as to provide a good loud output. That used in the prototype is a good compromise between size and cost.

The stripboard may either be mounted using 6BA hardware, or, as in the prototype, double sided sticky pads. The battery may also be mounted in this manner.

## IN USE

The major consideration when using the Fluid Detector is that of the construction of the probe. If the Detector is to be used as was initially envisaged, then the probe should, ideally, be as small as possible and possibly disguised in some way.

The range of possible probes is probably endless. For example: a two way terminal block, with 2in nails forming the probe, a phono plug, a small piece of stripboard, the end of two-core lighting flex (with the ends not bared), etc. Whatever probe construction is finally decided upon the Fluid Detector will cater for all.

Note that the probe need not be a single element. For example, if the Detector is to be used with, say, a water tank, then one side of the probe may be connected to the tank itself and the other side of the probe a simple insulated wire affixed to the top of the tank.

The adjustment of the resistivity control is quite straight-forward. By continuous immersion and removal of the probe in the fluid, the control should be adjusted such that the alarm *just* sounds when the probe is not in the fluid.

It should be found then, that the Fluid Detector is at its most sensitive and will sound the alarm at the slightest fall in fluid level. The alarm will sound for as long as the fluid level is low, if the level should rise, then the alarm will turn off.

Finally, remember that the Fluid Detector will normally be close to liquids of one form or another, and as such all precautions should be taken if a mains operated power supply is used. It is also worth noting that the length of connecting lead between the probe and the unit is of no real consequence. □

## COMPONENTS

See Shop Talk page 690

**Resistors**
VR1 100k lin. potentiometer

**Capacitors**
C1 5n6 polystyrene
C2 47n polyester

**Semiconductors**
IC1 LM1830

**Miscellaneous**
S1 s.p.s.t. miniature toggle
JK1 3·5mm jack socket
PL1 3·5mm jack plug
LS1 64 ohm $2\frac{1}{2}$" miniature loudspeaker (see text)
B1 PP3 9V battery
Stripboard 2" × 1", 0·1" matrix; 14 pin i.c. socket; control knob; plastic case, approx. dimensions $4\frac{1}{2}$" × 3" × $1\frac{1}{2}$"; connecting wire; lighting flex; materials for probe (see text); battery clip; solder, etc.

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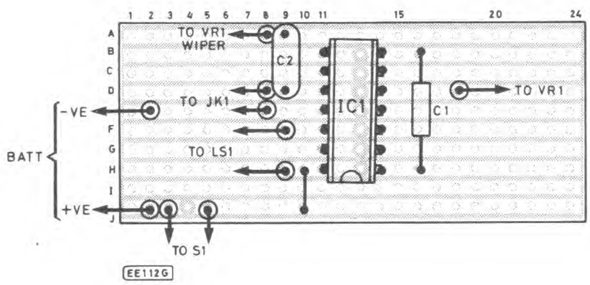
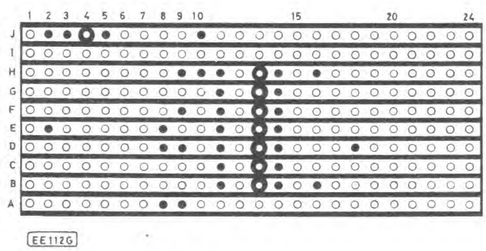



Component layout on stripboard (actual size).




Drilling details for stripboard.

Fig. 5.

# SQUARE ONE FOR BEGINNERS

THE COMPUTER is now almost as common a piece of household equipment as the television, the fridge, or the telephone. There are already more than two dozen different "home computers" available, by mail order, and through High Street shops, and new models are still appearing on the market.

Prices have dropped steadily over the last few years, while the power and flexibility of the machines has increased. For those who claim to know something about computers, as much as for those to whom they are "black boxes", knowing which is "best" is not easy. Further, it could be asked, what does anyone want a computer *for*, anyway?

## THE HARDWARE

All computers—whether ZX-81 or a massive IBM "mainframe" installation—have some things in common. Essentially, they have the ability to store information, to do simple calculations, and to communicate with the user. The "hardware" involved here is the Central Processing Unit (CPU), some memory chips, and "I/O Ports".

The "hardware" is the stuff that the computer is physically made of, and includes items such as the keyboard, as well as the silicon chips that are at the heart of a system. Small computers have a single, complex CPU chip. This CPU chip is a piece of electronics designed to store very small amounts of information, do simple arithmetic such as addition and subtraction, and keep track of what information is where in the system.

The CPU then, is relatively simple (although the electronics are not), and limited in what it can do. Its ability to do complicated tasks quickly is a result of the fact that it works very fast—millions of operations per second. It responds to a limited number of different electrical signals (usually about 250), which cause it to do different things; one pattern of signals may cause it to add two numbers, for example, while a different pattern might cause it to store a number in its memory. But because it works so fast, this limited ability is not a handicap in practice. To multiply together two numbers, it is only necessary to instruct the CPU to add repeatedly. Even if multiplying this way involves hundreds of thousands of such additions, the calculation will be done in less time than it takes to blink. Other tasks, such as sorting lists, can similarly be done very quickly.

## MACHINE CODE

The instructions that the CPU responds to are actually patterns of electrical signals, as mentioned. These patterns, in sequence, are called "Machine Code". Each wire to the CPU that carries a part of the instruction is either at +5 volts ("1") or zero volts ("0"). If, as in small machines, there are eight such wires, then any instruction is a particular, unique pattern of 1s and 0s. Putting sequences of such patterns onto the wires to cause the CPU to do some useful work is known as writing in Machine Code, and is obviously a tedious business. So "high-level languages", such as BASIC, have been developed to enable users to instruct the computer what to do.

The CPU itself cannot respond to instructions written in BASIC, but it is much easier for the user to write programs in "high-level" languages, which look like English, than in Machine Code. The BASIC statements have to be interpreted into the Machine Code which the CPU will respond to.

## MEMORY

The unit of information that the computer normally deals with and must store in memory, is a "byte". The smallest unit it *can* deal with is a "bit"—that is a single wire which is at a "1" or "0". Eight "bits" make up a "byte". A byte represents very little information: for example a single character from the alphabet takes up that much space when put into a form the CPU can work with. Consequently, computers have a need for memory chips capable of storing tens of thousands of bytes.

Memory chips now available can store over eight thousand bytes each. Memory is "hardware". The more memory chips, the more the computer can store. The actual amount of memory available is usually expressed in units of "k", for "kilobyte". A kilobyte is 1024 bytes, so a machine offering, for example, 48k of memory, can store—in theory—48 × 1024 (49152) bytes. In practice, because the CPU makes use of some of this memory itself, less is normally available to the user.

## INPUT AND OUTPUT

An "I/O port" is a "gateway" to the CPU from the outside world. "I/O" stands for Input/Output, and allows the computer to accept input from the keyboard, for example, and display output on a TV.

Many computers have additional such I/O ports, which are available to the user to add on extra memory, or even control the central heating or drive a robot. Usually there is a need for some specialised "interfacing" hardware between the computer's I/O port and the hardware it is controlling. Also, of course, there must be a program to control the hardware.

## SOFTWARE

The programs which allow the CPU to convert from a language such as BASIC to Machine Code are software. So are the programs which are loaded into the machine, whether they are business accounting or games programs.

Some programs, of course, are more important than others. The program to interpret BASIC must be permanent, or else once the machine were switched off, the "interpreter" would have to be reloaded every time. All the essential programs of this kind are normally held as bit patterns in "ROMs".

A "ROM" is a memory chip which retains the bit patterns programmed into it even when power is removed. The user cannot store any information in it—hence the name "**R**ead-**O**nly **M**emory". The complete set of such essential programs, permanently stored, forms the "Operating System" of the computer.

One of the programs is the one that just gives some kind of prompt character on the TV screen when the machine is first switched on. To do anything useful, or to play a game, the software must then be loaded into memory, either from a cassette player or a disc drive. This "loading" capability is part of the computer's operating system.

Because every home computer has its own, specialised operating system, a game written for a Spectrum, for example, will not run on a Commodore 64. In order for it to do so, the game would have to be re-written to fit in with the Commodore's operating system.

## TYPES OF MACHINE

There is no simple answer to the question, "Which of the many different types of machine is best?" Some people may make a decision based on the amount of memory the computer offers, others may want a machine with several I/O ports available. The amount of software on the market will usually influence the decision. But it may be the feel of the keyboard, or even the appearance of the system that is the deciding factor. In many ways, the question is like "Which car is best?"

Computers can be very useful, and they can be fun. Few people, in fact, actually *need* a computer. But nevertheless, a lot of people own them.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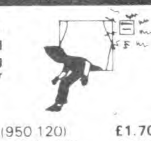

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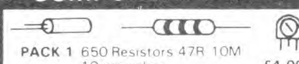

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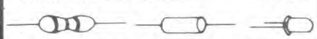

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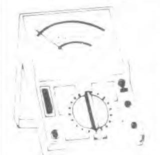

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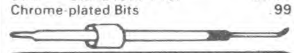

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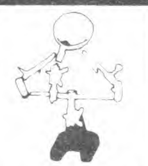

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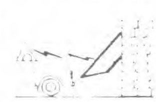

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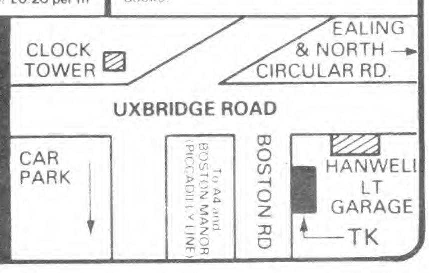


# BBC MICRO AUDIO STORAGE SCOPE INTERFACE

R.A.PENFOLD

Use your television or monitor screen as a digital storage oscilloscope. Allows the VDU to present an analogue signal as an oscilloscope-type display.

WITH THE AID of a suitable home-computer it is possible to produce items of equipment that would not otherwise be a practical proposition for most home-constructors. The interface for the BBC model B microcomputer which is featured in this article is a good example of this.

Basically the interface is just a fast analogue-to-digital converter which feeds into the BBC micro's user port. A series of 255 samples of the input signal are taken and results are stored in memory, after which the computer uses these readings to draw the input waveform on the television or monitor screen. The equipment thus functions as a simple digital storage oscilloscope.

This setup does have its limitations, and with a maximum sampling rate of only about 100000 to 200000 per second it is only suitable for audio frequency waveforms. However, for many purposes this is all that is required, and useful results can be obtained, as the accompanying oscillographs show. The interface includes a simple automatic triggering facility which enables intermittent as well as regular waveforms to be displayed.

It should perhaps be explained that although the BBC microcomputer has a built-in four channel analogue-to-digital converter, this has a maximum sampling rate of only about 100 per second. This is totally inadequate for the present application as it would only permit sub-audio waveforms to be displayed!

## BLOCK DIAGRAM

The arrangement used in the audio storage oscilloscope interface is shown in block diagram form in Fig. 1.

The input signal is applied to the input of the analogue-to-digital converter via an attenuator and an amplifier. The amplifier is needed to increase the maximum sensitivity of the circuit to a suitable level. A signal level of about 2·55 volts peak-to-peak is needed in order to fully drive the analogue-to-digital converter, and the amplifier boosts the sensitivity by a factor of about one hundred.

This gives an overall sensitivity of about 25·5 millivolts peak-to-peak to fully drive the unit, but the attenuator can be used to reduce sensitivity and prevent stronger signals from overloading the unit. The software includes clipping detection and indication.

In order to function properly the analogue-to-digital converter requires a negative supply of between about 3 and 30 volts. A −5 volt supply is available from the power output socket of the BBC machine, but as the current required here is only a few tens of microamps it is more practical to generate a suitable supply from the +5 volt supply available from the user port. This is achieved using a simple oscillator feeding into a smoothing and rectifier circuit.

The user port of the BBC computer provides 8 input/output lines plus two handshake lines. In this application the 8 data lines (PB0 to PB7) are used as inputs, and connect to the 8 data outputs of the converter. Handshake line CB2 is used as an output, and it provides a brief pulse to the "start conversion" input of the analogue-to-digital converter. The other handshake line, CB1, is used as an input, and is fed from the status or "end of conversion" output of the converter.

## OPERATION

In operation a "start conversion" pulse is first provided by CB2, and the CB1 handshake line then monitors the status output until it goes high, indicating that data on the 8 bit output is valid. The output of the converter is then read, another "start conversion" pulse is provided by CB2, and so on, until the 255 samples have been taken.

At the maximum sampling rate it takes only about 2 to 4 milliseconds for all 255 samples to be taken, and this is the effective sweep speed. This may sometimes be too short, and some means of slowing down the sampling rate to increase the effective sweep speed is required. This can be achieved by switching in the monostable multivibrator.

The monostable is triggered by the status output of the converter, and it provides an output signal to the CB1 handshake line after a delay which can be adjusted by means of a potentiometer. This enables a sweep speed of up to about 1 second to be obtained, so that even very low audio frequency waveforms can be displayed.

It is sometimes required to display a short burst of audio signal or a pulse, rather than a repetitive waveform, and some form of automatic triggering is then needed. This is achieved using a software loop which prevents the main program from executing until a trigger signal is received. This signal is provided by a simple trigger circuit which is fed from the output of the amplifier stage.

As there are no unused inputs on the user port one of the other ports of the BBC machine has to be used. Probably the most simple solution to the problem, and the one adopted here, is to use one of the digital inputs of the analogue port.

These are provided by one of the 6522 VIAs (versatile interface adaptors) of the computer, and they can be read using the BASIC ADVAL(0) function. However, in this case an assembly language routine has to be used in order to obtain adequate operating speed, and the appropriate port is read at address &FE40. Input PB1 of the analogue port is used, and this provides an output bit 5 of &FE40 (not bit 1 as one might reasonably expect).

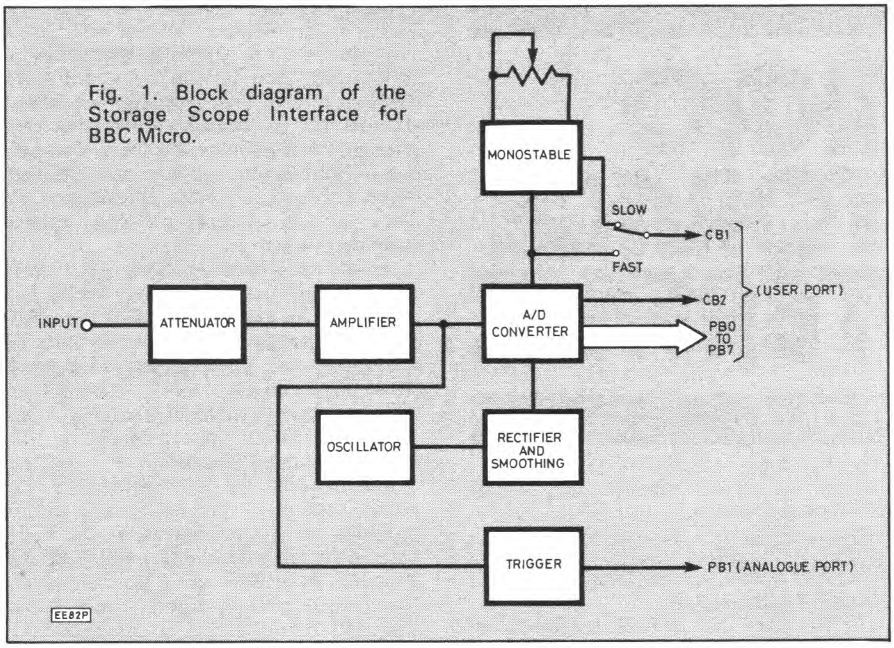



Fig. 1. Block diagram of the Storage Scope Interface for BBC Micro.

## CIRCUIT DESCRIPTION

The full circuit diagram of the BBC Audio Storage Scope Interface is shown in Fig. 2.

The input signal is applied to JK1, and from here it passes to a volume control type attenuator (VR2) and then to a three section switched attenuator. The latter provides attenuations of very roughly 0dB, 20dB and 40dB. In other words it can be used to reduce the sensitivity by a factor of 1, 10 or 100. However, with oscilloscopes the minimum sensitivity is normally considered at the X1 gain setting, with the other settings giving an increase in sensitivity (X10 and X100 in this case).

While this is not a strictly accurate way of looking at things it is often a convenient method in use. In this case the unit is not really intended for accurate voltage measurements, and a highly accurate attenuator is not provided. It is really only needed to provide reduced gain when a large input signal is present, so that fine adjustments using VR2 are easier.

IC2b is used as a straightforward non-inverting unity gain buffer stage giving an input impedance of 1 megohm. Although the attenuators shunt the input impedance of the amplifier, the overall input impedance is still typically quite high at around 500 kilohms.

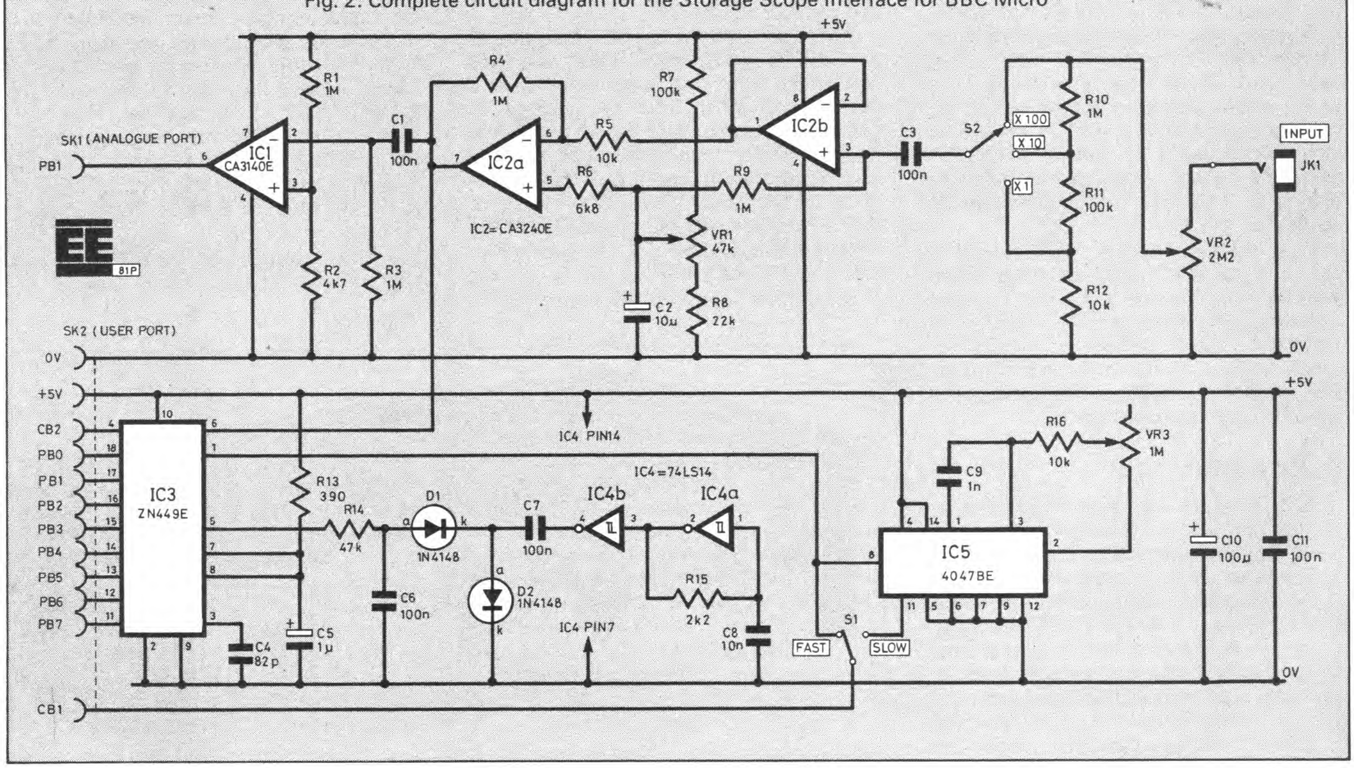
The voltage amplification is provided by IC2a, and this is used as a standard inverting mode amplifier having its voltage gain set at nominally 40db (100 times) by R4 and R5. The output of IC2a is direct coupled to the input of the analogue-to-digital converter device, IC3.

Ferranti, who manufacture the ZN449, recommend the input signal should be applied to the device by way of a resistor network in order to obtain the best possible temperature stability, but in this case the ultimate in stability is not needed, and direct connection is acceptable. VR1 enables the quiescent bias of the amplifier to be varied, and is effectively the X shift control.

IC1 is used in the trigger circuit, and this is basically just an operational amplifier used as a comparator. A small bias voltage is supplied to the non-inverting input by R1 and R2 while the input signal is capacitively coupled to the inverting input by C1.

An important point to bear in mind is that IC1 and IC2 are both devices which will operate well from a 5 volt supply, and that they can also operate properly with their outputs at practically the 0 volt supply potential. Most other operational amplifiers are unsuitable on both counts, and cannot be used in this design.

Fig. 2. Complete circuit diagram for the Storage Scope Interface for BBC Micro



## A/D CONVERTER

The ZN449 analogue-to-digital converter uses the successive approximation technique. With this method the input signal is fed to one input of a high speed comparator, while the comparator's other input is fed from the output of an 8 bit digital-to-analogue converter. This is operated from some logic circuitry, and it is the final signal fed to the digital-to-analogue converter that constitutes the 8 bit output signal.

When a negative "start conversion" pulse is received, the input to the digital-to-analogue converter is set with bit 7 (the most significant bit) at 1, and the other bits at 0. The output from the digital-to-analogue converter is therefore at about half its full scale value. This voltage is then compared to the input voltage, and bit 7 is reset to 0 if the latter is at the lower figure.

Next bit 6 is set at 1, the comparison process is repeated, and bit 6 is reset to 0 if the input voltage is the lesser of the two. This process is repeated for bits 5 to 0, with the output voltage of the digital-to-analogue converter gradually moving closer to the input potential. Of more importance, the digital output gradually becomes more accurate until it is a true representation of the input voltage.

A clock signal is needed to operate the control logic circuit of the device, and it takes no more than nine clock cycles to complete a conversion. An attractive feature of the ZN449 is its internal clock which requires just one discrete component. This is C4 which sets the clock operating frequency.

A value of 82p gives a nominal operating frequency of 1MHz, which is the maximum guaranteed operating frequency for the ZN449. This gives nearly 100000 conversions per second (allowing for the time taken for the computer to read the output), but in practice a lower timing capacitance can be used, and it is often possible to obtain something approaching 200000 conversions per second. It is advisable to use the highest clock frequency that gives reliable results as this gives the unit optimum high frequency resolution.

R13 and C5 are the load resistor and decoupling capacitor for the internal voltage reference of the digital-to-analogue converter. R14 is the discrete emitter resistor for the long-tailed-pair input stage of the high speed comparator. This must be fed from a negative supply in order to permit voltages right down to the 0 volt rail to be compared. One of the inverting Schmitt triggers of IC4 is used as a relaxation oscillator, and another section of IC4 is used as an output buffer (the other four sections are unused). D1, D2 and C6 rectify and smooth the output of IC4 to give a negative supply of about −3 volts.

Pin 4 of IC3 is the "start conversion" input and is driven direct from the CB2 line of the user port. The status output is at pin 1 of IC3, and with S1 in the "fast" position this is coupled direct to the CB1 line. With S1 in the "slow" position CB1 is driven via the monostable multivibrator based on IC5. This is a CMOS 4047BE device used in the positive trigger mode, and it is therefore triggered by the status output when it goes high at the end of a conversion.

The CB1 line is fed from the "not Q" output of IC5 which goes from the low logic state to the high one at the end of the output pulse. This system works satisfactorily because the CB1 input does not respond to a particular logic state, but is an edge sensitive type which (in this case) is activated by a low to high transistion. C9, R16 and VR3 are the timing components, and VR3 is effectively the sweep speed control.

The data outputs of the ZN449 are tristate types which can be directly interfaced to a microprocessor data bus, but this facility is not needed here, and the outputs are permanently enabled by taking pin 2 low.

## CONSTRUCTION

A metal instrument case having approximate outside dimensions of 229 × 133 × 63·5mm is suitable for this project. A substantially smaller case could be used, but there might then be difficulty in accommodating the five controls and input socket on the front panel. The use of a metal case is strongly recommended since the input wiring is highly sensitive to stray pick up of electrical noise, and a metal case provides screening against mains hum, etc. The front panel layout is not too critical, but it is advisable to mount SK1, VR1 and S2 fairly close together.

Details of the printed circuit board and wiring are provided in Fig. 3. IC1, IC2 and IC5 are MOS types, and they should therefore be fitted in intergrated circuit sockets, and the usual MOS handling precautions should be taken. As IC3 is a fairly expensive device it is probably worthwhile using a socket for this component as well. Use pins at points where connections to SK1, SK2, and the controls will be made.

The connection to the user port of the computer is made using a piece of 20-way ribbon cable about 0·5 to 1 metre long terminated in a 20-way i.d.c. header socket. A ready-wired socket and lead of this type are readily available, and it is probably best to obtain them in this form. The free end of the lead is connected to the printed circuit board, and great care should be taken to avoid mistakes when doing this. The lead could be connected via pins, but due to the close spacing of the connections it would be difficult to avoid accidental short circuits.

It is more time consuming to connect the lead direct to the board, but this is the safer option. Make sure the lead is connected the right way round. Fig. 4 shows the user port connections (as seen looking onto the port), and reference to this should help to avoid errors.

An exit hole for the lead must be made in the rear panel of the case, and a rectangular cutout about 27 × 8mm cut or filed at a suitable position in the top of the rear panel should suffice. Alternatively, a multiway connector could be mounted on the rear panel of the case and the connections to the user port could be made by way of this. However, this would entail more wiring and the cost of a multi-way plug and socket.

SK2 is a 1mm socket mounted at any convenient place on the rear panel. It is connected to PB1 of the BBC computer's analogue port using an insulated lead about 1 metre long and fitted with a 1mm plug at each end.

The printed circuit board is mounted on the base panel of the case using 6BA or M3 fixings, including spacers to keep the underside of the board clear of the metal case. The final wiring is then added. Keep the wiring to JK1, VR2 and S2 as short as possible, and it should then be unnecessary to use screened leads in order to keep stray pick up of noise to an insignificant level.

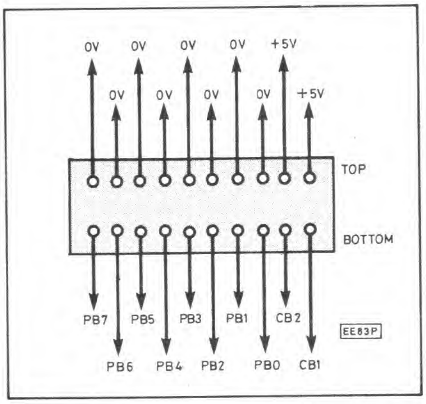



Fig. 4. Details of the BBC Micro's user port connections.

## IN USE

With SK2 connected to the user port, SK1 connected to PB1 of the analogue port (refer to page 499 of the "User Guide"), and the computer switched on, the computer should function normally. If there is any sign of abnormal operation switch off immediately and recheck all the wiring.

The Storage Oscilloscope Program should then be loaded and run. Function keys 0 and 1 enable a simple graticule to be switched on and off, as required. If function key 2 is operated the unit is taken into the triggered mode, and it is then activated by a suitably strong input signal. The trigger circuit is quite sensitive, and if the input signal fails to trigger the unit it would not give a meaningful trace anyway. The attenuator controls should then be adjusted for greater sensitivity. If, on the other hand, the signal is clipped, a warning tone is produced from the computer. The attenuator controls should then be adjusted for lower sensitivity, and a fresh sample of the input signal should be taken.

# COMPONENTS

See **Shop Talk** Page 690

**Resistors**

| | |
|---|---|
| R1,3, 4,9,10 | 1M (5 off) |
| R2 | 4k7 |
| R5,12, 16 | 10k (3 off) |
| R6 | 6k8 |
| R7,11 | 100k (2 off) |
| R8 | 22k |
| R13 | 390 |
| R14 | 47k |
| R15 | 2k2 |

All $\frac{1}{4}$W 5% carbon

**Capacitors**

| | |
|---|---|
| C1,3, 6,7 | 100n polyester (4 off) |
| C2 | 10µ 25V radial electrolytic |
| C4 | 82p ceramic plate (see text) |
| C5 | 1µ 63V radial electrolytic |
| C8 | 10n polyester |
| C9 | 1n mylar |
| C10 | 100µ 10V radial electrolytic |
| C11 | 100n ceramic |

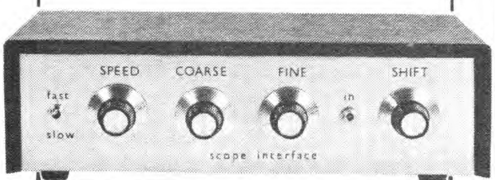
**Semiconductors**

| | |
|---|---|
| IC1 | CA3140E MOS op-amp |
| IC2 | CA3240E dual MOS op amp |
| IC3 | ZN449 A/D converter |
| IC4 | 74LS14 hex Schmitt Trigger |
| IC5 | 4047BE CMOS monostable/astable |
| D1,2 | 1N4148 silicon signal diodes (2 off) |

**Miscellaneous**

| | |
|---|---|
| JK1 | 3·5mm jack socket |
| SK1 | 1mm socket |
| SK2 | 20-way i.d.c. header socket (with cable) |
| S1 | s.p.d.t. miniature toggle type |
| S2 | 12-way 1 pole with end stop (set for 3-way operation) |
| VR1 | 47k linear carbon |
| VR2 | 2M2 linear carbon |
| VR3 | 1M linear carbon |

**Printed circuit board:** Single-sided size 100 × 78mm, *EE PCB Service,* Order code 8411-01; metal case about 229 × 133 × 63·5mm (type WB4); four control knobs; two 1mm plugs and insulated lead; 6BA or M3 fixings; Veropins; wire, etc.




**Approx. cost Guidance only** **£26.00**

# BBC MICRO AUDIO STORAGE SCOPE INTERFACE

## SOFTWARE PROGRAM

```
10 REM STORAGE OSCILLOSCOPE PROGRAM
20 REM BY John Penfold
30 REM COPYRIGHT EVERYDAY ELECTRONICS
40 REM for BBC Microcomputer model B 32K
50  MODE 1
60 *FX225, 160
70  ?&FE6C=176
80 DIM START 50:DIM STORE 255
90 P%=START
100 COPT 2
110 .START
120 CLD
130  SEI
140 LDX #255
150 .WAIT
160 LDA #32
170 AND &FE40
180 BNE WAIT
190 .LOOP
200  LDA #0
210  STA &FE60
220 .INLOOP
230  LDA #16
240 AND &FE6D
250 BEQ INLOOP
260 LDA &FE60
270 STA STORE,X
280 DEX
290 BNE LOOP
300 CLI
310  RTS
320 .DIRECT
330  CLD
340  SEI
350  LDX #255
360  BNE LOOP
370 ]
380  CLS
390 COLOUR 129:PRINTAB(0,2)"Storage 'scope (c) Everday Electronics"
400 PRINTTAB(8,3)"Program by John Penfold"
410 VDU 28,3,31,39,26,24,130;255;1150;765;
420 PRINT"f0=Graticule on: f1=Graticule off","f2=Trigger mode: f3=Direct
    mode "
430 REPEAT
440  key=INKEY(20)
450  IF key=160 G%=TRUE
460  IF key=161 G%=FALSE
470  IF key=162 CALLSTART:PROCgraph
480  IF key=163 CALLDIRECT:PROCgraph
490  UNTIL FALSE
500 END
510  DEF PROCgraph
520  CLG
530  IF G%PROCgraticule
540  GCOL0,2
550 reading=255
560 MOVE130,510
570 FOR X%=130 TO 1146 STEP 4
580  Y%=?(STORE+reading)
590  DRAW X%,Y%*2+255
600  IF Y%(1 OR Y%)254 VDU7
610  reading=reading—1
620  NEXT X%
630  ENDPROC
640 DEF PROCgraticule
650  GCOL0,1
```

```
660 MOVE 130,255:DRAW 130,765:DRAW 1150,765:DRAW 1150,
    255:DRAW 130,255
670 MOVE 385,255:PLOT 21,285,765:MOVE 640,765:PLOT 21,640,
    255:MOVE 893,255:PLOT 21,893,765
680 MOVE 130,383:PLOT 21,1150,383:MOVE 1150,510:PLOT
    21,130,510:MOVE 130,638:PLOT 21,1150,638
690 ENDPROC
```

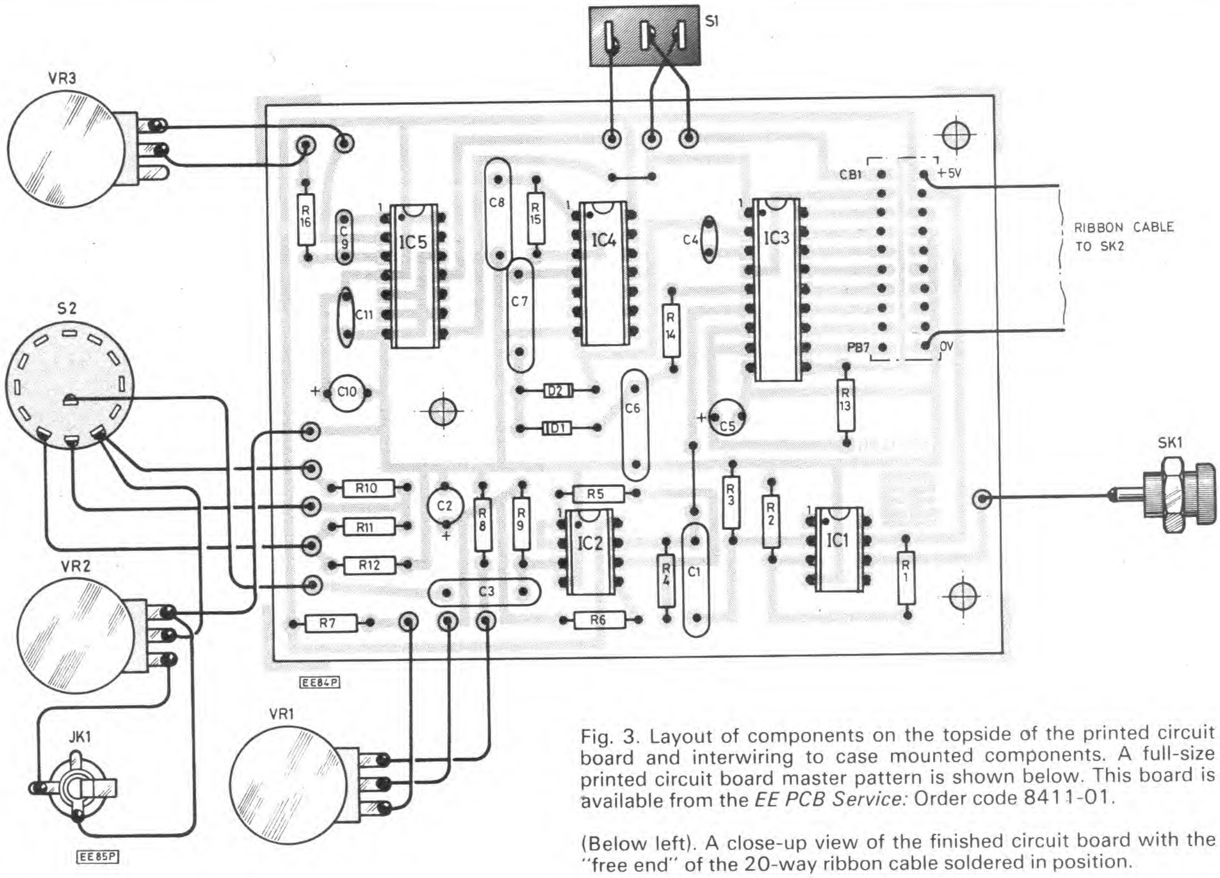
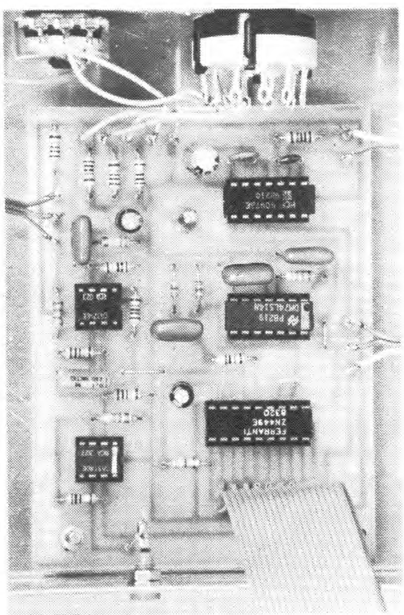
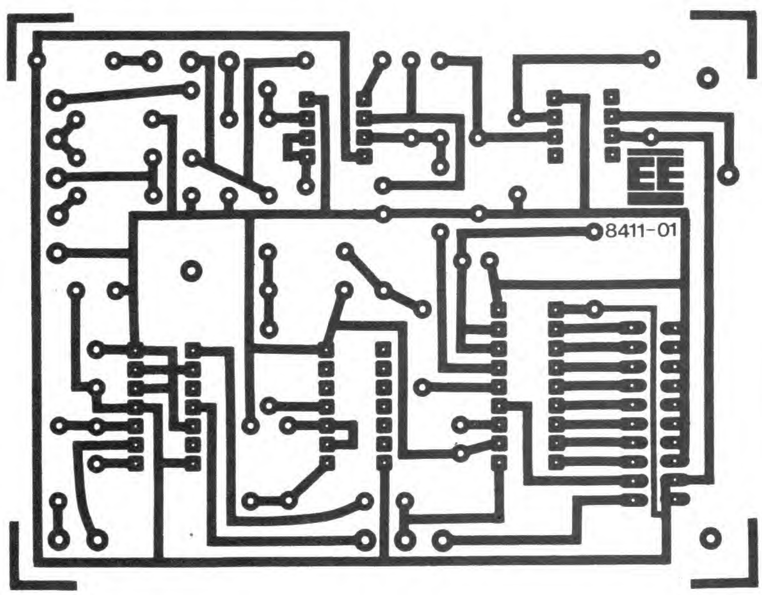
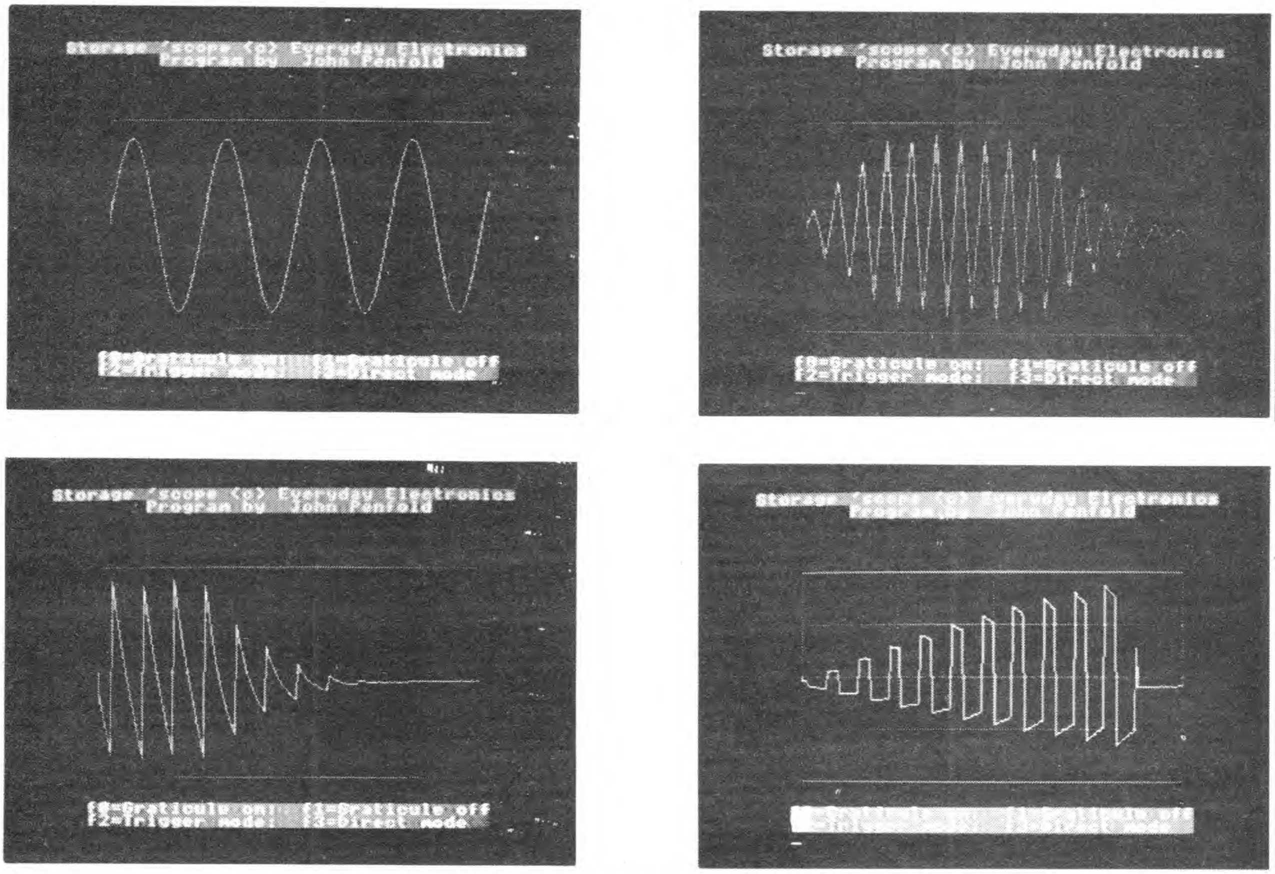




Fig. 3. Layout of components on the topside of the printed circuit board and interwiring to case mounted components. A full-size printed circuit board master pattern is shown below. This board is available from the *EE PCB Service:* Order code 8411-01.

(Below left). A close-up view of the finished circuit board with the "free end" of the 20-way ribbon cable soldered in position.








Examples of waveforms obtained using the Storage Scope Interface for BBC Micro unit.

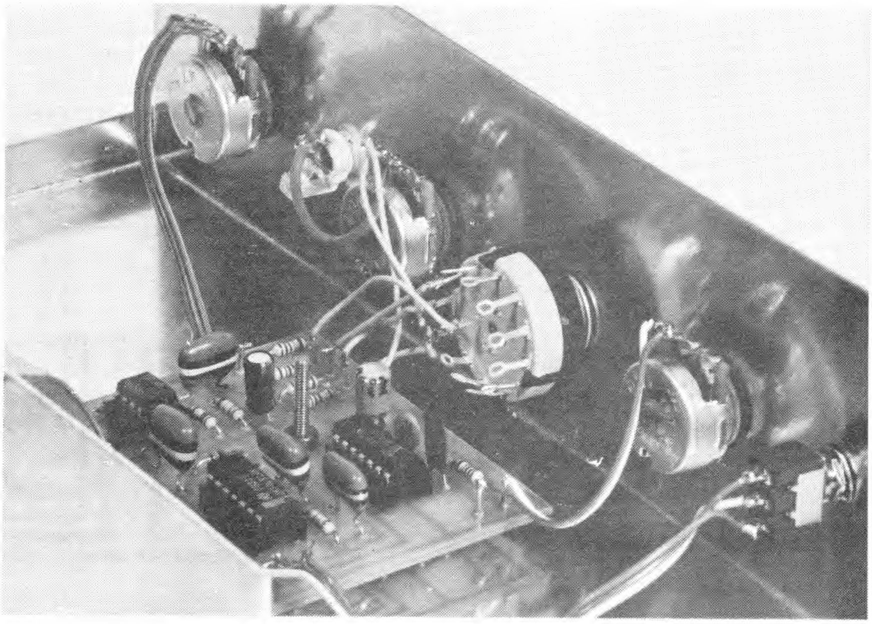
If function key 3 is operated the unit is immediately triggered. This mode is suitable for repetitive waveforms, although the triggered mode has a slight advantage even for this kind of waveform in that it will always start the trace at the beginning of a half cycle. Of course, in both modes the trace is not produced in real-time, and it takes a second or two for it to be drawn on the screen.

An important point to bear in mind when S1 is switched to the "slow" mode is that the total number of samples remains at 255. When an ordinary oscilloscope is used at a slow sweep speed with a much higher input frequency the trace is in the form of a band across the screen, with the width of the band varying in sympathy with the amplitude of the input signal. To produce this type of trace with this equipment would require more sophisticated software where the sweep speed would be slowed down wholly or partially by taking a greater number of samples, and the suggested program is only suitable for displaying audio waveforms.

The vertical position of the trace can be adjusted somewhat using VR1, but it takes a couple of seconds for the d.c. levels of the circuit to settle after VR1 has been adjusted.

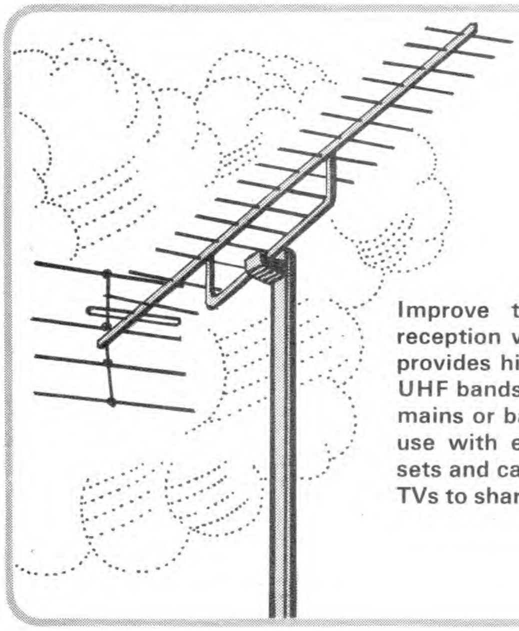
As explained earlier, it is worthwhile trying lower values for C4 in order to increase the maximum sampling speed. This is just a matter of trying various values to find the lowest one which gives proper operation of the circuit. It is possible that the unit operates with C4 removed, and just the internal capacitance of IC3 to act as the timing capacitance. □

Internal view showing the front panel wiring.

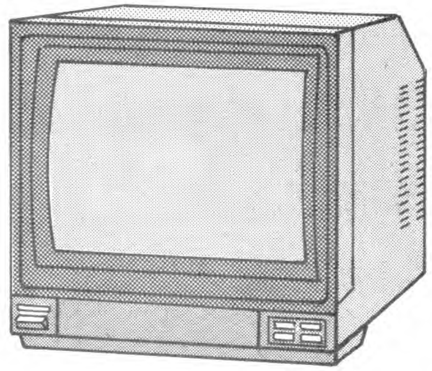


# DECEMBER FEATURES...

## TV AERIAL PRE-AMP



Improve the performance of your TV reception with this pre-amp design which provides high gain over both the VHF and UHF bands. Because the unit can be either mains or battery operated it is suitable for use with either portable or domestic TV sets and can also be used to enable several TVs to share the same aerial.



## Mini Workshop PSU

A variable voltage power supply is a basic requirement for all home constructors. Our design offers a continuously variable output from 3 to 30 volts with built-in current limiting.

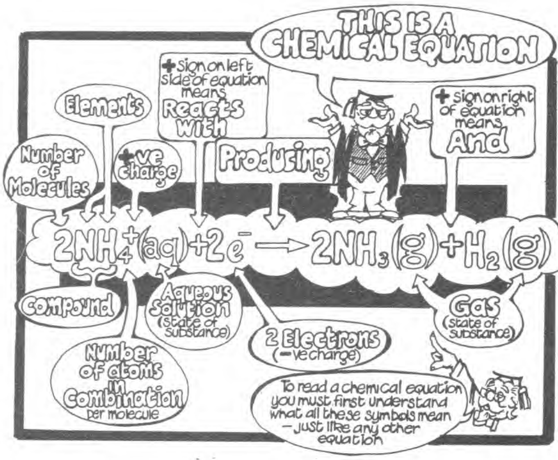
## DOOR CHIME

Enhance your home with our electronic doorchime. This unit will produce a resonant gong-like chime the volume and pitch of which can be easily adjusted to your individual taste.

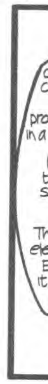
**EVERYDAY ELECTRONICS and computer PROJECTS**

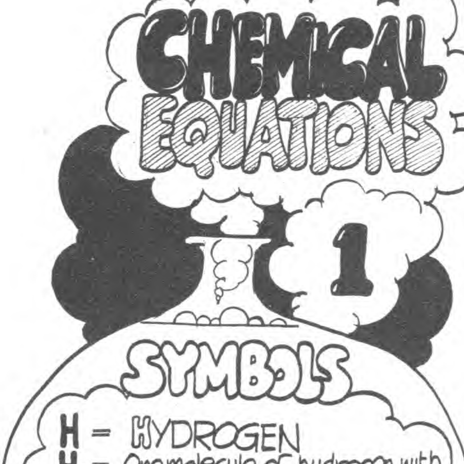
**DECEMBER 1984 ISSUE ON SALE FRIDAY, NOVEMBER 16**

FUNTRONICS
WITH THE
BATTERY
PART 1

THIS IS A CHEMICAL EQUATION
+ sign on left side of equation means Reacts with
+ sign on right of equation means And
Elements
Number of Molecules
+ve charge
Producing
2NH4+(aq)+2e− ⟶ 2NH3(g)+H2(g)
Compound
Aqueous Solution (State of Substance)
Number of atoms in combination per molecule
2 Electrons (−ve charge)
Gas (State of substance)
To read a chemical equation you must first understand what all these symbols mean — just like any other equation

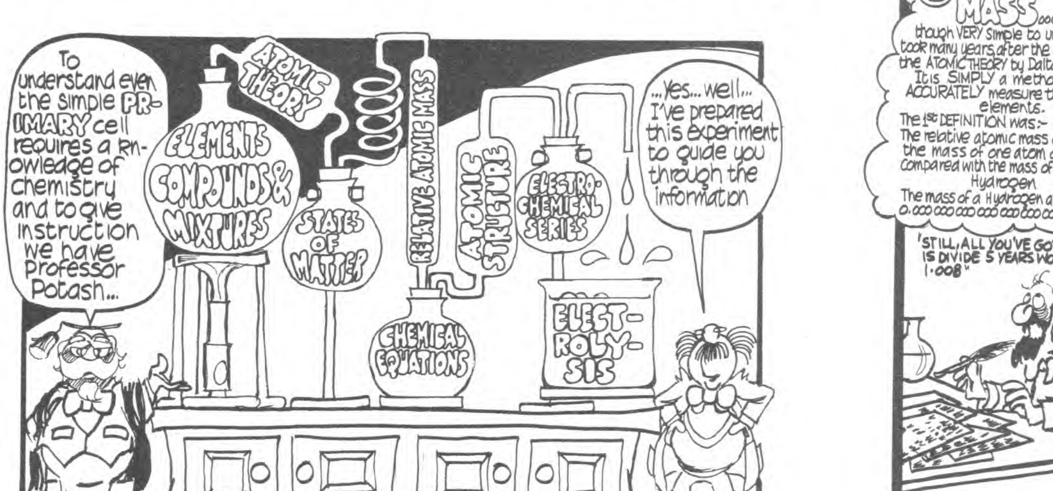


CHEMICAL EQUATIONS
1
SYMBOLS
H = HYDROGEN
H2 = One molecule of hydrogen with 2-atoms in combination.
S = Sulphur
O = Oxygen.
H2SO4 = Sulphuric acid, which contains 2-atoms of hydrogen, one atom of sulphur, and 4-atoms of oxygen in combination.
This is only one example of how elements combine to form a compound.


SALT & SAND mixture
Chemical equations are developed by EXPERIMENT and to understand chemistry one must experiment. Let's visit the "SALT MINE" to see how the mixture is seperated into the compounds of salt and sand
HOT SOLUTION
RESIDUE OF SAND
EVAPORATION DISH
BOILING WATER
FILTRATE: SALT SOLUTION
MINE
SALT
SAND


DEVELOPMENT
NOW, if you immerse a strip of copper and zinc into DILUTE sulphuric acid they will... CORRODE
1 But why do we choose COPPER and ZINC for the electrodes?
2 ...And why do we immerse both these metals into DILUTE SULPHURIC ACID?
For answers to these major questions have a look at the 'electro-chemical series' and 'electrolysis'
3


by Thakery

To understand even the simple PRIMARY cell requires a knowledge of chemistry and to give instruction we have Professor Potash...
ATOMIC THEORY
ELEMENTS COMPOUNDS & MIXTURES
STATES OF MATTER
RELATIVE ATOMIC MASS
ATOMIC STRUCTURE
ELECTRO-CHEMICAL SERIES
CHEMICAL EQUATIONS
ELECTROLYSIS
...Yes... well... I've prepared this experiment to guide you through the information


RELATIVE 1 ATOMIC MASS...
though VERY simple to understand it took many years after the discovery of the ATOMIC THEORY by Dalton, to develop. It is SIMPLY a method used to ACCURATELY measure the weight of elements.
The 1st DEFINITION was:-
The relative atomic mass of an element is the mass of one atom of the element compared with the mass of one atom of Hydrogen
The mass of a Hydrogen atom is:- 0.000 000 000 000 000 000 000 001 7g
...HOWEVER the ISOTOPE of Carbon 12 6 C was to become the modern choice as the unit one in RELATIVE ATOMIC MASS
'STILL, ALL YOU'VE GOT TO DO IS DIVIDE 5 YEARS WORK BY 1·008'
RELATIVE ATOMIC MASS OF H NOW EQUALS 1·008


# ELECTROLYSIS

Electrolysis is about the chemical changes by the passage of current through an electrolyte.

Electrolyte is a substance which produces a conducting medium when dissolved in a suitable SOLVENT (usually water)

Now, Electrolysis is at the heart of the BATTERY and will be the subject of the next Funtronics on batteries

There are MAJOR differences between electrolyte and metal conductors e.g. Electrolytes decompose while it conducts current — METALS DO NOT.

# LINK-UP.

Start at R and form a chain of words related to electronics

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| C | I | R | T | C | E | ■ | D | L |
| C | E | Y | R | E | L | E | I | E |
| H | L | D | ■ | S | S | P | I | N |
| R | T | O | ■ | N | O | R | R | E |
| O | R | P | L | A | T | O | R | F |
| N | A | P | A | E | R | T | S | I |
| O | H | L | O | S | O | A | N | S |
| P | R | E | R | R | N | R | T | O |
| H | E | R | C | E | P | H | O | T |

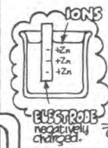
| WORD | CLUE |
|---|---|
| ① R _ N T _ N | WATER COOLED TETRODE |
| ② P _ _ O _ _ _ _ _ _ _ TO _ | SENSITIVE TO LIGHT |
| ③ _ _ B _ _ P _ E _ | SATISFIES 'X' |
| ④ _ _ _ _ L _ TR _ _ | AIR MAKES A GOOD ONE |
| ⑤ C _ _ _ _ PH _ R | TIMES SIGNAL FROM CLOCK |
| ⑥ H _ _ TLE _ | — 3·223 bits |
| ⑦ _ _ _ _ L _ _ | EFFECT |
| ⑧ C _ _ _ OS _ _ _ | A SOFT SOLDER. |

# 1 Electrochemical series!

| ELEMENT | ELECTRIC POTENTIAL IN VOLTS |
|---|---|
| Lithium | − 3·02 |
| Potassium | − 2·92 |
| Sodium | − 2·71 |
| Magnesium | − 2·34 |
| Aluminium | − 1·66 |
| Zinc | − 0·76 |
| Iron | − 0·44 |
| Cobalt | − 0·29 |
| Nickel | − 0·23 |
| Tin | − 0·14 |
| Lead. | − 0·12 |
| HYDROGEN | 0·00 |
| Copper | + 0·34 |
| Mercury | + 0·80 |
| Silver | + 0·80 |
| Gold | + 1·68 |

## Why do we choose COPPER and ZINC for the ELECTRODES?

Before looking at the ELECTROCHEMICAL series let's consider what happens when ZINC is placed in DILUTE SULPHURIC ACID




When Zinc is placed in Dilute sulphuric acid metal ions $Zn^+$ go into solution leaving the electrode NEGATIVELY charged. A DOUBLE LAYER of charge builds-up and eventually prevents any further net transfer of ions. This sets-up an electrical potential between the electrode and the liquid.

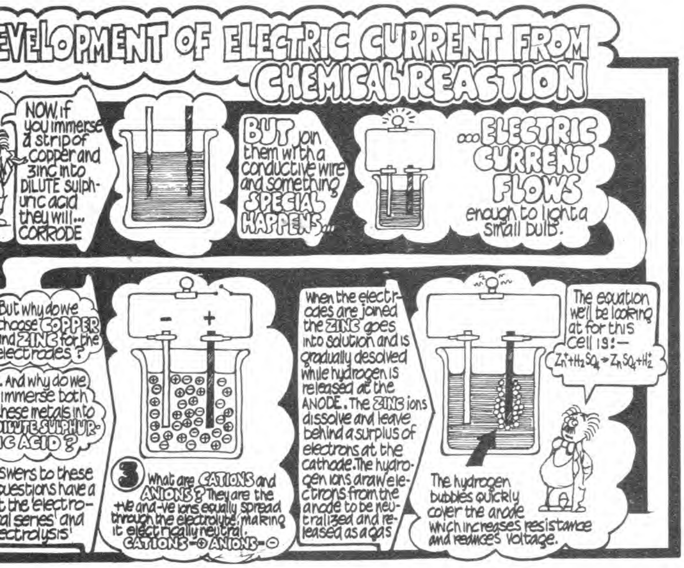
Now it's important to realize that different metals exert different electrode potentials and they can be arranged in a definite order according to their ELECTRODE POTENTIAL and this is the ELECTROCHEMICAL series

Now to measure a potential difference there must be a ZERO potential and in this case HYDROGEN is the electrode at ZERO potential.

So let's work out the potential difference between the copper and zinc electrode!

$$+0{\cdot}34-(-0{\cdot}76)=+0{\cdot}34+0{\cdot}76=1{\cdot}10V$$

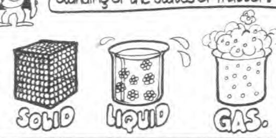
Remember, a minus x a minus = a plus




# STATES of MATTER

| State of the substance | state symbol. |
|---|---|
| Solid | s |
| Liquid | l |
| Gas | g |
| Aqueous Solution | aq |

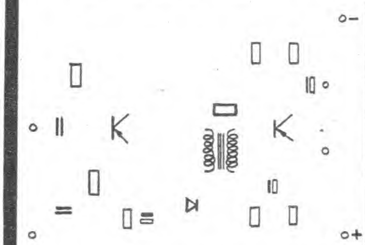
KENETIC THEORY deals with the motion of the particle and is crucial to the understanding of the states of matter.




In the case of a SOLID the particles are arranged in a fixed pattern, and they form a lattice of vibrating masses. In a LIQUID, however, the particles are fairly randomly arranged and consist of CLUSTERS in which they are very close together. In a GASEOUS state the particles are moving independently of each other in all direction and at great speed. The kinetic energy of the particles tends to keep them spaced out.

# Transistor teaser.

Link-up the components below to form a well kown circuit ... 3 of the components are not required.




Two-stage small signal amplifier.


"SHALL WE TRY THE MIXTURE FIRST — ATLEAST, WE CAN DIVIDE IT!"

Solutions on page 693

# The WORLD of the ATOM

The ancient Greeks argued amongst themselves about how MATTER was made. What happened when something was cut into SMALLER and SMALLER pieces?


The problem was not properly solved until the English scientist JOHN DALTON at the beginning of the 19th century produced his ATOMIC THEORY

DALTON said that EVERYTHING was made up of indivisible tiny particles, called ATOMS. He imagined these atoms to be like tiny billiard balls, which joined together in groups to form arrangements called MOLECULES


John Daltons ATOMIC THEORY was a very important foundation stone for modern chemistry.

The Atomic theory explains many properties of Solids, liquids and gases (Have a look at STATES of MATTER)

But what is an ATOM? Well, it's not very big!

Most atoms have a radius of about $10^{-10}$m or 0·1nm or 10 Angström BUT how can we comprehend such a very small particle?

Well, this dot →·← would contain about one BILLION atoms one atom thick.

Let's have a closer look at the ATOM. The atom consists of a number of electrons moving around a NUCLEUS and the nucleus consists of protons and neutrons.

- NEUTRON. The neutron has no charge i.e. its neutral, but it does contribute to the mass of the atom.
- PROTON. The proton is POSITIVELY charged and is equal in mass to the neutron
- ELECTRON. The electron is NEGATIVELY charged and is equal and opposite to the protons charge.

## DALTON

### DALTON'S ATOMIC THEORY

(STATES)

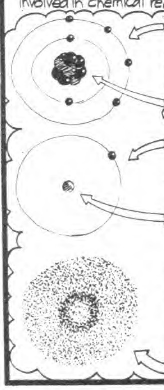
1. Matter is made up of small, indivisible particles called ATOMS
2. ATOMS are indistructable and they cannot be created.
3. The ATOMS of a particular element are exactly alike in every way and are different from the atoms of all other elements.
4. Chemical combination takes place between whole numbers of ATOMS

... This theory was first put forward in 1808

DALTON'S ATOMIC THEORY is the FOUNDATION of MODERN SCIENCE!

These were most remarkable thoughts to have in Dalton's time and they formed a very important theory but they are all now subject to revision. Number 1, for example, is not quite true for we all now know that the atom can be split.

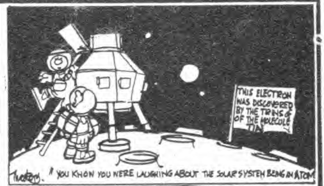
The ELECTRON is the most important part to study because it is the only part of the atom involved in chemical reaction.



This is a CARBON atom. Notice how the electrons are divided into 2-orbits, one with 2 and the outer with 4. The outer orbit or 'shell' is the VALENCE RING. Nucleus with 6-protons and 6-neutrons.

This is a Hydrogen atom. This is the lightest atom with a nucleus containing only one proton and one electron revolving round it. Nucleus is one proton

Well, that's what an atom looks like ... or is it? Actually, if it were possible to see an atom with its electron revolving round it then the atom would have a cloud appearance. Even the hydrogen atom with its one electron would look like this.




'To discover new worlds ... and to boldly go where no man has gone before' has always held a great fascination for us all! How deep is space? How old is the Universe? Inconceivably large dimensions!

But the world of the ATOM is equally fascinating and full of surprises.

It still remains the only world within our reach not fully explored.

Next month we'll explore the world of 'Valancy rings' and discover how atoms bond together.

# EVERYDAY news ... from the world of

# NEW ROLE FOR TELEPHONE NETWORK

## "INFORMATION HANDLING WILL BE MAIN MONEY MAKER"—BRITISH TELECOM

# TOMORROW'S TECHNOLOGY REVEALED AT MARTLESHAM

**BRITISH TELECOM'S research laboratories, at Martlesham Heath, near Ipswich, were on public display last September.**

**Recent achievements at what is claimed to be Europe's most advanced centre for communications research include:**

- ***High-reliability microchips to be used in undersea optical fibre cable.***
- ***Radio links for local networks operating at the highest frequency used to date for civil communications.***
- ***A voice-activated telephone which will automatically dial home when told to do so.***
- ***Doubling of 100km "four-minute mile" record distance for optical fibre communications.***

Welcoming the Secretary of State for Trade and Industry the Rt. Hon. Norman Tebbit, MP, the Chairman of British Telecom, Sir George Jefferson, said: "British Telecom, in its new status as a public limited company, is at the threshold of a challenging future. Telecommunications is now emerging from the plain ordinary telephone stage into the digital era and over the next decade will move into the information handling business.

"In the period we are now entering, we may see the telephone replaced by information itself as the main money maker for British Telecom. The data which is already travelling down the telephone lines could inherit the starring role that the telephone has held for so long.

### Intelligent Network

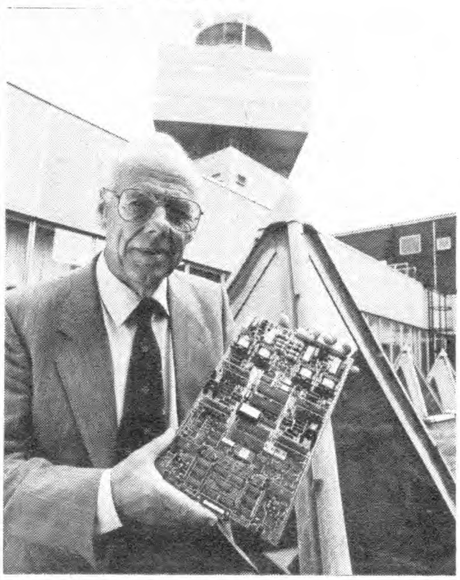
"The arrival of what is being called "the intelligent network" is inevitable and necessary for customer and information technology business development. We are resolved that Britain will be at the forefront, and British Telecom's skill and financial resources are essential elements in bringing that about. In this field we need to think of and use know-how on an international scale and our customers and the UK information technology industry's cause will not be advanced by national insularity, false protection, or special pleading.

"We are competing both at home and abroad. And the only way to command success in such a climate is to sustain inventiveness, constantly honing the technological edge as well as looking for new products and services to offer our customers when they want them and at the right prices. We must never cease trying to increase the effective exploitation of Martlesham's work.

"Martlesham has made a very valuable contribution to world developments. All our customers are benefiting from its many successes. There is no doubt in my mind that this will continue—indeed, its forward-looking attitude is essential to British Telecom's success as a major information technology business, and this will contribute to the further success of British Telecommunications Plc."

*Opposite, the computer demonstrates visually how it identifies a word from its memory, during a laboratory experiment.*

# MEDAL FOR MICROPROCESSOR PIONEER



The engineer who originated the idea of using for telecommunications what the world now knows as the microprocessor has been awarded the prestigious 1984 Martlesham Medal.

It was presented to Mr. Charles Hughes, MSc, CEng, FIEE, by the Secretary of State for Trade and Industry, the Rt. Hon. Norman Tebbit, MP, at British Telecom's research laboratories located at Martlesham Heath, near Ipswich.

Mr. Hughes, who is Deputy Director, British Telecom's System Evolution and Standards Department, received the Medal in recognition of the outstanding work he has done at Martlesham and previously, at the Dollis Hill Research Centre, since 1955.

In particular, he conceived in 1968 the idea of using programmable logic in microelectronic form and progressing for telecommunications the application in this field of what the world now calls microprocessors. He is seen here with a programmable line card in which the principles he described are applied.

The "Open Week" is the seventh occasion since the war that the organisation has made its research laboratories public in this way. The first was in 1954 at the Post Office Research Station at Dollis Hill—predecessor of the present laboratories. The most recent was at Martlesham in 1980, five years after the building had been opened by the Queen.

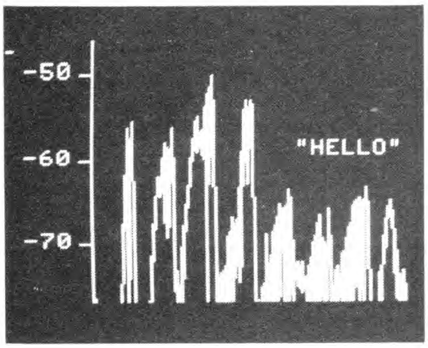
*Just a few examples from the many exhibits which demonstrate the wide range of research conducted at Martlesham and the practical developments that stem from this work are highlighted below.*

## SPEECH CONTROLLED TELEPHONE

Responding to spoken commands, the Automatic Speech Controlled Telephone (ASCOT) recognises the instruction spoken into the mouthpiece. Using a range of words already stored in the telephone's computer memory, such as "dial" and "home", it will automatically make a call. Alternatively, it will perform all the functions needed to make a call to a particular telephone on hearing the command "dial" followed by the correct number.

Up to 50 words may be stored in the memory. Each time it receives an instruction, the telephone compares the voice pattern with its "template" contained in the memory and acts accordingly. It will give a visual display of a stored number upon receiving the command "view" followed by the appropriate name or code.

Among its practical applications is its potential as an aid to physically disabled users who may not be able to move an ordinary telephone dial or press buttons.




## *Computer Design For New Telephones*

*Using their own adaption of a special design computer, researchers are speeding-up the development of new telephones and reducing pre-production costs.*

*Our photograph shows assistant executive engineer, Debbie Reeves, demonstrating how Computer Aided Engineering (CAE) can be used to progress a new design of telephone handset direct from the initial engineering drawing to final production mouldings, eliminating time consuming and expensive intermediate processes.*

*The computer also ensures that the production moulds are cut to the precise shape required and are exact interpretations of the original design.*

## PHOTO VIDEOTEX

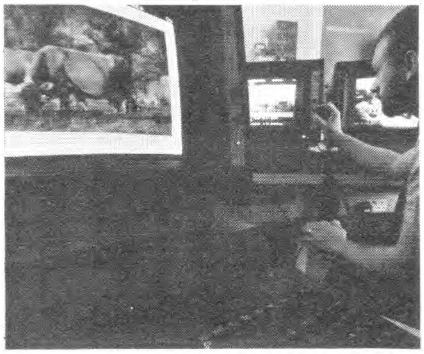


Photo Videotex, which will go into service next year, will exploit the high-bandwidth and high speed capacity (64kb/s) of BT's advanced voice and data Integrated Service Digital Network (ISDN) due to start later this year, or through the many cable television networks being developed.

The Photo Videotex library of pictures is built up by photographing subjects using a special editing terminal with a television camera. Instead of transmitting a live image to a distant screen, coded information is stored in a central computer.

A full colour picture can be summoned out of the library by any user with a compatible terminal in their home or office. It takes only 10 seconds to transmit, receive and display a full-colour, full-frame photograph; and only five seconds for black and white.

## Hi Fi Terminal Audio-Conferencing

Termed "the Lighthouse" by BT researchers, this acoustic terminal is a combined microphone and loudspeaker unit designed to sit in the centre of a table while the audience holds a long-distance conference with participants at the other end of the telephone line.

Current audio-conferencing over the public telephone network has limitations imposed by the 3·4kHz bandwidth. Advances in digital coding now enable bandwidth of 7kHz to be compressed so that high fidelity conference calls can be transmitted over the same bandwidth as a normal telephone call.

It is claimed that appreciable improvements in sound quality will be obtained when it goes into service giving 7kHz bandwidth, hi fi, via the Integrated Services Digital Network.

## *TROUBLE SHOOTING*

*Spectacular lightning flashes are a vivid example of the capacity of static electricity to cause death and destruction.*

*A nasty jolt through the finger when a metal object is touched after walking over synthetic floorcoverings is a reminder of the everyday occurrence of natural charges.*

*But even harmless human static can destroy or disrupt the sensitive components used in today's modern telephones. So Martlesham scientists are continuously applying the shock treatment to prototype phones destined for the home and office.*

# FOR YOUR ENTERTAINMENT

**BY BARRY FOX**

## The Telecom Connection

In the winter of 1981 British Telecom proudly launched its new plug and socket system for British telephones. These are the sockets now being installed in British homes. So far BT has bought 25 million and soon every home with a phone will have at least one. The size chosen was quite deliberately different from that used in America.

Was this to protect the UK market from cheap foreign imports? No, said BT, the British plug is better because it is safer. It isn't possible for someone with a small finger (for instance a baby) to push it in and get a shock.

There is 50 volts d.c. standing on the British telephone lines and the ringing tone can be anything between 75 volts and 150 volts, depending on how close you are to the exchange. Although the current available is low (130 milliamps); the voltages are at around skin-puncture level and can upset anyone with a nervous disposition.

After the press conference I measured the British plug and socket against the US version. As I suspected the British socket was actually larger. You can't get a UK plug in a US socket, however hard you try. But BT clung to its story. "The European test finger does not reach the metal contacts on our sockets" a spokesman confirmed to me in writing, in December, 1981.

Now the scene changes to October, 1983. British Telecom is busily installing its sockets in British homes. The electronic mail service Telecom Gold is also moving ahead; and people with home computers like the idea of plugging into TG. But to do this you need a modem, and it has to be approved for connection to the British telephone service.

It was in October, 1983, that the British Approvals Board for Telecommunications, an independent body acting under mandate from the Government, started testing modems. Before that the testing work had been done by BT.

Many of the modems submitted for test to BABT have a plug and socket that matches the BT plug and socket. This lets you plug the modem into the phone line and the computer and phone into the modem. So it takes literally only a moment to make a permanent hook-up.

## Euro Shock

Almost at once BABT started rejecting modems. The socket on the modem didn't meet the European finger test. While the modem makers fumed, an unpalatable truth dawned on BABT, BT and the Government. BT had goofed! All 25 million BT plugs and sockets already ordered, and all the tens or even hundreds of millions to follow in future years, did not meet the EEC regulations.

If it had been only a few modem makers involved, the directive would have stood. But because of the magnitude of the problem, the Government (to be strictly accurate the Department of Trade and Industry which is actively encouraging the liberalisation of telephones and the spread of information technology) moved fast.

Behind the scenes the DTI assured the BABT that it would change the law so that the EEC directive does not apply to the BT sockets. With this assurance BABT withdrew its objection to modem sockets. BT is now safe to go on fitting its own sockets.

But at the time of writing, the DTI has not yet worked out a way of publicly announcing the change in law without also publicising BT's gaffe and proving that there is one law for the rich multi-million supplier and another for the poor small-volume firm.

## Behind The Scenes

William Goldman is the man who wrote the screenplays for everyone's favourite films: "Butch Cassidy", "All The President's Men", "How To Steal A Diamond" (The Hot Rock), "A Bridge Too Far", "Marathon Man" and many others. Talking earlier this year at the National Film Theatre he let slip a couple of interesting facts on the making of Butch Cassidy.

Originally the two buddies were to have been Paul Newman and Steve McQueen. But their agents couldn't agree on who would get top billing. So McQueen pulled out and they negotiated with Brando.

Then they negotiated with Warren Beatty and only finally settled for Robert Redford. He desperately wanted the part but was number umpteen on the list. It opened to terrible reviews but became famous by word of mouth.

Goldman has a fascinating observation on modern film-going habits. Are you old enough to remember the phrase: "This is where I came in"? Before and during the war people would go to the cinema halfway through a film, watch it to the end, sit through the supporting "B" picture and ice cream ads, then watch the first half of the main feature and leave where they came in. No-one (except William Goldman it seems) would dream of going back to the cinema next day, and seeing the same film again.

Today audiences go out of their way to watch a film right from the beginning. You would hardly watch a film on tape without first fully rewinding to the beginning, would you? Also people watch films more than once. Otherwise, why would anyone buy a video tape or disc?

Next time you watch an old film bear this in mind. It explains a lot. Most old films make some kind of sense wherever you drop in. But many modern films make no sense at all once you have passed the main title.

## Licence To Smuggle

We hear a lot in the news about people skipping across the border between the North and South of Ireland. But have you ever thought what it means in commercial terms to have a sales tax of 35 per cent on electronics in the South, with tax at the British rate in the North? What it means is that there is a massive black market in smuggled electronics!

Although the Irish Government gives money on a plate to any firm willing to manufacture goods in the South no one wants to make colour TV sets there. Why?

By some brilliant legal manoeuvring Telefunken and Thorn-EMI still manage to persuade manufacturers that they need to take a licence under the patents which protect the PAL colour TV system. It is brilliant because many of the patents have now died of old age.

The licence contains a strict requirement that only half the PAL sets made can be exported. The other half have to be sold on the home market. Southern Ireland has such a tiny population (around three million) that the market for TV sets is very small. It is not worth building a factory to mass produce colour TV sets of which half must be sold locally. So they are all imported and carry VAT at 35 per cent.

Monochrome sets are made in Southern Ireland but also carry the heavy tax. That is why around one-in-three colour TV sets now sold in Ireland has been smuggled over from the North.

## *Museum Piece*

We now take electricity for granted. Too much for granted, in fact. Mains power is inaudible and invisible. You can't smell it but you certainly know if you touch it—or, if you are unlucky, you don't know because it kills you.

Familiarity breeds contempt. In the early days of electricity they had to put up signs. *"This room is equipped with Edison electric light. Do not attempt to light with match. Simple turn key on wall by the door."* In small print they added—*"The use of electricity for lighting is in no way harmful to health, nor does it affect the soundness of sleep."*

How do I know this? Well inexpensive re-prints of the original posters are on sale at the Greater Manchester Museum of Science and Industry. This museum (free entry) really is worth a visit if you are in the Manchester area.

It's on the site of Liverpool Road, the oldest passenger railway station in the world and it backs onto the Granada TV studios. You can see where they have built full-scale Coronation Street and Baker Street replicas for shooting modern TV programmes.

The museum is still expanding but the Power Hall is already finished. The station was built in 1830 and the Power Hall is in a freight handling shed built in the 1850s.

The theme is harnessed energy; steam, internal combustion, diesel and electricity. Manchester was the centre of the Industrial Revolution in Britain and the museum has rescued working engines from the remains of now derelict industries.

One exhibit in the new Textile Hall will explain the origin and meaning of overtime. As the workers worked faster a water wheel providing factory power turned the clock faster!

# SPECIAL OFFER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Just in time for Christmas we are pleased to make this special EVERYDAY ELECTRONICS offer to readers. Using a proportional digital radio control system, the steering and speed of the car can be accurately varied, giving total manoeuvrability both going forwards and in reverse.

The neat package contains the complete radio control transmitter, battery-operated car with built-in radio control receiver and aerial, bollards, decorative labels, a motoring handbook and a sheet of obstacles and road signs to cut out. In short, everything you need to practice driving, except the batteries, at a special price for EE readers.

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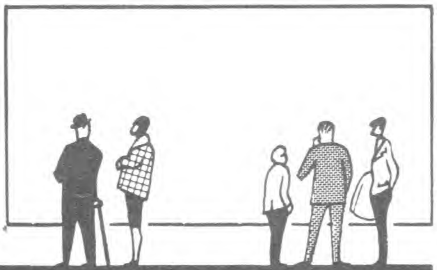
# SHOP TALK



**BY DAVE BARRINGTON**

## CONSTRUCTIONAL PROJECTS

### Alfred

This month making his debut in the pages of EE is *Alfred,* a robot trainer project. He is a truly inexpensive, by current prices, model of an industrial "big brother" that can be programmed by a home computer, such as the Acorn Electron.

A complete kit of parts for Alfred would normally cost £170, plus VAT. However, special arrangements have been made with Robot City Technology whereby readers of EE may purchase a kit for the sum of £160, plus VAT. A saving of over £10! Also under development (but *not* part of the kit) is a solid state vision system.

Robot City Tech are also prepared to supply all components as individual items. This includes mechanical mechanisms and pulleys, servo motors and interface board.

For full details, readers should write to **Robot City Technology, Dept EE, 20 Burners Lane, Kiln Farm, Milton Keynes MK11 3AU.**

### Digital Multimeter

Most of the components used in the *Digital Multimeter* project appear to be "off the shelf" items.

The integrated circuit IC3, type 7106, is a $3\frac{1}{2}$ digit A/D converter (with display drivers) and is currently listed by Maplin, Rapid, Electrovalue and TK Electronics.

The $3\frac{1}{2}$ digit liquid crystal display is now a common item stocked by most of our advertisers. The display should be mounted on the circuit board via Soldercon pins.

The "range" and "mode" switches are not available as single items, a system called "Maka-switch" is used where the switch mechanism and wafers are purchased as separate components. When purchasing the wafers you should specify: 3 off, 2-pole 6-way and 2 off, 2-pole 6-way wafers for S1 and S2 respectively. Makaswitches are held by Electrovalue and Maplin.

Other components that require mention are the precision resistors. These are specified as 0·5 per cent tolerance and should be purchased if reasonable accuracy is to be obtained. If resistors with such a close spec. cannot be obtained then it is perfectly in order to use lower tolerance types, if, of course, a reduction in overall performance is acceptable.

### Proximity alarm

The key operated switch used in the *Proximity Alarm* is available from most of our advertisers. The majority of suppliers will sell a "double-pole double-throw" version. If this is the case only one set of contacts need to be used.

The peizo-electric resonator used for the warning siren is stocked by Bi-Pak, Cirkit and Greenweld.

### BBC Micro Audio Storage Scope Interface

The only source of supply we have been able to find for the ZN449 A/D Converter used in the *BBC Micro Audio Storage Scope Interface* is **Midwich Computer Company Ltd., Dept EE, Gilray Road, Diss, Norfolk IP22 3EU.**

### Fluid Detector

We cannot foresee any component buying problems for the *Fluid Detector.* The "fluid level detector" i.c. LM1830 is listed by Maplin Electronic Supplies: Order code YY99H (LM1830).

# FAULT FINDING

## E. A. Rule Part 1

In this series of short articles it is intended to deal with fault finding on various types of equipment in a completely practical way. The emphasis will be on home constructed or kit equipment using examples taken from actual workshop or production line experience. The methods used to locate faults depend on many factors but in this series we shall divide the faults into three main groups.

The first of these is where faults have occurred on newly built or production line equipment, in other words, equipment that has either never worked or only partly worked since it was built and may contain actual mistakes in wiring or wrong components, as well as actual faulty components.

The second group concerning us is with equipment that has been working perfectly well up to the time a fault occurred. In this group, faults are almost always due to faulty components although sometimes a manufacturing fault could be the problem (dry soldered joint for example).

The third group (and the worst) is where someone has "had a go" and the result is a piece of equipment which has now more faults on it than before it was "serviced!" Personally I have encountered many examples of this, where people have tried to save money by doing it themselves, only to finish up with a larger repair bill due to the damage they have done owing to their inexperience. Unless you really know what you are doing, do not attempt repairs in this group because the chances are that you will take the blame for anything else that goes wrong. Many hours can be spent putting right other people's mistakes before you even get around to the original fault and often (as in my experience) this type of work cannot be charged for because the service charge would be completely out of proportion to the value of the equipment. You have been warned!

### TEST EQUIPMENT

An experienced engineer is often asked what type of test equipment should be purchased for a service department to enable effective repairs to be carried out? This is not easy to answer, because it depends so much on the type of work involved and the relative skills of the engineer. For example, I have recently been involved in repairs to domestic hi fi, tape units and cassette radios etc., about 80 per cent of the work in recent weeks has been mechanical, no electronic test equipment was used at all. However, sometimes the reverse is true and one never has the right equipment to hand, a recent repair to an oscilloscope resulted in a Megger being the most useful item in locating the fault, the more normal multimeter being of no use.

It is just not practical to give a hard-and-fast rule regarding test equipment but good detective work and commonsense can make up for the lack of test equipment, whereas the reverse is not true! One thing is very sure, there is no such thing as a "textbook fault". During this series some examples of *real* faults will be given, although some of these will seem to have come from the realms of science fiction!

### ROUTINE PROCEDURES

Faults by their very nature tend to be "one-offs", no two ever being quite the same; however we can use the same basic method to locate similar types of fault and although some of the examples given may never cross the path of the reader the method used can be used over and over again for many different faults of a similar nature. It is important to develop a routine approach to fault finding and to use it *every* time, even when sometimes it may not seem worth while. In my experience a routine procedure has located more faults in less time than any other method. True, there are exceptions but in practice the advantages of a routine approach far outweigh the disadvantages. A good routine also ensures that you do not miss anything that may otherwise go undetected. Each of the groups of faults mentioned earlier requires a different procedure although there is of course considerable overlap.

### VOLTAGE MEASUREMENT

One thing that can be applied to all groups, is the measurement of voltages around the circuit. This should always be carried out as the first step to locating a fault and many seemingly complicated faults will be found by simply doing a voltage check and comparing it with the manual or author's voltage table (if available). If no such table is available, then one has to rely on personal experience, for example, a transistor operating normally would not exceed about 0·7 volts between its base and emitter connections, if you measured (say) 5

volts then an open circuit base/emitter junction could be suspected. With a.c. coupled amplifiers the collector voltage could be expected to normally be about half the supply rail voltage, etc., etc. It will depend on your own experience as to how far you can go, but it is always worth doing a voltage measurement and noting the results, even if only for future reference.

One area where voltage measurement is difficult is when the various stages are d.c. coupled. With this type of circuit *all* the voltages around the circuit will be wrong and often not much can be gleaned; however it is still worth doing because you may find something, like the base/emitter example mentioned above. The method of fault finding in a d.c. coupled circuit will be covered later in the series. It is worth mentioning at this point a very useful tool, this is the "solder-sucker". This tool is used for de-soldering a joint by first melting the solder with the soldering iron and then "sucking" the solder away from the joint, leaving it clean and *undamaged*, the component can then be simply "lifted" out of the board. These tools are not expensive and quickly repay their cost in undamaged components and printed circuit board tracks. It goes without saying of course, that when removing components or touching a board with a soldering iron, the equipment must be switched off, or better still, disconnected from the supply. Considerable damage can be done if equipment is left on while soldering. This is one of the most common reasons for faults in group three.

## FAULT ANALYSIS

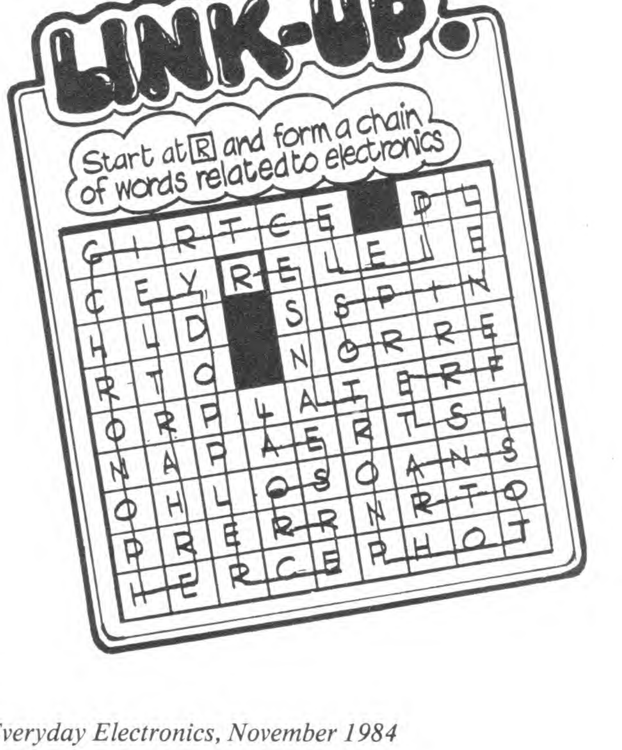
Do not "invent" faults, it is surprising how many people look for a complicated explanation for a faulty condition in a circuit, when quite often the fault is a simple one. Recently I had a set in for service which had what seemed at first to be a complicated fault in a digital display. It was of an intermittent nature, with the display seeming to have a will of its own. Sometimes it would work perfectly and the fault could not be provoked under any conditions, at other times the display would show either the wrong display (frequency instead of time, etc.) or show only parts of the segments of the numbers. At other times a very slight touch on a front panel control would correct the condition. On the face of it a number of faults seemed to be present. Actually the fault turned out to be small specks of solder "spattered" across the underside of the printed circuit board during assembly, thus shorting out the tracks; these solder bridges are very common. The only "tool" required for this fault is a magnifying glass! Simple faults can cause quite mystifying results at times, especially on newly built equipment. Always consider the simple explanation first. Often, a good pair of eyes and detailed observation is all the "equipment" you will need, coupled of course with commonsense.

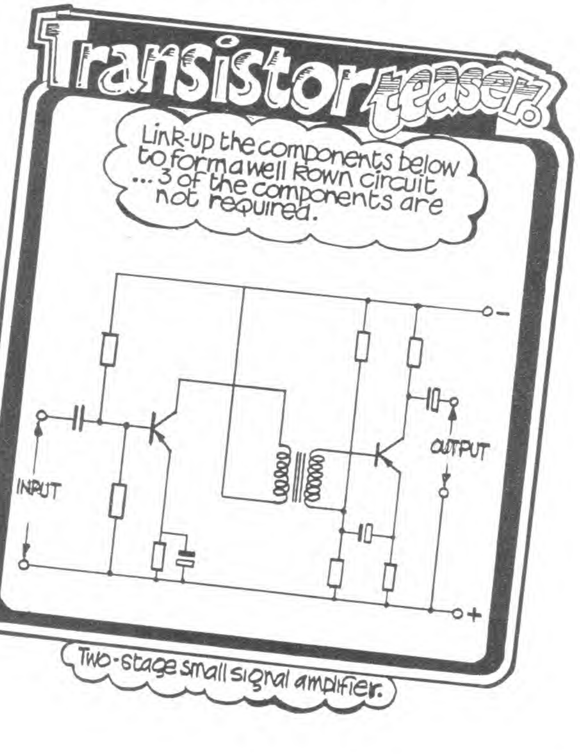
Make sure that you really understand how your test equipment works. It is no good connecting up a very expensive oscilloscope (which looks impressive) if you do not understand the picture it gives you. With a multimeter, be sure you understand how its loading on certain circuits can affect the results. Some of these points will be dealt with later in this series, but the point is, that you must always be on your guard against self-induced false information, it is very easy to fall into one's own traps.

Do not be misled by the above comments, that you can do all service work without the proper equipment, you cannot. However, most of the time simple tests will locate the fault, but there will be times when only the proper test equipment will enable the fault to be found. For example, tracing the reason for a high distortion level in a hi fi amplifier. For this type of testing you will require a low distortion audio oscillator, a distortion meter, and possibly an oscilloscope as well. Nevertheless, most hi fi faults are of a "go", "no go" nature and simple tests will normally reveal the fault.

In next month's issue we will look at some of the faults found on newly built equipment and give some practical examples of these and the methods employed in locating them.

# FUNTRONICS Solutions...




Two-stage small signal amplifier.

# DIGITAL MULTIMETER

## I. A. DUNCOMBE PART 1

ONE ITEM of test equipment not generally found in the average constructor's workshop is the digital multimeter. There are many reasons why this is so, perhaps the most common being the high cost involved for a multimeter of good quality. This article describes how a basic meter of quality comparable to many commercial meters can be constructed simply.

Obviously a home-built multimeter cannot, in most circumstances, be better than commercial meters. However, by careful selection of components as will be explained later, there is no reason why the performance figures, shown in the Specification opposite, should not be obtained. Digital multimeters are highly regarded by many people, and for many reasons. Perhaps the two most popular reasons are as follows:

1) They are inherently more accurate than conventional analogue meters.

2) They are easier to read.

### ACCURACY

The accuracy of any multimeter depends on a number of factors, by far the most important being "loading effect" presented to the circuit under measurement. For any meter to function, a current must be drawn from the circuit under test. The value of current required depends on the overall sensitivity of the meter, which in turn determines the "input impedance". We can illustrate this point by referring to Fig. 1. Here we have a simple circuit of two resistors forming a potential divider across a supply of 10 volts. By using the following formula we can work out the voltage at point "X".

$$V_{out} = \frac{V_{in}}{R1 + R2} \times R2$$

$$= \frac{10}{100k + 100k} \times 100k$$

$$= \frac{10}{100000 + 100000} \times 10000$$

$$= \frac{10}{200000} \times 100000$$

$$= 5 \text{ volts}$$

Now, suppose we try to measure the voltage at point "X" with an analogue multimeter, with an input impedance of 100 kilohms. This is shown in Fig. 2. With the multimeter directly across the lower resistor, the resistance in that part of the circuit is now 50k (Ohm's Law). Inserting these new values in our equation we find:

$$\frac{10}{100k + 50k} \times 50k$$

$$= \frac{10}{150000} \times 50000$$

$$= 3{\cdot}333\text{r volts}$$

Quite a different voltage from what we would expect! If we now measure the voltage at the same point, but use a digital multimeter with a very high input impedance, say 10M, and work out the equation as before (Fig. 3) we find the following results (R2 is now 99·009k (Ohm's Law)):

$$\frac{10}{100k + 99009} \times 99009$$

$$= \frac{10}{199009} \times 99009$$

$$= 4{\cdot}975 \text{ volts}$$

The difference is obvious.

## SPECIFICATION

| MODE | F.S.D. | RESOLUTION | ACCURACY |
|---|---|---|---|
| Direct Voltage | 200mV | 100µV ±1 digit | 0·7% |
| | 2V | 1mV ,, | 0·25% |
| | 20V | 10mV ,, | 0·72% |
| | 200V | 100mV ,, | 0·35% |
| | 2000V | 1V ,, | 0·5% |

NOTE: Max voltage is 1000V applied via separate socket

| MODE | F.S.D. | RESOLUTION | ACCURACY |
|---|---|---|---|
| Alternating Voltage | 200mV | 100µV ±1 digit | 1·1% |
| | 2V | 1mV ,, | 1·4% |
| | 20V | 10mV ,, | 0·7% |
| | 200V | 100mV ,, | 0·45% |
| | 2000V | 1V ,, | 0·61% |

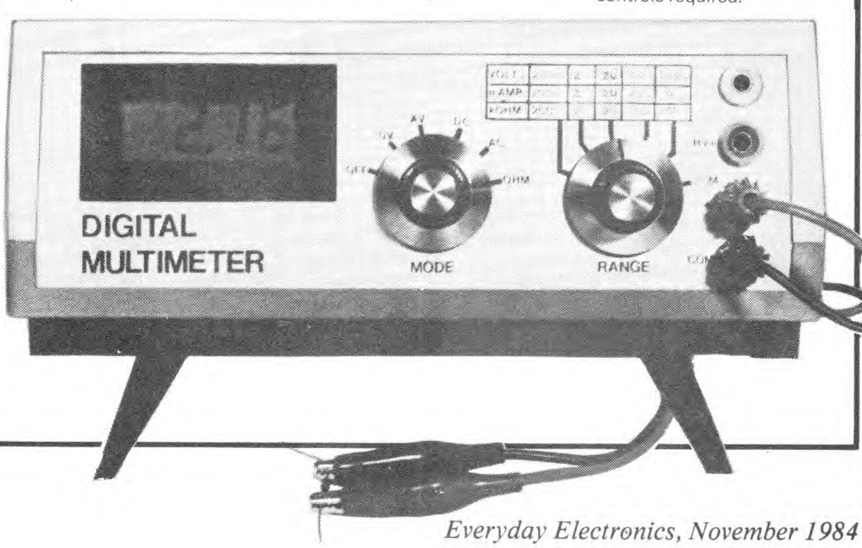
NOTE: Max voltage is 1000V applied to separate socket

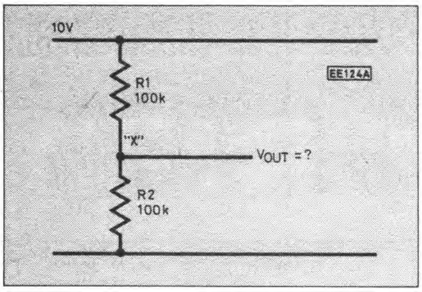
| MODE | F.S.D. | RESOLUTION | ACCURACY |
|---|---|---|---|
| Direct Current | 200µA | 0·1µA ±1 digit | 0·45% |
| | 2mA | 1µA ,, | 1·0% |
| | 20mA | 10µA ,, | 1·2% |
| | 200mA | 100µA ,, | 2·8% |
| | 2000mA | 1mA ,, | 3·6% |
| Alternating Current | 200µA | 0·1µA ±1 digit | 0·8% |
| | 2mA | 1µA ,, | 1·0% |
| | 20mA | 10µA ,, | 1·3% |
| | 200mA | 100µA ,, | 2·8% |
| | 2000mA | 1mA ,, | 3·1% |

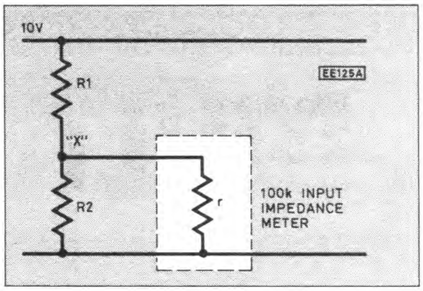
| MODE | F.S.D. | RESOLUTION | ACCURACY |
|---|---|---|---|
| Resistance | 200ohms | 0·1 ±2 digits | 1·7% |
| | 2k | 1 ,, | 0·9% |
| | 20k | 10 ,, | 0·8% |
| | 200k | 100 ,, | 1·1% |
| | 2M | 1k ,, | 1·1% |
| | 20M | 10k ,, | 1·5% |

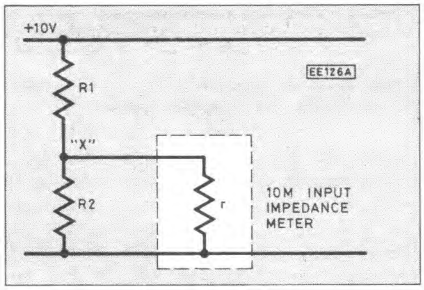
NOTE: No external voltage must be applied

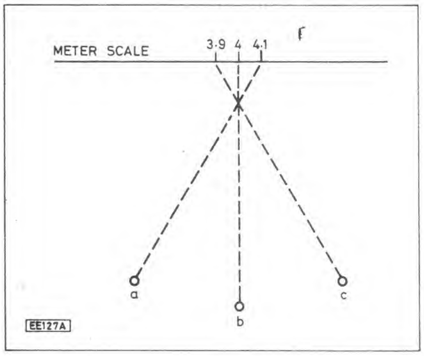
| | |
|---|---|
| Junction Test | Direct measurement of semiconductor junctions at a current of 100µA. |
| Input Resistance | 10MΩ shunted by 42pF. |
| Display | $3\frac{1}{2}$ digits liquid crystal. |
| Frequency Response (a.v.) | Substantially flat from 50Hz to 10kHz, within ±0·6dB from 30Hz to 20kHz. |
| Protection | Internal A/D i.c. protected by a current limiting resistor. 2-amp fuse in common line for current. |
| Overload | Worst case voltage overload, safe for approximately one minute. |
| Inputs | Two panel mounted sockets used for all measurements, except junction test mode and voltages above 200V. |
| Front Panel Controls | One rotary switch for Mode and one for Range, no other controls required. |





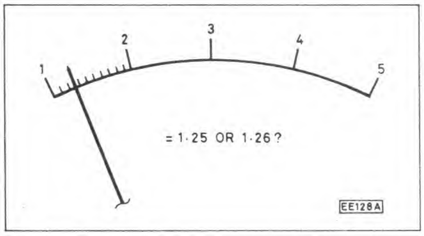





Fig. 1 (top left). Simple circuit for a potential divider.
Fig. 2 (top centre). Measuring the voltage at point X with an analogue meter with an input impedance of 100k.
Fig. 3 (above). Measuring the voltage at point X with a digital voltmeter (10M input impedance).
Fig. 4 (far left). Example of possible meter reading errors likely to occur with analogue types.
Fig. 5 (left). Example of interpolation error.
Fig. 6 (bottom left). Typical digital multimeter display.

## READABILITY

Readability in analogue meters is solely dependent on the construction of the meter scale, and errors here are just two.

(1) Parallax error and; (2) Interpolation.

The first error can be simply demonstrated as in Fig. 4. Here we view the meter scale from above. In (a) an observer views the meter needle from an angle which is not the intended angle. The result is he reads the meter as 4·1. In another position (c), the angle is similar but opposite, and the observer this time reads the meter incorrectly as 3·9. The correct viewing angle is 90° from the scale face and is shown correctly at (b).

The second error, interpolation is demonstrated in Fig. 5. Here we see a typical meter scale labelled 1 to 5, with major divisions indicated. The first division has also been calibrated in tenths. Suppose the meter needle came to rest between the second and third minor division of the first major division. The reading is obviously 1·2 something, but what precisely is the value? The difficulty here lies in the inability to judge precisely the very small parts between the minor divisions. The result is the reading being guessed. Could it be 1·25 or could it be 1·26?

With digital multimeters, both the readability errors are overcome at the same time. Parallax error is no longer a problem, and the guesswork is eliminated entirely—depending on the number of digits in the display of course, Fig. 6 shows the appearance of a typical display.

From the foregoing paragraphs, it can be seen that digital multimeters have certain very important advantages over comparable analogue meters.

## MULTIMETER DESIGN

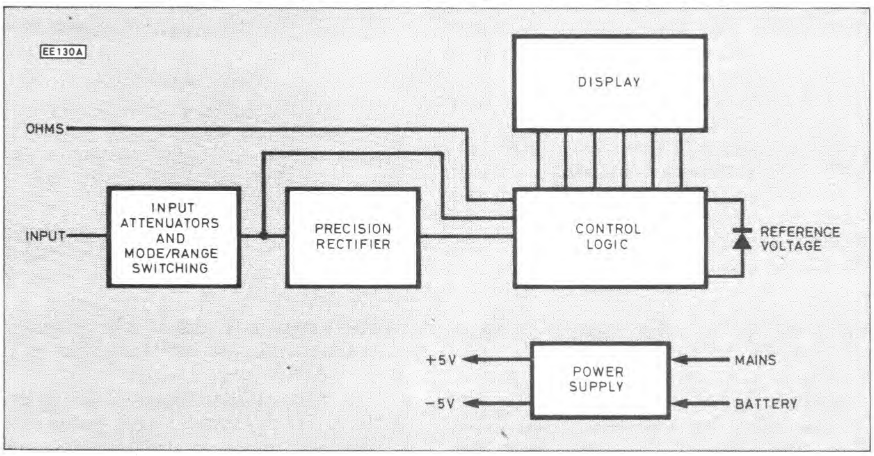
The digital multimeter described here has a total of 26 measurement ranges, these being shown in the Specification. Briefly however, the meter is capable of measuring from 200mV up to 1000V on the voltage ranges. And from 200μA up to 2A on the current ranges. Resistance ranges cover from 200 ohms to 20 megohms in six ranges. All ranges being full-scale deflection (f.s.d.).

A useful facility provided within the meter is a junction test. The particular type of circuit used for resistance ranges is unsuitable for the normal type of junction test on semiconductors, as the voltage available at the terminals is below that normally required to turn junctions on. In fact the maximum current that can flow is approximately 6mA, resulting in a voltage of just less than 0·6V appearing at the terminals. The junction test terminal is therefore connected to a 1·2V source within the meter and used on the 200μA range. Any junction now being tested will be turned on, and cause a reading, typically 60, to be displayed, indicating that the junction is forward biased.

The input impedance of the meter is 10M shunted by approximately 42p. The capacitance is due to a simple frequency compensating network which is used on the alternating ranges. The capacitance does not interfere with any other range. The display used was chosen mainly for its ease of being seen in sunlight or other bright conditions. The meter can be powered by batteries for portable work, or connected to the mains for bench work. The current drawn by the meter is fairly small, giving the two PP3 batteries used a very long life.

Simple overload protection is provided by a current limiting resistor in the input lead to the logic i.c. It is possible that the circuit can survive a severe overload for a minute or two, any longer than this then

Fig. 7. Block diagram of how the Digital Multimeter functions.



the protection component will be destroyed with the possibility of the main logic i.c. also being damaged. Further protection is provided by a 2A quick blow fuse in the common lead.

The meter is fairly complex to construct, but the few adjustments needed in setting up have been kept to a minimum without the need for expensive equipment. In fact the only item required is a d.c. voltmeter of reasonable accuracy, although an accurate a.f. signal generator would be helpful.

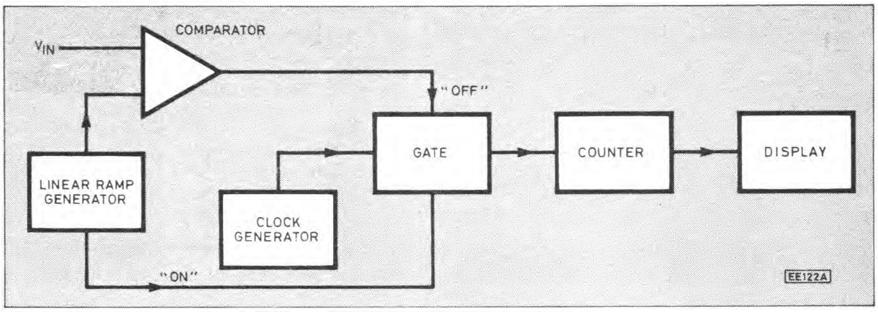



Fig. 8. Basic arrangement for a single slope A/D converter.

## BLOCK DIAGRAM

A block diagram showing in simple form how the Digital Multimeter functions is shown in Fig. 7.

The quantity to be measured is connected by way of a mode switch to a network of attenuators (for voltage), or to shunts (for current). A range switch selects a suitable range for the value to be measured. For example, a voltage of 6·7V would be measured on a range which had a f.s.d. of 20V. The quantity being measured is further selected by a mode switch, which passes it to a precision rectifier if the value is alternating, or direct to the logic circuit if it is direct.

The logic circuit converts the quantity, which in passing through previous parts of the circuit is now a small direct voltage, into a form more readily accepted by the display. This conversion is known as the "Dual slope analogue-to-digital conversion", and will be explained in more detail later. Basically the voltage is compared with a rising voltage, a ramp voltage, within a comparator. When the two voltages coincide, a switch is turned off which stops a series of clock pulses previously started when the ramp voltage turned on. During the period when the ramp voltage was rising, a counter was counting the number of clock pulses arriving at its input. With the clock pulses now finished, the counter transfers them to the display, which shows the precise value of the quantity being measured.

The measurement of resistance is slightly different and uses the logic circuitry and a set of ranging resistors. The method used is called the "ratiometric system". A detailed explanation will be given later, but at this stage it is worth mentioning that the accuracy is dependent solely on the stability and precision of the ranging resistors.

The remainder of the block diagram is the power supply. This is quite conventional and supplies two voltages of +5V and −5V. Switching is included to change over from battery to mains operation and vice-versa. When used on batteries, the multimeter uses two PP3 9V types, which have a very considerable life.

## THE DUAL SLOPE PRINCIPLE

The idea of single slope analogue-to-digital (A/D) conversion was briefly given earlier when we considered the block diagram. Although the design here uses dual slope A/D conversion it is worthwhile considering the single slope principle as this will give a better understanding when considering the dual slope principle.

A basic arrangement for a single slope A/D converter is shown in Fig. 8. Here the blocks mentioned previously can be seen; a comparator, switch (gate), clock pulse generator and ramp generator. Refer also to the timing waveforms of Fig. 9.

An input voltage $V_{in}$, is applied to one input of a voltage comparator, the second input being connected to the ramp voltage generator. When the ramp generator is first turned on, several things happen. The gate is turned on from its previously off state, clock pulses from the clock generator are allowed through the gate to the counter. The counter then starts to count each clock pulse as it arrives.

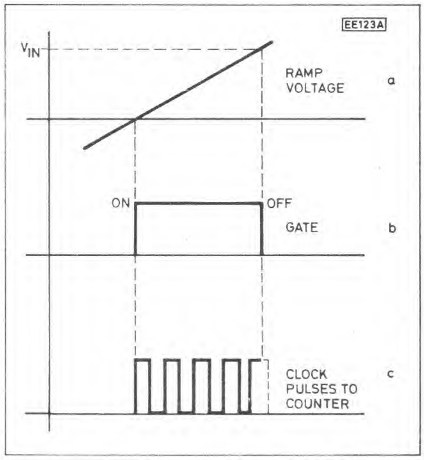



Fig. 9. Timing waveforms for the A/D converter.

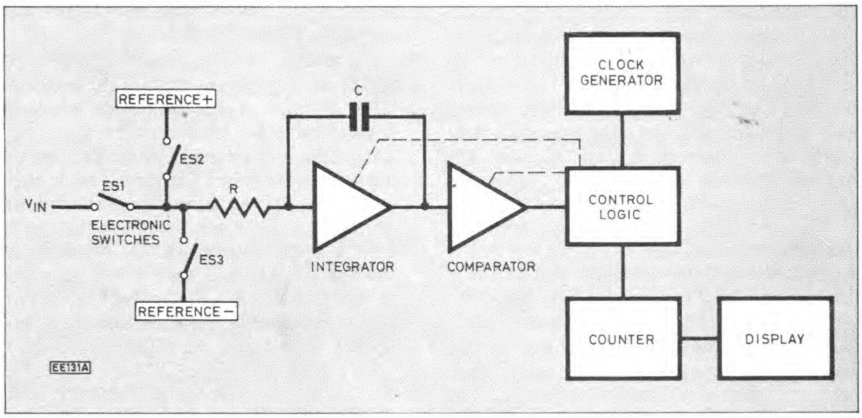
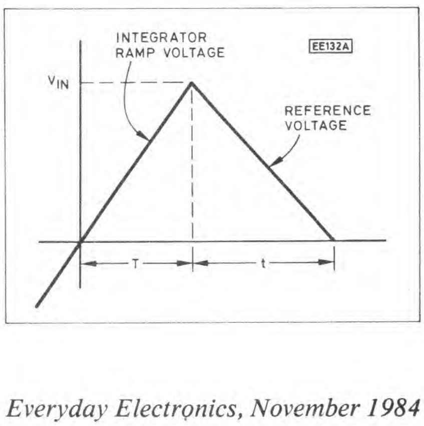



Fig. 10. Block diagram for a simple dual slope A/D converter.

During the time the ramp voltage is rising there is a relatively stable state in the circuit. Once the ramp voltage reaches the value of $V_{in}$ as shown in Fig. 9a, the comparator detects the similarity between the voltages and causes the gate to turn off, Fig. 9b. In doing so the gate prevents any further clock pulses from reaching the counter, Fig. 9c. The counter now decodes the clock pulses and passes the result to the display where the voltage $V_{in}$, is displayed directly in volts.

The major disadvantage of this system is the need to generate a very stable clock signal, and to ensure that precision with

Fig. 11. Action of the variable ramp generator.



# COMPONENTS

**Approx. cost Guidance only £35 excluding boards**

### Resistors

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| R1 | 9M | 0·5% | R13 | 100 | 0·5% | R25 | 15k | |
| R2 | 900k | 0·5% | R14 | 1k | 0·5% | R26 | 390k | |
| R3 | 90k | 0·5% | R15 | 100 | 0·5% | R27 | 15k | |
| R4 | 9k | 0·5% | R16 | 1k | 0·5% | R28 | 1k | |
| R5 | 900 | 0·5% | R17 | 10k | 0·5% | R29 | 1k | |
| R6 | 90 | 0·5% | R18 | 100k | 0·5% | R30 | 1M | |
| R7 | 10 | 0·5% | R19 | 1M | 0·5% | R31 | 1M | |
| R8 | 10k | | R20 | 10M | 2% or 5% | R32 | 1M | |
| R9 | 1k2 | | R21 | 1M | | R33 | 1M | |
| R10 | 0Ω1 | 2% or 5% | R22 | 3M3 | | R34 | 100k | 2% |
| R11 | 1 | 0·5% or 2% | R23 | 6k8 | | R35 | 47k | |
| R12 | 10 | 0·5% | R24 | 15k | | | | |

All resistors are $\frac{1}{4}$W ±5% except where stated. (R10 can be 14in of 30 s.w.g. wire)

### Capacitors

| | | | |
|---|---|---|---|
| C1 | 10n disc ceramic 1000V | C10 | 100n polyester |
| C2 | 5–65p trimmer (fail type) | C11 | 100n ,, |
| C3 | 470p polystyrene | C12 | 470n ,, |
| C4 | 4700p ,, | C13 | 220n ,, |
| C5 | 220n polyester | C14 | 10μ 10V tant. |
| C6 | 4μ7 10V elec. | C15 | 10μ 10V ,, |
| C7 | 220n polyester | C16 | 1000μ 16V elec. |
| C8 | 10μ 10V elec. | C17 | 1000μ 16V ,, |
| C9 | 100p ceramic plate | | |

### Semiconductors

| | | | | | |
|---|---|---|---|---|---|
| IC1 | CA3140 d.i.l. | D1 | 1N914 | D5 | 1N4002 |
| IC2 | 4070 | D2 | 1N914 | D6 | 1N4002 |
| IC3 | 7106 | D3 | ZN423 | D7 | 1N4002 |
| IC4 | 78L05 | D4 | 1N4002 | | |
| IC5 | 79L05 | | | | |

### Potentiometers

| | |
|---|---|
| VR1 | 1k ten turn horizontal preset |
| VR2 | 1k ,, ,, ,, ,, |
| VR3 | 1k ,, ,, ,, ,, |

### Switches

| | |
|---|---|
| S1a–f | 6-pole 6-way, maka-switch |
| S2a–d | 4-pole 6-way, maka-switch |
| S3a,b | 2-pole 2-way slide switch |
| S4a,b | 2-pole 1-way rotary switch to fit S1 |

### Miscellaneous

| | |
|---|---|
| SK1–4 | 4mm sockets, two red, one black, one white |
| SK5 | miniature 3-pole mains socket |
| T1 | mains transformer 6–0–6V at 200mA |
| FS1 | 2A quick blow fuse |
| FS2 | 1A quick blow fuse |
| B1,2 | PP3 9V batteries (two off) |
| LCD | $3\frac{1}{2}$ digit liquid crystal display |

Case—Verobox type 21035 8in × $5\frac{1}{4}$in × 3in, two printed circuit boards.
Low profile i.c. sockets (8-pin, 14-pin, 40-pin), one of each.
Display bezel, two round control knobs, two Terry clips.
Soldercon pins, two battery clips, two 20mm fuseholders, 6BA mounting hardware.
Connecting wire, spirawrap, suitable test leads with 4mm connectors, etc., etc.

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which the comparator detects the coincidence of the two voltages is sufficiently accurate. The dual slope arrangement overcomes these problems by making the sampling time constant.

A block diagram for a simple dual slope A/D converter is shown in Fig. 10. Here the ramp generator is replaced by an integrator, which can be simply considered as a variable slope ramp generator.

Initially, capacitor C in the integrator is discharged with all Electronic Switches (ES) off. When the circuit is turned on, ES1 is turned on allowing the input voltage $V_{in}$ to be applied to the integrator, which begins to charge the capacitor C. The integrator now ramps positively, for a period set by the clock generator, time "T" in Fig. 11. The slope, or angle of this ramp voltage is determined by the magnitude of the applied voltage $V_{in}$. At the end of this time period, ES1 switches off and one of the two reference switches, ES2 or ES3 turns on, depending on the polarity of $V_{in}$, at the same time the comparator resets the clock, which begins counting from zero.

With one of the reference voltages applied to the integrator, C now discharges and the integrator proceeds to ramp to zero, time "t" in Fig. 11. When the integrator reaches zero, the comparator stops the clock pulses. The number of clock pulses, and thus time "t" is directly proportional to the value of $V_{in}$. The counter decodes the clock pulses and presents the actual value, in terms of voltage to the display.

Conversion accuracy using this type of converter is generally independent of component values and stability of the clock generator. Accuracy is primarily dependent on the reference voltage stability.

## THE 7106 I.C.

The heart of the multimeter is of course the logic circuitry, and this is handled entirely by one i.c. the 7106. The i.c. is a l.s.i. device in a 40-pin package. The i.c. incorporates all the analogue-to-digital conversion circuitry as well as circuits for auto-polarity and auto-zero. The device also includes display decoder/drivers thus allowing a liquid crystal display to be driven direct without any interfacing circuitry or current limit resistors, etc.

The i.c. uses the dual slope A/D conversion as described earlier and is able to sample the input quantity at approximately three per second, thus giving the meter a fast response to rapid changing inputs. The input impedance of the i.c. is specified as greater than $10^{12}$ ohms, although this is reduced when in the remainder of the circuit.

The input to the i.c. is pin 31, and is protected by resistor R30. In the event of an excessive voltage being applied, R30 limits the current applied to the i.c. This arrangement is not infallible, if the overload is not removed within a certain time, the resistor will simply burn away and allow the full force of the overload to rest on the i.c!

The 7106 i.c. is able to drive liquid crystal displays direct. For l.c.d.s to operate, they require an a.c. signal, this is provided for by the i.c. and a suitable signal is available at pin 21. For a particular segment to be turned on, it must be driven by a signal of equal amplitude but opposite phase to that of the backplane, pin 1 on the l.c.d. This is used to good effect when auto-polarity is considered.

Within IC3 is a voltage comparator which is used to detect the polarity of the input. Voltage comparators are designed to give a logic 1 output if the difference between their inputs is positive, and a logic 0 if the difference is negative. This is the basis of the auto-polarity circuit and the signal so produced by the comparator is available at pin 20.

## DECIMAL POINT

Decimal point switching is achieved by selection of the appropriate Exclusive-Or gates of IC2. The truth table for an Exclusive-Or gate shows that, if one *or* the other inputs is high the output will be high, but if *both* inputs are high the output will be low. If we take one input low and use the other as the back-plane signal, the output will vary between low and high, but *not* out-of-phase as is required. If we thus take the control input high, the gate will invert the back-plane signal which will now be out-of-phase as required and drive the appropriate decimal point.

The control inputs, pin 2 of IC2 for example, are kept low by taking them to the negative rail. The selection of the decimal points is made by S2d. The pole of this switch is taken to the positive rail which allows the control inputs to be taken high when they are selected.

Over-voltage is indicated by all digits turning off except for the most significant one. The display will read just "1".

The typical accuracy for the i.c. is 0·05%, this being typically $\pm 1$ count. In other words this means the last digit of the display can vary by either plus one or minus one. For example, a reading of 1·234, can be either 1·233 or 1·235. This is not a fault of the i.c. and is common in all digital equipment. The i.c. can also provide an over-range indication by turning off all digits in the display except the most significant one.

The internal circuitry of the i.c. is far too complex to describe in great detail, however, the block diagram given in Fig. 10 is a fair representation of how the i.c. works. A number of discrete components are required to set various functions within the i.c., and these are not shown in the block diagram.

Together with the display, the i.c. can form a very accurate panel meter with a f.s.d. of 200mV. It was with this in mind that the construction of the whole digital multimeter included provisions for using this part of the circuit separately. Experienced readers will be able to work this out quite simply.

## CIRCUIT DESCRIPTION

The complete circuit diagram for the Digital Multimeter is shown in Fig. 12, which also shows the power supply.

The power supply is conventional in design and uses two small three-terminal regulators to provide the two supplies required by the circuit. Considering the mains side of the power supply; mains voltage is stepped down by the transformer to give about 12V a.c. to the bridge rectifier consisting of diodes D4 to D7. The bridge rectifier now provides about 8V d.c. to each of the smoothing capacitors C16 and C17 (it is assumed that S3a/b is in the mains position).

The two regulators, IC4 and IC5 provide regulation to the required $\pm 5$V required by the circuit. The two small capacitors on each of the outputs from the i.c.s provide a final smoothing of the d.c. In some regulator circuits very small value capacitors (10n for example) are sometimes found on the outputs of the regulators. These are usually provided to prevent high-frequency transits from appearing on the supply lines. They are not required here as the main i.c. has a very low noise threshold and is virtually unaffected by r.f. spikes, noise, etc.

The remaining part of the power supply is the switching arrangement used to switch from mains to battery operation. Total isolation of the two supplies is necessary and is carried out here by S4a and S4b (part of mode switch) switching the mains supply, and S1e and S1f (also part of the mode switch) switching the battery supply off. Switching between the two different supplies is carried out by the small rear panel mounted switch S3.

Some constructors may feel that the expense incurred in providing this type of complex switching is not justified. It is suggested therefore, that just one type of supply is chosen thus eliminating the extra switches. This does not give the multimeter that certain flexibility, but nevertheless can be tried if desired.

The heart of the multimeter is of course the 7106 i.c., IC3, the basic operation of which was outlined earlier. Mention was made of a few setting components, and these will now be described.

## REFERENCE VOLTAGE

The stable reference voltage is provided by a band-gap reference diode, D3. The device is a small integrated circuit which provides an extremely stable voltage of 1·2V. The exact voltage may vary from device to device, but will at all times be stable. The temperature coefficient is 30ppm/°C, while that of the internal reference of the i.c. is only 100ppm/°C. A potential divider consisting of R27, R28 and VR3 is used to adjust the output of D3 to give a precise reference of 100mV at pin 36 of IC3. This voltage is also used to measure resistance and in consequence is connected to a number of ranging resistors. The full 1·2V of D3 is taken via R8, R9 and VR1 to the Junction Test terminal. With the multimeter set to read 200µA d.c. full-scale, the preset is adjusted to give a reading of 100.

Components R34 and C9 set the internal oscillator of IC3 at approximately 50kHz. This can be adjusted more accurately by using a small preset in place of R34, although for most purposes the accuracy of the oscillator is unimportant.

The dual slope integration components (R and C in Fig. 10) are R35 and C13. Capacitor C12 is the auto-zero component which at the end of a count, charges up to a value determined by the offsets between the integrator and the comparator. When the circuit is counting, this voltage offset is added or subtracted to the actual input voltage thereby compensating for any drift, etc.

## D.V. MEASUREMENT

The direct voltage to be measured is connected between the "COM" terminal and the "+" terminal, and then via the mode switch, S1. For the purpose of this explanation we shall assume the input voltage is 20V. As already stated, the logic i.c., IC3, cannot accept this voltage direct, its maximum input being just 0·2V. Obviously this high voltage must be stepped down, and is done here quite simply by the precision potential divider consisting of R1 to R7.

Returning briefly to the introduction, a simple equation was given, which gives the output voltage from a potential divider, reference to this will show that the correct combination of resistors is 9M9 for R1, and 100k for R2. This is position three on the range switch, and S2a is switched to this position. As the quantity being measured is a direct voltage it does not need to be passed through the a.c./d.c. converter. In consequence it passes via S1b and S1c to the input pin of IC3. S2d, selects the appropriate position for the decimal point in the display. All other switches not mentioned do not play any part in this mode of measurement. Finally, as already described, the logic circuit performs the necessary analogue-to-digital conversion on this output (0·2V), and displays the result.

## D.C. MEASUREMENT

The measurement of direct current is quite simple and involves passing the current to be measured through a series resistor, and then measuring the voltage drop produced across the resistor. As with d.v. the a.c./d.c. converter is not required and the path is as follows. From the (+) terminal via S1a to the range switch S2b, through the selected resistor, and then via the 2A protection fuse to the circuit under measurement. The voltage drop produced is taken via the wiper of S2b to S1b and finally via S1c to the input of the logic i.c.

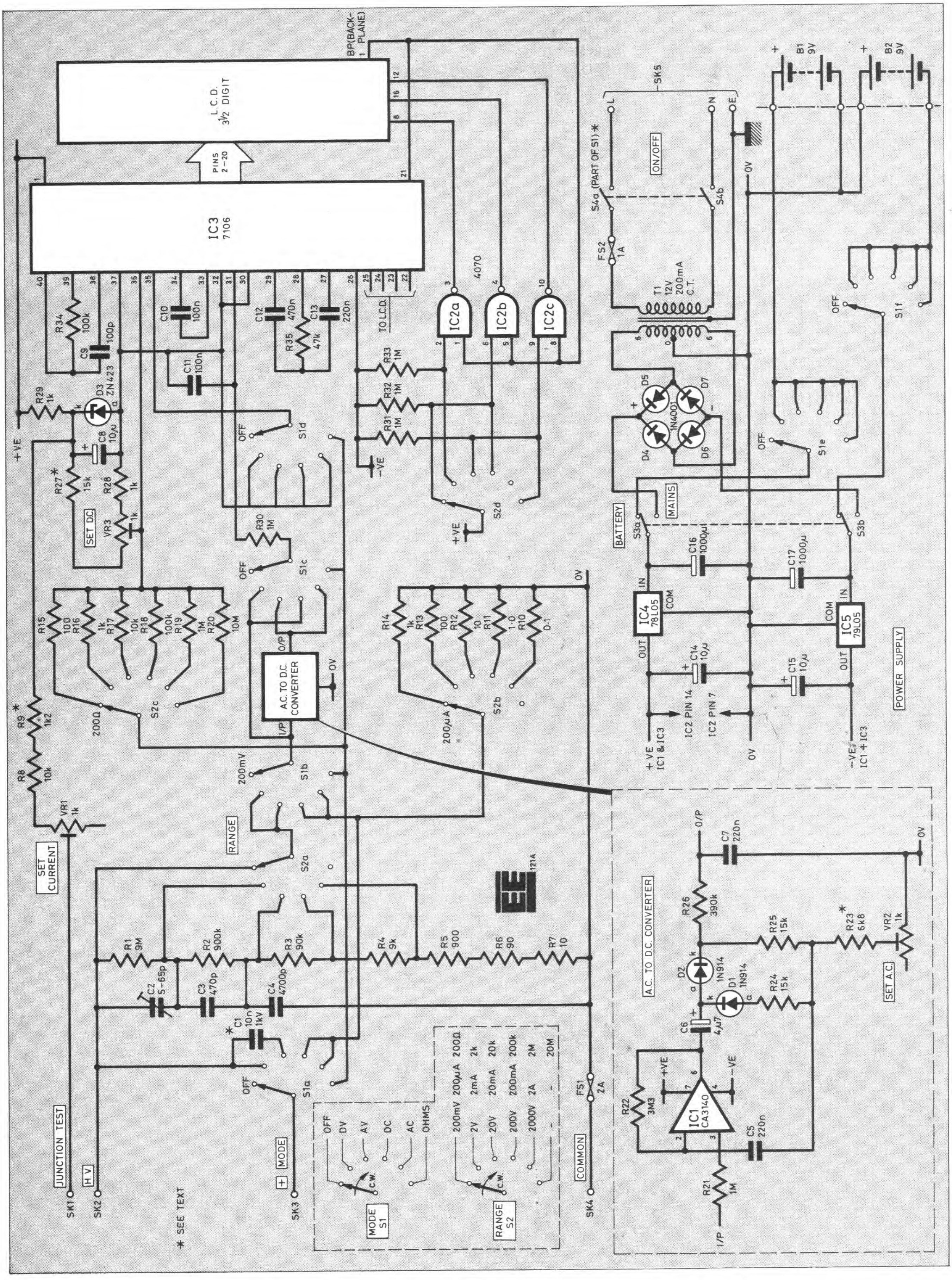
## A.V. MEASUREMENT

The alternating voltage to be measured is applied to the meter in a similar way, however, this time the voltage is required to go via a high voltage isolating capacitor, C1. This capacitor blocks any direct voltage which may be present. An example here is the measurement of ripple on a d.c. power supply.

The particular range required is selected by S2a, this time however the voltage does not go direct to the logic i.c., but passes through the a.c./d.c. converter, shown as a block on the main circuit diagram. The converter is selected by S1b and then by S1c which connects the output of the converter to IC3. Throughout the d.v./d.c. measurements, the converter was short circuited and thus did not affect the remainder of the circuit.

Conversion from alternating voltage to a direct voltage is carried out by IC1 and associated components, together they form a high precision half-wave rectifier. The use of such a circuit greatly increases the accuracy of rectification than if a standard single silicon diode was to be used. Conventional diodes are imperfect at very low level a.c. signals because they do not begin to conduct until the applied voltage exceeds a certain value, often called the "knee". In most diodes this knee value is usually 600mV, much higher than the 200mV or so we are applying to the circuit. By combining diodes with operational amplifiers the effective

Fig. 12 (facing page). Complete circuit diagram for the Digital Multimeter, including the power supply. The A/D converter circuit is shown within the dotted area.



L.C.D. 3½ DIGIT
IC3 7106
4070
ON/OFF
BATTERY
MAINS
POWER SUPPLY
A.C. TO D.C. CONVERTER
SET A.C.
SET D.C.
SET CURRENT
RANGE
MODE
JUNCTION TEST
H.V
COMMON
MODE S1
RANGE S2
* SEE TEXT

knee value is reduced by a factor which is equal to the open loop gain of the op-amp. In this way the circuit acts as a perfect rectifier even down to voltages of a few hundred microvolts.

## CONVERTER

The circuit for the converter is shown within the dotted area of Fig. 12. The op-amp is wired as a high impedance a.c. amplifier with gain adjustable by VR2. The input is applied via R21, and negative feedback via D1, R24, C5 or by D2, R25, C5. On negative half-cycles of the input, D1 conducts with D2 reversed biased, the output is zero. On positive half-cycles the op-amp swings positive, D2 conducts with D1 reversed biased, the output is now positive.

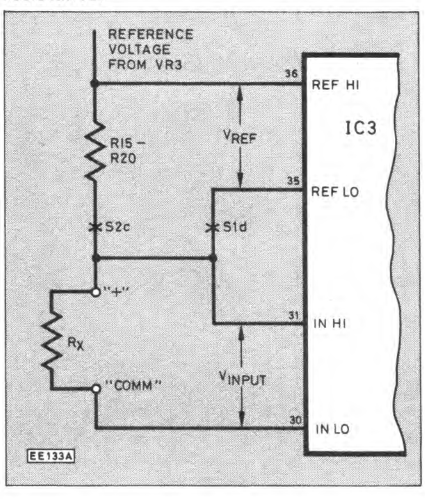
When the input voltage is zero, the diodes act as open circuits, which cause zero negative feedback to be applied to the op-amp. Under this condition the op-amp operates in the open loop mode and gives a high voltage gain. Consequently, only a very small voltage, typically 3μV or less is needed to raise the forward diode voltage above the knee, beyond which rectification as described takes place. Once the knee value has been exceeded, the diode acts as a virtual short circuit and under this condition the gain is determined by the ratio of R22 to R23/VR2.

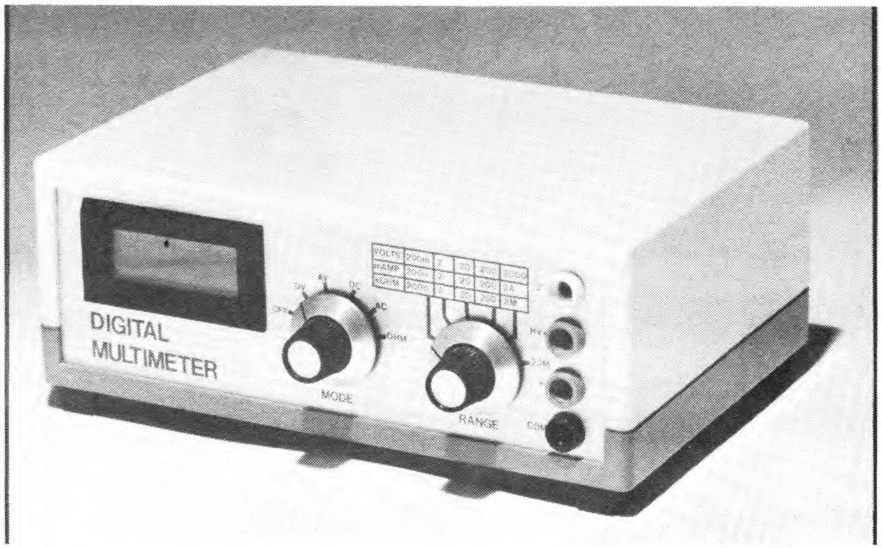
Using this circuit as near a perfect rectifier is obtained.

## A.C. MEASUREMENT

As with previous measurements, the alternating current is applied to the "+" and "com" terminals. The path for the current is the same as for direct current. The voltage drop produced across the range resistor is alternating, thus it requires rectification to a direct voltage before being applied to the logic circuit.

Fig. 13. Simplified diagram showing the "ratiometric" method of measuring resistance.




This is carried out by the a.c./d.c. converter which is switched into circuit by S1b and S1c. The resulting direct voltage can now be applied to the logic circuit and shown on the display, and read as current rather than voltage.

## RESISTANCE MEASUREMENT

The principle, known as the "ratiometric" system, is used to measure resistance. A simplified diagram of the operation is shown in Fig. 13. In this system, we require to apply the reference voltage across both a standard resistor and the unknown resistor. To achieve this as simply as possible we disconnect the reference low input from the 0V line and connect it across the standard resistor. This is carried out by switch S1d. The actual path the reference voltage takes is; from VR3 wiper, through one of the range resistors R15–R20, through the unknown resistor via S1a and returned to the common line by way of the "com" test lead. This path is shown simply in the diagram of Fig. 13.

By its name, the "ratiometric" system uses a ratio to determine the value of the unknown resistor, this being the ratio of the voltage across the standard resistor to the voltage across the unknown resistor. These voltages are monitored between the ref hi and ref lo pins on the logic i.c., and by input hi and input lo/common pins, the latter monitoring the voltage across the unknown resistor.

The logic circuitry inside the i.c. is so arranged that, the ratio between

$$\frac{V_{INPUT}}{V_{REF}} \times 1000$$

$$= \text{Actual reading on display}$$

For example, suppose we select the 2k ohm range and measure a resistor of exactly 2000 ohms. We know that from Ohm's Law, the unknown resistor will have twice the voltage across it than will the standard resistor.

Expressed as a ratio, 2:1. Inserting these in our equation

$$\frac{V_{INPUT}}{V_{REF}} \times 1000$$

$$= \frac{2}{1} \times 1000$$

$$= 2000 \text{ ohms}$$

You can try this yourselves by measuring (mathematically) 500 ohms! The ratiometric system has two main advantages, first only 100mV is used for the measurement thus enabling in-circuit measurements to be made without turning on transistor junctions. Second the accuracy is totally independent of the reference voltage stability, providing the voltage remains stable for the duration of the measurement, the accuracy is solely determined by the accuracy of the range resistors. This also means that no calibration is required.

## JUNCTION TEST

Referring to the resistance measurement above, the voltage used as already stated cannot be used to turn on transistor or semiconductor junctions. Thus a separate terminal is provided which can deliver the required voltage to turn on a junction. This is provided by the reference voltage circuit consisting of D5 and other components.

In use, the mode switch is set to d.c. and the range switch to the 200μA range. The semiconductor junction to be tested is connected between the "junction test" terminal and the "+" terminal, connections to other terminals are not used. In this condition a voltage of 1·2V appears between the terminals, and is sufficient to turn on any junctions.

The preset VR1 is used to set the current flowing with the test leads shorted, to 100μA, a semiconductor junction when forward biased will show a reading of approximately 60·0.

**NEXT MONTH:** Construction, setting up and use.

# PROXIMITY ALARM

R.A.PENFOLD

THIS unit is mainly intended for use as a simple burglar alarm, and it simply sounds an audible alarm if someone comes within about one foot or so of the unit. One way of using the unit is to hang it from a door handle so that the alarm sounds if an intruder approaches the other side of the door. The alarm signal will give warning of the intrusion if the house is occupied, or should deter any would-be burglar if the house is unoccupied.

The circuit is quite simple and is a true proximity detector which uses an oscillator and a sensor wire to detect the presence of anyone near to the unit, rather than using infra-red, radar, or ultrasonics as the basis of detection. The stand-by current consumption of the circuit is a little over 300 microamps which is low enough to permit economic battery operation of the alarm even though it will be left operating for long periods of time in normal use.

## BLOCK DIAGRAM

The block diagram of the Proximity Alarm is shown in Fig. 1. The sensor is just two pieces of wire which are very close together but are not in electrical contact with one another, and these are connected to the input and output of an oscillator. However, the oscillator is biased so that its quiescent output voltage is zero and oscillation normally fails to occur. Any electrical noise picked up by the sensor tends to briefly take the output of the oscillator away from its zero volts quiescent level so that oscillation can take place. The circuit has its sensitivity adjusted so that under stand-by conditions the noise picked up by the sensor is insufficient to produce these bursts of oscillation, but only marginally so. Anyone in close proximity to the sensor tends to pick up electrical noise and capacitively couple it to the sensor, and this resultant increase in electrical noise received by the sensor causes bursts of oscillation from the oscillator.

The output from the oscillator is rectified and smoothed, and the d.c. voltage produced is used to drive a latch circuit. This in turn activates an audio oscillator which drives a loudspeaker and produces the alarm sound, a low frequency oscillator modulates the audio oscillator to give a two tone alarm signal. The two tone alarm has the advantage of being much more noticeable than a single tone of similar volume. Once triggered the alarm continues to operate until the unit is switched off due to the inclusion of the latch circuit in the unit. The on/off switch is a key-operated type so that there is no quick way for an unauthorised person to switch off the alarm.

In order to be usable it is clearly necessary for the unit to incorporate a circuit which prevents the device from operating properly until a few seconds after switch-on so that the user has a chance to move away from the unit before it becomes operational, and the unit does not simply trigger as soon as it is switched on. This is achieved using a simple timer circuit which prevents the smoothing circuit from producing an output signal until about three seconds after switch-on.

## CIRCUIT

Three integrated circuits form the basis of the unit, as can be seen from the full circuit diagram which appears in Fig. 2.

The oscillator is built around operational amplifier IC1, and this is used in the non-inverting amplifier mode. Variable resistor VR1, together with R1, form the negative feedback network which determine the voltage gain of the amplifier, and the gain can be adjusted from less than unity to about 11 times by means of VR1. Resistor R2 biases the non-inverting input to the negative supply rail so that the circuit has the necessary reluctance to oscillate; R2 has a high value which makes the circuit sensitive to stray pick-up by the sensor. This also ensures that the capacitance in the sensor is adequate to produce oscillation when there is sufficient pick-up to bias IC1 into linear operation. Capacitor C2 is the discrete compensation for IC1.

The smoothing and rectifier circuit is comprised of R3, D1 and C3. Resistor R3 is included to reduce the attack time of the circuit slightly, and this gives the circuit some immunity to noise spikes picked up by the sensor and helps to prevent spurious triggering.

IC2 is a CMOS 4001BE integrated circuit which is a quad 2-input NOR gate, but in this circuit the two inputs of each gate are connected together so that four simple inverters are produced. Gates IC2c and IC2d are connected in series so that they act as a non-inverting buffer stage. Initially C7 is uncharged so that the input and output of this buffer stage are both at logic 1. Transistor TR1 is

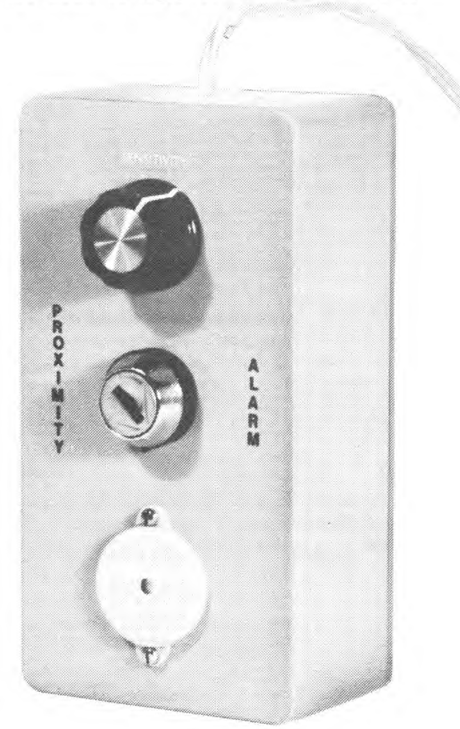
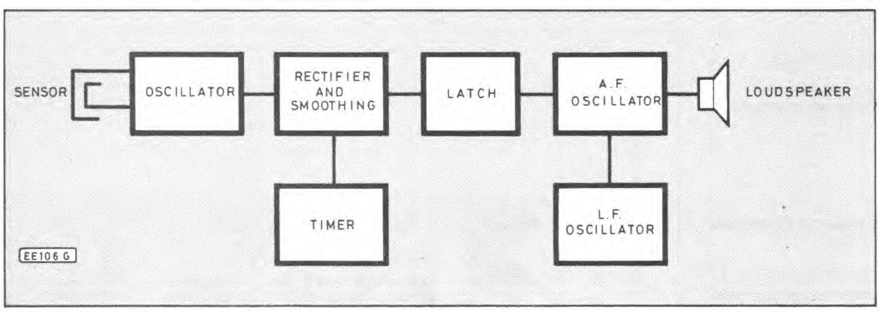



Fig. 1. Block diagram of the Proximity Alarm.



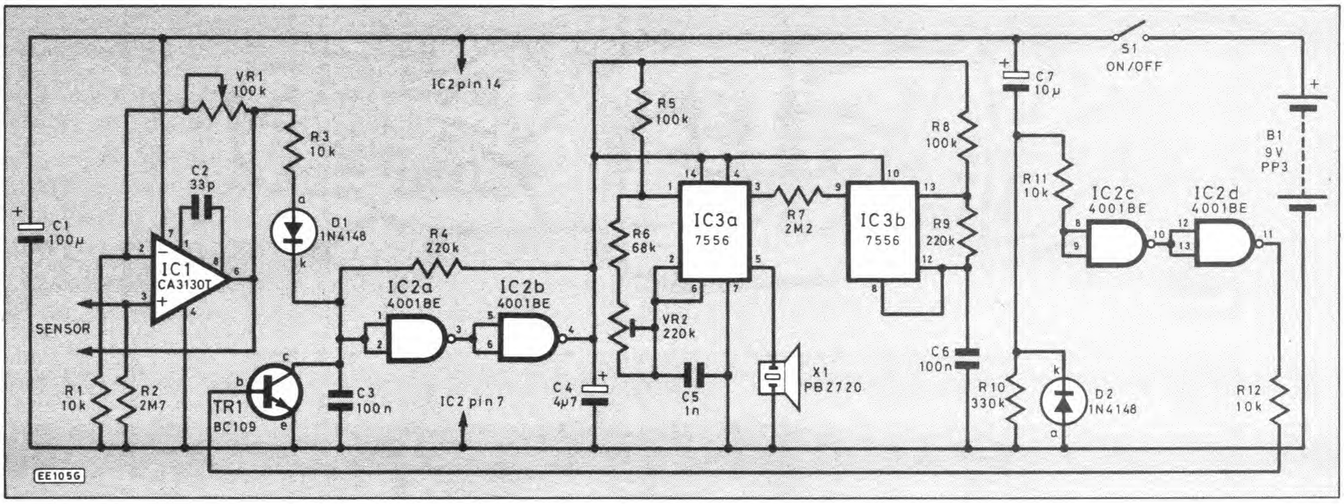



Fig. 2. Full circuit diagram of the Proximity Alarm.

biased into conduction by the base current it receives from the buffer amplifier via R12, and C3 is therefore held in an uncharged state. Capacitor C7 is charged quite quickly by way of R10 though, and about three seconds after switch-on the input to the buffer stage falls to logic 0, the output also goes to logic 0, TR1 is cut off, and the rectifier and smoothing circuit is then able to function normally. Thus the switch-on delay is obtained. Diode D2 ensures that C7 discharges rapidly when the unit is switched off so that it is ready to give a further switch-on delay as soon as S1 is returned to the "on" position again.

A simple latch circuit is formed from the other two gates of IC2, and these are connected in series with positive feedback provided by R4 giving the latching action. Normally the input and output of the latch are at logic 0, but when the unit is activated the bursts of oscillation from IC1 charge up C3 to a potential which is high enough to take the input and output of the latch to logic 1.

The audio alarm generator is powered from the output of the latch circuit, and is therefore switched on when this output goes to logic 1. The alarm generator uses the two timer circuits in a 7556 device, this is the dual version of the 7555 timer i.c. (which is the CMOS version of the popular 555 device). It is essential to use the 7556 in this circuit and not the standard 556 device, since the latter requires a supply current which is substantially higher than the latch circuit can provide. The current consumption of the 7556 is about one hundred times lower at a mere 160 microamps (typically).

The alarm tone is generated by IC3a and its output directly drives X1 which is a ceramic resonator. This produces quite a loud signal but consumes a current of only about 2 milliamps. The timer formed by IC3b is used as the low frequency modulation oscillator, and this drives the modulation input of IC3a via R7. This resistor limits the shift in the output frequency of the tone generator as the output of IC3b switches back and forth between virtually the two supply potentials. The modulation frequency is about 2Hz. Variable resistor VR2 is used to adjust the tone generator so that it produces two frequencies that give good efficiency from LS1, and the loudest signal obtainable.

## CONSTRUCTION

A plastic box having outside dimensions of 150 by 80 by 50mm makes an ideal case for this project. The case is used vertically with VR1, S1 and X1 mounted in a row down the front panel (as shown in the photographs). The key-operated switch used in the prototype required a 19mm mounting hole which can most easily be made using a chassis punch of the appropriate diameter. Resonator X1 has provision for two small fixing screws, but the mounting holes can be slightly enlarged to take 6BA mounting bolts. The resonator itself can be used as a template when marking the positions of the two mounting holes on the front panel. A third small hole is required to enable the two leadout wires of X1 to pass through to the interior of the case.

All the other components fit onto a printed circuit board which measures 146 by 38mm. This must be accurately cut to size if the specified case is used since it slots into a set of guide rails in the case, and will not do so properly if the board is slightly over or under size. There are spaces at the ends of the board where mounting holes can be drilled if a different case is used.

The board is constructed using the normal constructional methods, but it should be noted that all three integrated circuits are CMOS types. The 7556 device has internal protection circuits that render special handling precautions unnecessary, but the other two integrated circuits should be handled as little as possible,

## COMPONENTS

See Shop Talk page 690

### Resistors

| | |
|---|---|
| R1,3, 11,12 | 10k (4 off) |
| R2 | 2M7 |
| R4,9 | 220k (2 off) |
| R5,8 | 100k (2 off) |
| R6 | 68k |
| R7 | 2M2 |
| R10 | 330k |

All $\frac{1}{8}$W carbon ±5%

### Potentiometers

| | |
|---|---|
| VR1 | 100k linear carbon |
| VR2 | 220k 0·1W horizontal preset |

### Capacitors

| | |
|---|---|
| C1 | 100µ 10V elect. |
| C2 | 33p ceramic plate |
| C3,6 | 100n polyester (2 off) |
| C4 | 4µ7 63V elect. |
| C5 | 1n mylar |
| C7 | 10µ 25V elect. |

### Semiconductors

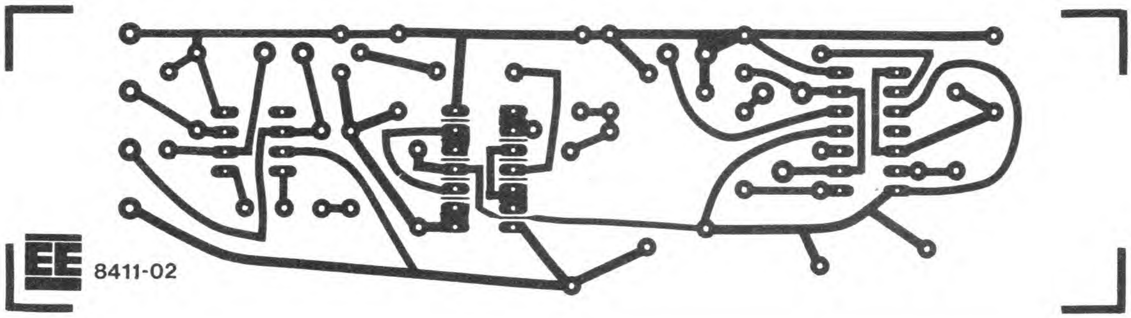
| | |
|---|---|
| D1,2 | 1N4148 silicon diode (2 off) |
| IC1 | CA3130T or CA3130E CMOS op-amp |
| IC2 | 4001BE CMOS quad 2-input NOR gate |
| IC3 | ICM7556 dual CMOS timer |
| TR1 | BC109 silicon *npn* |

### Miscellaneous

| | |
|---|---|
| S1 | Keyswitch |
| X1 | PB2720 ceramic resonator |
| B1 | 9 volt PP3 size |

Single-sided printed circuit board 146mm × 38mm; plastic case measuring 150 × 80 × 50mm (type 5005); twin lead for sensor; battery clip; control knob; wire, etc.

**Approx. cost Guidance only £11.00**



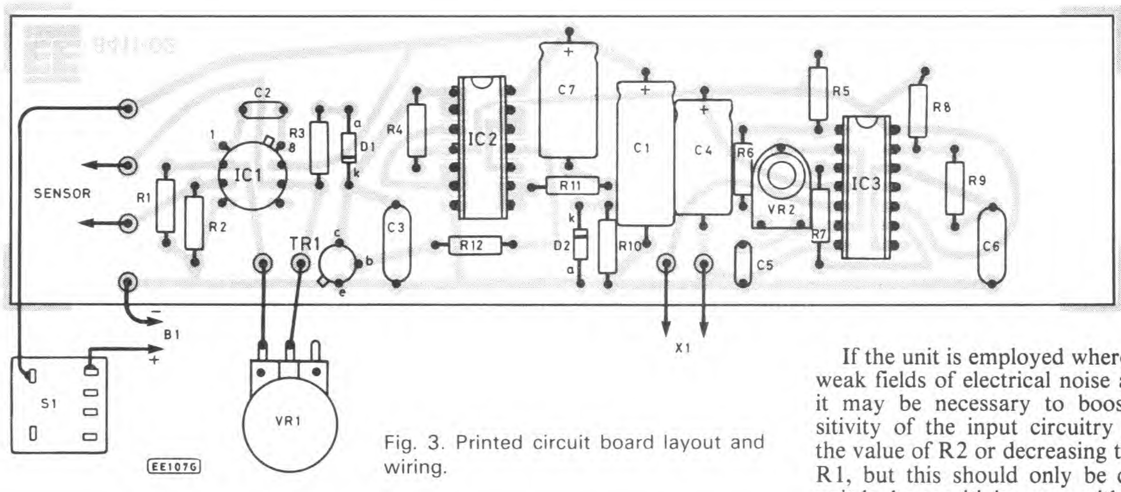




Fig. 3. Printed circuit board layout and wiring.

they should be the last components to be fitted onto the board, and be soldered in place using an iron having an earthed bit. The board will take either the CA3130T TO–99 cased device or the CA3130E 8-pin d.i.l. version in the IC1 position. Connections to off-board components are made via Veropins. This wiring is shown in Fig. 3 which also provides full details of the printed circuit board.

The sensor is simply a piece of twin (figure-of-eight) cable about 700mm long. One end of one connector and the opposite end of the other connector are soldered to the board, so that only one end of each wire is connected to anything, and there is no path of conduction through the sensor. A small hole is drilled in the top of the case to provide an entrance hole for the sensor wire.

## ADJUSTMENT AND USE

With VR1 set in a fully clockwise direction and the unit switched on the alarm signal should be produced after approximately three seconds. VR2 is then adjusted to give the loudest alarm signal that can be obtained.

A simple way of using the unit is to hang it from a door handle by looping the sensor wire over the handle. Start with VR1 adjusted fully anti-clockwise, switch the unit on, wait a few seconds, and then slowly advance VR1 in a clockwise direction. At some point the alarm should be activated, and this point represents roughly the correct setting for VR1.

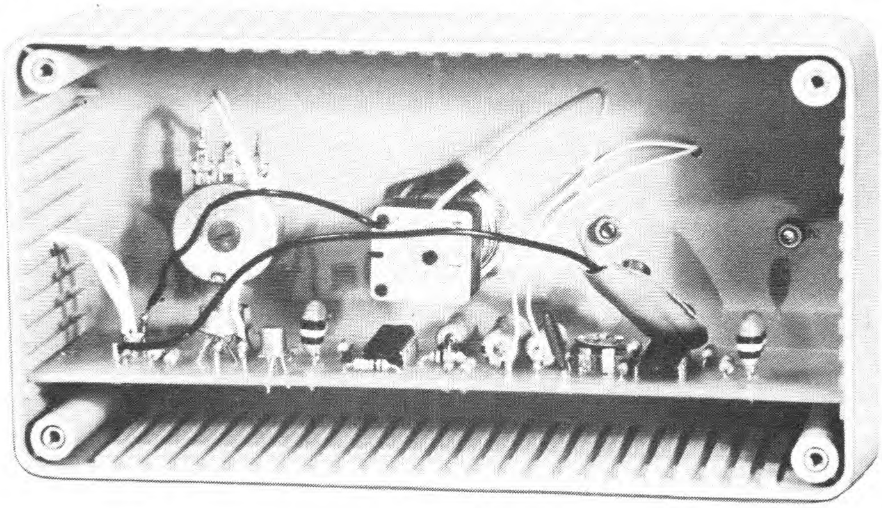
The unit is reset by switching off and allowing the alarm signal to decay, and then switching on again. Move away from the unit before the switch-on delay ends, and then move back to it again. If the alarm sounds when you are within about a foot or so of the unit VR1 has the correct setting. If the unit lacks sensitivity advance VR1 very slightly, reset the unit and try again. If the alarm triggers before you approach, adjust VR1 slightly in an anti-clockwise direction, reset the unit and try again.

By a process of trial and error it should be possible to eventually obtain correct operation of the unit, but the setting of VR1 may be quite critical. With careful adjustment of VR1 it is usually possible to obtain an operating range of over one metre, but it is not advisable to use the unit at such a high level of sensitivity as spurious triggering can easily occur.

If the unit is employed where only very weak fields of electrical noise are present it may be necessary to boost the sensitivity of the input circuitry by raising the value of R2 or decreasing the value of R1, but this should only be done if the unit lacks sensitivity even with VR1 fully advanced. Another problem that can sometimes occur is that of the unit failing to operate the alarm if someone is in close proximity to it, but with the alarm being triggered if the person moves away; the exact opposite of what is required!

This is presumably due to signals coupled into the sensor by the person close to the unit tending to phase out the normal pick-up in the sensor. When the person moves away the normal pick-up is sufficient to trigger the unit. Slight repositioning of the alarm and sensor, especially turning the sensor at right angles to its position, should eliminate this.

It may take a little experimentation to successfully install and set up the unit, but once a suitable arrangement has been found it should not be necessary to repeat this procedure unless the unit is used at a different location. □



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| Nicad chargers, mains | £0.75 |
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| Counter 6 digit mains operated | £1.15 |
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| Magnetic Clutch | £4.50 |
| Mouth operated suck or blow switch | £2.30 |
| Solenoid with slug 8 - 12v battery op. | £1.82 |
| ditto 230v mains | £2.30 |
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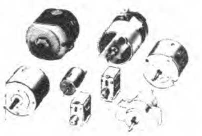
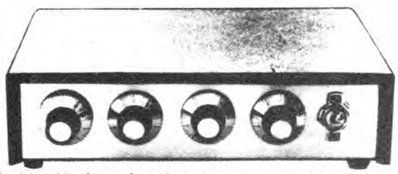
| Key switch with 2 keys dp mains | £1.75 |
| Air valve mains operated | £3.75 |
| Latching relay mains operated | £3.50 |
| Dry film lubricant aerosol can | £0.65 |
| Coin op switch, cased with coin tray | £4.60 |



**8 POWERFUL MODEL MOTORS (all different)** for robots, meccanos, drills, remote control planes, boats, etc. **£2.95.**



Complete kit of parts for a three channel sound to light unit controlling over 2000 watts of lighting. Use this at home if you wish but it is plenty rugged enough for disco work. The unit is housed in an attractive two tone metal case and has controls for each channel, and a master on/off. The audio input and output are by ¼" sockets and three panel mounting fuse holders provide thyristor protection. A four-pin plug and socket facilitate ease of connecting lamps. Special price is **£14.95** in kit form or **£25.00** assembled and tested.

**WANT A PART OF HISTORY?** During the last war, cars and army lorries were able to travel without lights. The drivers looked through binoculars which contained infra red Converter Cells (a British invention). We have these infra red binoculars and you can obtain this bit of history for only £3.50 + £2.50 pp (Cases are a bit rusty through long storage and although unused, we cannot guarantee the cells are in working order, although working cells can be obtained).

**40w 1 metre FLUORESCENT TUBES** ideal for pelmet lighting etc. Large quantities to clear box of 25 for £12, carriage paid, or £25 per 100 you collect other tubes in stock also chokes and accessories very cheap.

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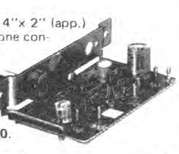
**MINI MONO AMP** on p.c.b., size 4"x 2" (app.) Fitted volume control and a hole for a tone control should you require it. The amplifier has three transistors and we estimate the output to be 3W rms. More technical data will be included with the amp. Brand new, perfect condition, offered at the very low price of **£1.15 each, or 10 for £10.00.**



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Other uses are as a "get you to sleep radio", you could even take it with you to use in the lounge when the rest of the family want to view programmes in which you are not interested. You can listen to some music instead.
Some of the features are: long wave band 115 – 270 KHz, medium wave band 525 – 1650KHz, FM band 87 – 108MHz, mono, stereo & AFC switchable, tuning meter to give you spot on stereo tuning, optional LED wave band indicator, fully assembled and fully aligned. Full wiring up data showing you how to connect to amplifier or headphones and details of suitable FM aerial (note ferrite rod aerial is included for medium and long wave bands. All made up on very compact board.
Offered at a fraction of its cost: **only £5.95** 10 for **£50**

**AMSTRAD SPEAKER SYSTEMS** 25 watt RMS loading 8Ω 8' woofer, 4" tweeter with crossover. £12.00 per pair + £4 post. New and unused but cabinets slighty damaged hence this low price, carry our normal guarantee.

**COMPONENT PACKS** All brand new components, price is £1 per pack, if you order 12 you get one extra free, your choice:
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7 – 4 in flex line switches with neons
8 – 2 80 watt brass cased elements
9 – 2 mains transformers with 6v 1a secondaries
10 – 2 mains transformers with 12v ½a secondaries
11 – 1 extension speaker cabinet for 6½" speaker
12 – 5 octal bases for relays or valves
13 – 12 glass reed switches
14 – 4 OCP 70 photo transistors
15 – 25 assorted gemanium transistors OC45 etc
16 – 4 tape heads, 2 record, 2 erase
17 – 2 ultra sonic transmitters and 2 ditto receivers
18 – 2 15000 mfd computer grade electrollics
19 – 2 light dependent resistors similar ORP12
20 – 5 diff micro switches
21 – 2 mains interference suppressors
22 – 2 25 watt crossover units
23 – 1 40 watt 3 way crossover unit
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**TELEPHONE ITEMS (ex-GPO)**

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| External bell unit | £6.50 |
| Bell ringing power unit | £6.50 |
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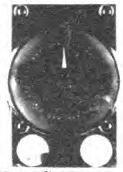

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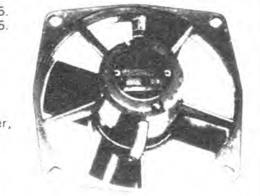

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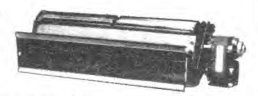

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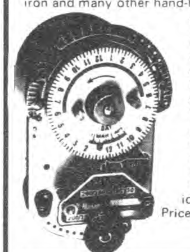

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# RADIO WORLD

BY PAT HAWKER G3VA

## Amateur Radio Defined

Many years ago a series of articles was published in one of our national newspapers under the title "It's fun finding out". Appropriately, one article covered "Amateur Radio". It reflected the view that while undoubtedly the operation of your own h.f. or v.h.f. transmitter as a hobby can be great fun, it is also capable of providing a valuable insight into the theory and practice of radio communication engineering.

In the days when at least some part of a station, if only the aerial, aerial matching unit, and some test equipment were home constructed there was every incentive to keep abreast of current technical developments and to grapple with understanding a.c. theory (reactance as well as the resistance), impedance matching, the j-operator, Smith charts, "loaded Q", equivalent noise resistance and the like, little of which is necessary to pass the Radio Amateur's Examination.

Amateur radio owes many of its privileges to the fact that the International Telecommunication Union formally recognises the hobby as: "A radio communication service for the purpose of self-training, intercommunication and technical investigations carried out by amateurs, that is, by duly authorised persons interested in radio technique solely with a personal aim and without pecuniary interest." This definition is incorporated in the ITU's Radio Regulations. Amateur radio is thus a hobby defined by an international treaty drawn up by some 150 nations.

While the DTI has the power at any time to withdraw all amateur operating privileges in the UK it could not re-allocate any of the "exclusive" frequencies allocated to the amateur service for any other purpose unless it could be shown that this would not cause interference to amateur radio operation outside the UK—a virtual impossibility in the case of, for example, the 7, 14, 21 and 28MHz bands.

## Self-training?

Nevertheless, there is a growing danger that the current UK licensing system singularly fails to encourage the important "self-training and technical investigations" aspects of the hobby.

The Radio Amateur's Examination, as conducted by the City & Guilds of London Institute, has the aim of ensuring only that UK amateurs have sufficient technical understanding of radio transmission that they do not wreak havoc in the electromagnetic environment. It does not—and indeed should not—be regarded as representing a level of technical knowledge in regard to modern communications theory and practice to which a licensed amateur should aspire.

## An Incentive To Learn?

In many overseas countries, including the USA, Japan and the USSR, this problem has always been tackled by "incentive licensing"—making it reasonably easy to acquire a licence providing limited privileges but then insisting on further tests or other evidence of "learning by doing" before granting additional privileges: in many countries there are several grades of licence open to those prepared to serve their "apprenticeships". No such distinction is made in the UK—the technical requirement for Class A (h.f. and v.h.f.) and Class B (v.h.f. without a Morse test) being identical.

Martin Atherton, G3ZAY has recently proposed that the UK should introduce "a voluntary 'advanced' RAE" akin to the advanced driving test with the aim of encouraging amateur enthusiasts to continue their technical studies on a structured basis well beyond the level of the RAE. He believes that new amateurs, including the many who have no professional connection with radio or electronics, should be encouraged to learn more about the technical side of the hobby rather than to allow national and international conversation, contests, DXing, etc., to become the dominant aspects of the hobby, as they appear to be doing at present.

Whether a voluntary "advanced" RAE would carry much weight could be questioned but it does seem, if the hobby is to retain the respect of governments and justify its internationally-defined status, that more needs to be done in the UK to live up to the ITU's definition of the service without detracting from the social pleasures of holding two-way conversations by radio.

## The New Schedule

On September 10, the DTI formally introduced their new schedule to the UK amateur licence, setting out the frequency bands, modes of transmission, maximum power output (carrier or peak envelope power), the status of each band, and whether this is available for the amateur satellite service. This detailed table is accompanied by a long series of footnotes, definition of symbols, and an explanation of the technical terms.

The schedule has thus become extremely complex yet needs to be most carefully studied by anyone taking the RAE. The vast majority of amateurs do not have the time or inclination ever to take full advantage of all bands and all modes—yet have to answer questions on them for the RAE. This is another argument in favour of an initial limited-facility licence followed by extra grades under a carefully thought-out incentive scheme.

Curiously enough licensed amateurs are expected to keep abreast of changes in licence conditions by reading the London, Belfast or Edinburgh Gazette. It seems many years since the licensing authorities provided any revised copies of the licence to individual amateurs.

## Diamond Jubilee

An amateur who has been licensed for 25 years is often called an "old-timer" but what one wonders should one call those few who can claim 50 or even 60 years as amateurs?

Recently I had the pleasure of attending at Bromley, Kent the "Diamond Jubilee of G2MI" marking the anniversary of the happy day in August 1924 when a youthful Arthur Milne first received what was then officially an "experimental" licence for wireless telegraphy. Few people have contributed more to the hobby: honorary editor for many years of the *RSGB Bulletin*; with the help of his wife, Lucy, he ran the UK QSL Bureau for over a quarter of a century; he has transmitted the weekly RSGB News Bulletin (3650kHz, Sundays 9am local time) on almost 1300 occasions. For the occasion he put on a fascinating exhibition of some of his home-built equipment and components, and valves of the pre-war era.

There has been a marked revival of interest in some early communications receivers marketed between about 1936–46, not as museum pieces but as operational receivers. Classic designs such as the series of HRO and Super-Pro receivers, the AR88D and some of the Hallicrafters sets are still capable of giving good performance on 14MHz and below, particularly for Morse (c.w.) operation.

I have even been stirred into refurbishing a valve receiver I built in 1946 based loosely on the Tobe Deutchmann tuner kit of 1936 and still capable of sorting out the many signals on the crowded amateur bands. The real breakthrough in receiver design came in the early thirties with the first use of piezo-quartz crystals as i.f. selectivity filters—an invention of the British engineer Dr. J. Robinson but first implemented in h.f. communications receivers in the USA by James Lamb of the American Radio Relay League.

## CQ on TV

The transmission of the well-constructed play "CQ" by Paula Milne on *Channel 4*, October 11, was the subject of some heart-searching among radio amateurs. Did this drama in which great efforts were made to present a technically authentic view of some aspects of the hobby do more or less for the public image of the hobby than Tony Hancock's classic "The Radio Ham" with its not entirely unrelated plot?

Both presented radio amateurs involved with maintaining radio communication with lone sailors—but Hancock's version of the outrageously bumbling "ham" is held by some to have seriously denigrated the hobby. My own view is that it was the affectionate work of a true comic genius and likely to remain in the memory long after Paula Milne's diligent "Norman" has been forgotten.

Curiously, although the disc of Hancock's sketch still circulates, the TV recording is among those which the late Tony Hancock's executors seem anxious not to screen.

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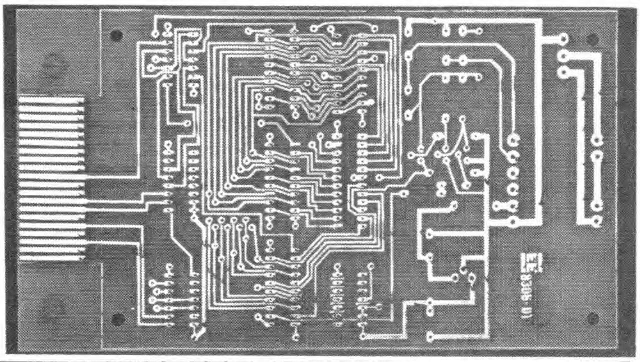


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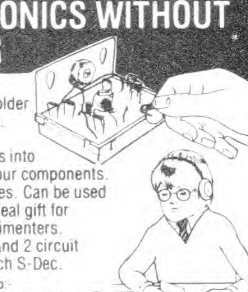

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|---|---|---|---|---|---|---|
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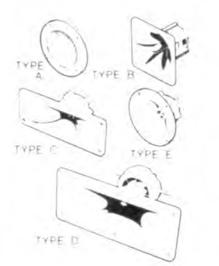


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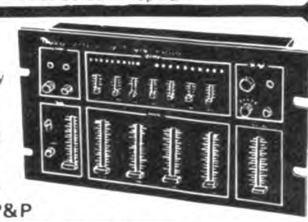

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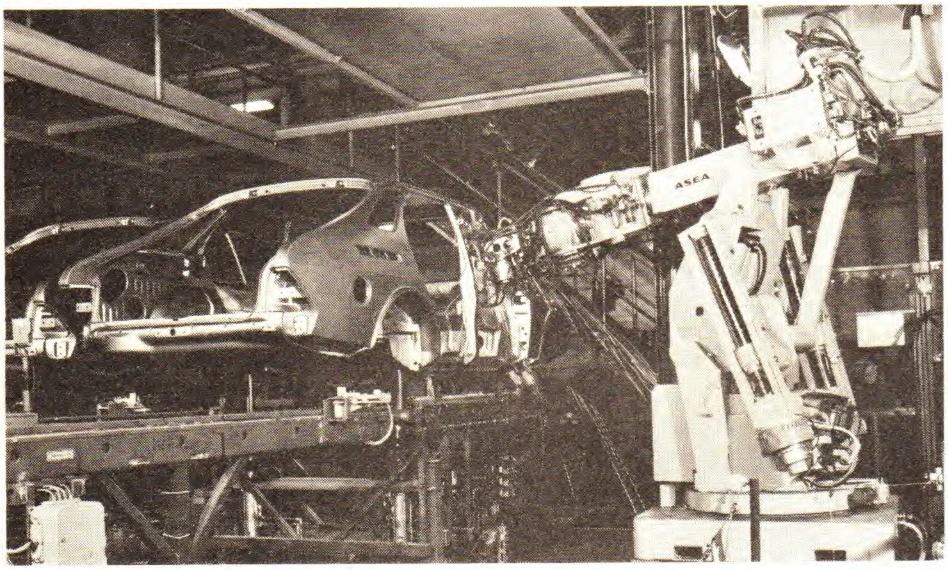
# SMALL ROBOTS & Their




# BIG BROTHERS!

## TOM IVALL

DEPENDING on your point of view, the small robots or 'microrobots' now on the market can be seen as toys or as educational equipment. In practice they can be both. Most children get their first 'hands on' experience of machinery through mechanical toys. This early empirical approach, purely for fun, provides valuable intuitive knowledge for those who may later take up engineering as a career.

On the hobby or amusement level, 'personal' robots, as they are being called, are to be welcomed as something interesting one can do with a home computer. All that skill acquired in 'driving' a computer can be adapted to the concrete business of programming movements of real objects in three-dimensional space—instead of just churning out symbols or graphics on a flat screen.

On the level of education and training, small robots costing a few hundred pounds are being used as models or simulators to allow students and factory staff to get some understanding and feel for industrial robots in a safe and economical way. Full-scale industrial robots usually cost tens of thousands of pounds—very expensive as educational equipment! And the machines already working in factory production lines are far too busy to be interrupted for training purposes.

Because the market for educational robots is much more predictable than that for personal robots—which could be just a short-lived fad—most of the small robots now on sale are being designed as miniature, low-power training versions of the industrial machines. (Though in some cases they are well enough built to be used in factories for light packing or assembly tasks.) This means, in general, that they imitate the commonest and most versatile form of robot found in manufacturing industry—

the single-arm manipulator with multiple joints, as widely used in automatic spot welding of car bodies for example.

## SMALL ROBOT STRUCTURES

The typical small single-arm robot is designed to stand on a table or lab bench. It is about a foot or more high and weighs roughly the same as a heavy-duty typewriter. The arm is made up of several sections or members constructed of metal plates or pressings, which are jointed in much the same sort of arrangement as an industrial robot (Fig. 1).

These members are comparable with the human trunk, upper arm, forearm, hand and fingers. They are articulated by rotating joints corresponding to the human waist, shoulder, elbow, wrist and prehensile joints in the hand. The robot is driven by low-power electric motors or hydraulic cylinders, under the control of a microprocessor or microcomputer system. It will lift and move loads which are typically to be measured in grams, compared with the kilograms of industrial robots.

Also classed as personal robots are little wheeled vehicles called buggies or tortoises ('turtles' in the USA). These run about on the end of a flexible cable under remote control of a computer. Although they may well have some educational value in control systems generally, they do not have industrial 'big brothers' as directly as the single-arm manipulators do. Perhaps the nearest thing in industry is the AGV (automatic guided vehicle) used, for example, in automated warehouses.

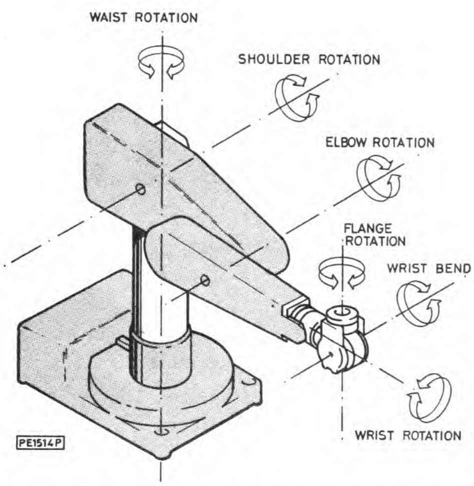



**Fig. 1. Level of articulation and joint rotations (axes of movement) available in a typical industrial robot—the Puma 260, a light-duty machine made by Unimation (Europe) Ltd. The manipulator arm members are driven by d.c. servomotors position controlled by the user's software program held in a 16K RAM**

## ROBOTS, AUTOMATION AND PRODUCTIVITY

But why have these small robots emerged as commercial products at this particular time, in the early 1980's? One reason is that cheap stepping motors (£10–£15) and cheap programmable controllers in the form of microprocessors and home computers have recently become widely available. These make it possible to manufacture and sell the robots at prices low enough to be afforded by individuals and educational establishments. We shall be looking at this technical design aspect in another article.

A more fundamental reason is that only in the past few years have industrial robots really 'taken off' in British manufacturing industry. According to the British Robot Association, the average growth in the UK's robot population has been more than 60% per annum over the past couple of years. But before that it was much lower. This recent rapid increase has occurred because British industry is now trying to catch up with the rest of the industrialised world, after being a long way behind Japan, USA, Germany and Sweden in the application of robots.

British manufacturers have had robots available to them on the open market for twenty years or more, but have simply not woken up to what these machines can do to boost productivity. Now, competition from abroad is forcing our industry to get moving. So the sudden interest in training people to understand and use robots is a direct result of this belated response by UK manufacturers.

## HISTORICAL DEVELOPMENT

The idea of the robot has been around for many centuries. In literature it has existed from Homer to modern science fiction. The name itself comes from 'robota,' the word meaning *work* in Russian and other Slavonic languages (written in the appropriate Cyrillic characters of course). It was, in fact, a Czech, the author Karel Capek, who coined the word in the 1920s, in his play *Rossum's Universal Robots*.

In the real world, robots have been known for several centuries in the form of automata (machines imitating animate creatures). The 18th century clockmakers Jacquet-Droz, for example, constructed several mechanical humanoids which wrote, drew or played musical instruments. But in the 20th century the term robot has been applied to almost anything automatic—for example traffic lights, because they replace policemen for directing road traffic.

With modern industrial robots, however, there is a return to the concept of machines with structures and actions similar to those of living creatures, as we have seen with the single-arm manipulator. Of course, this is not being done merely for the sake of imitation, as with the 18th century automata, but because the modern robots are intended to replace manual operations to some degree. They must therefore be designed to get as near as possible to the flexibility and versatility of the brain-directed human arm and hand.

Moreover, the robot manufacturer cannot afford to produce many different types of highly specialised machine with restricted markets. He wants to make and sell large quantities of standardised robots which are versatile enough to work in many different manufacturing processes. Taken to its logical conclusion, this policy would end up in manufacturing robots which were in fact very similar to human beings. But in practice, of course, this is not necessary.

The present level of articulation in single-arm manipulators—five or six axes of rotation of the kind shown in Fig. 1—can be seen as developing slowly from the automation systems of fifty or more years ago. These were the early transfer lines in Detroit automobile plants and conveyor belts in other industries. Automatically operated rods or gates were used for simply pushing or pulling objects on or off these moving production lines at the right times and in the right directions.

Such simple devices, which are still in wide use, are only programmed to make one particular movement, and they repeat it tirelessly and reliably every time they receive the appropriate mechanical or electrical trigger. Thus they are rather like the mindless physiological reflexes in humans or other animals.

Some of the early programmable robots were derived from this pushing/pulling type of action, in that they were based on the principle of the telescopic arm—a rod that would extend and retract but not bend in the middle. But the telescopic arm was pivoted to allow it to move round in a horizontal plane, so that it could act in different directions, and also had a manipulatory hand or gripper on the business end. The early Unimate robots of this kind, for example, could pick up, set down and manipulate tools or objects under the control of instructions stored on a magnetic drum.

The increasing versatility of automation systems—especially with computer control coming in—led to the development of the articulated arm capable of performing much more complex movements. Unlike the telescopic arm, it could move its gripper up and over, or down and under or some other path, as necessary to avoid obstructing parts of the fixed machinery in a plant.

We now have both types working in factories. In general they are called first-generation or 'pick and place' robots. They will operate tools, such as welding heads or paint-spraying guns, or handle materials or workpieces, such as placing chocolates into paper trays or positioning metal components for machining processes.

They operate, however, with a fixed sequence of positions and actions, for which they have been initially programmed. And they are somewhat 'mindless' in this, because even if the tool or workpiece is missing for some reason they will just go on uselessly beating the air, repeating the same movements.

But first-generation robots are versatile devices when they can be re-programmed. This calls for a method of programming which allows the instructions to be quickly and easily changed. In the early days programming was done by hardware—mechanical stops, limit switches, hand-set electrical connections and pneumatic air tubes, cam-operated contacts and so on. This kind of technology is now being replaced by software programming, through minicomputers and microcomputers. Software programming is not only more convenient and flexible to use but also allows a higher level of machine intelligence to be introduced.

One technique of programming by software is to start from the desired movements and positions of the robot's hand in three-dimensional space (using Cartesian or cylindrical co-ordinates) then calculate by a long string of transformations the various arm and drive positions, control signals and program instructions required to achieve them. This is highly complex and difficult. Most manufacturers of commercial robots provide means for a much easier and quicker method of programming—empirical rather than analytical.

The user has a hand-held keyboard or control box which allows him to drive the various axes of the robot arm so that he can find the correct movements, positions and actions experimentally for the task involved. When each correct position or action is found in this way, the user presses a key to record it in the robot's programmable memory (e.g. a RAM). Thus a complete software program is built up empirically, and from then on can be repeated automatically. This is called 'training' or 'teaching' the robot.

## CONTROL AND SENSING SYSTEMS

Drives for the various parts of the articulated arm—often electric but sometimes hydraulic or pneumatic—are controlled by electrical/electronic circuits which receive commands from the stored program. These control systems are either open-loop (sometimes called 'non-servo') or closed-loop (or 'servo'), as shown in Fig. 2.

In an open-loop control system—typically a sequence of pulses fed into a stepping motor—a given electrical change, say a single pulse, produces a known angular or linear displacement in the motor and arm mechanism. Open-loop systems have the advantages of simplicity and low cost and can be very accurate for position control if there in no backlash, slip or other play in the mechanism. The more advanced designs of industrial robots, however, tend to use closed-loop control.

Here, as shown in Fig. 2 (b), the position resulting from a mechanical movement is measured by a transducer, such as an analogue potentiometer or a digital shaft encoder, and the information—the 'actual position'—is continuously compared with the 'desired position' supplied by the stored program. When they are different an error signal is produced. The motor, which could be an a.c. or d.c. servomotor or an hydraulic cylinder, drives the mechanism to reduce the error signal to zero and then stops. Such servomechanisms automatically deal with any mechanical lost motion because this is contained within the feedback closed loop. By their use, repeatable positioning accuracies in robots of better than 0·1mm are now being obtained.

But even the monitoring action of the closed-loop control system is confined within the robot itself. In the latest robotic systems now emerging, called 'second-generation' robots, greater accuracy, versatility and intelligence are obtained by extending the monitoring concept outside of the robot to include the workpieces, materials or tools being manipulated. Various sensing techniques are being developed, both privately and through publicly-funded research projects. Japan is spending about £55M on such work, the UK about £1·2M.

At present most of the sensors actually constructed or operating are optical and are therefore called 'vision systems' or 'machine vision'. Typically, a small television camera mounted near or actually on the robot views the objects being manipulated in relation to the operating end of the robot arm. The video signal from the camera undergoes analogue and digital signal processing to derive numerical data on size, position, shape, colour and any other information required, and this is used, via a computer, to control the robot arm in relation to the work.

For example, at a General Motors automobile plant in Canada, a vision system guides two co-ordinated robots to pick different gear housings off a moving conveyor and sort them into stacks according to type. RCA Laboratories have developed a vision guided equipment for assembling loudspeakers onto mounting points. The vision system locates the holes in the speakers and the studs on the mounts, while force transducers 'feel' to check whether a successful assembly has been achieved.

Conditional branching in computer programs, based on the logical operator *implication* (or IF *p*, THEN *q*), allows robots to make decisions—or rather implement human decisions—on the basis of inputs from sensors and transducers.

Some robots on the market already have force transducers built into their hands to detect if the grippers are actually in contact with the workpiece and holding it. The idea of incorporating speech recognition systems to enable robots to respond to spoken commands has been tried experimentally. It may well prove genuinely useful in industrial processes where an operator's hands are busy with other tasks requiring human levels of skill and dexterity.

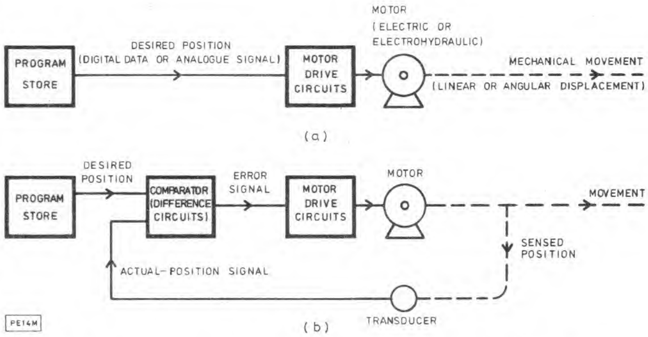



**Fig. 2. Two methods of position control used for drive motors or hydraulic cylinders in articulated arms: (a) open-loop, and (b) closed-loop. (For simplicity, diagrams do not show whether functional blocks and signals are analogue or digital)**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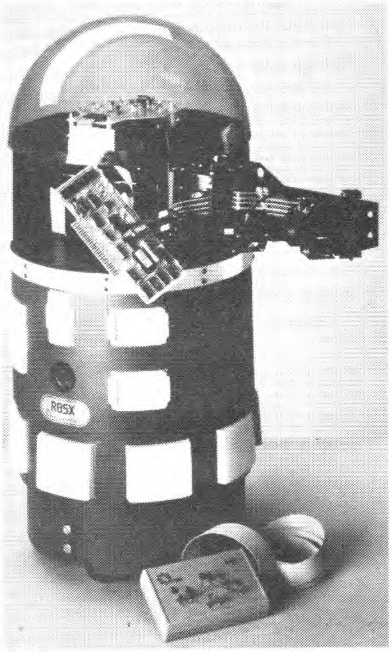
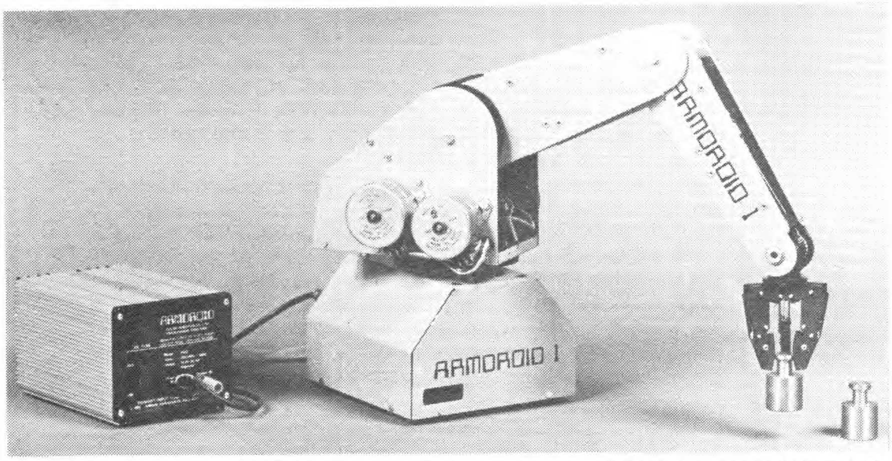
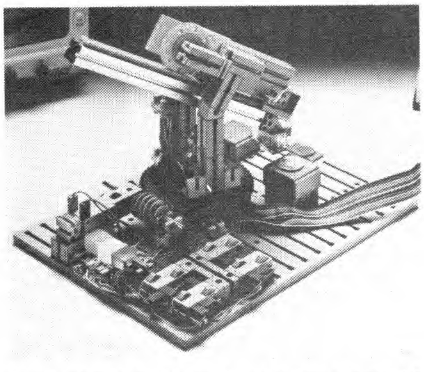


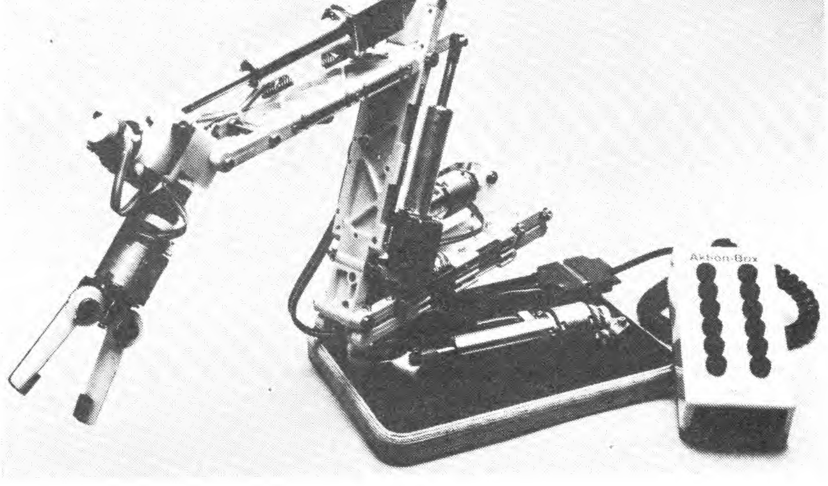

**RB5X** is a mobile robot with onboard processor (+8K RAM) which is programmed by downloading from an external computer. Its language is Tiny BASIC, and software is available which allows the mobile to learn from its environment. Other features include: Plug-in space for custom electronics boards, a sonic rangefinder for up to 10 metres, 8 tactile sensors and an ability to find its charger and recharge itself when detecting a low battery state. There is a socket for preprogrammed software modules, two RS232 interfaces, six 8-bit I/Os, a horn and flashing l.e.d.s, plus an undercarriage photodiode system. Dimensions 330mm dia., height 580mm. Optional extending arm payload 0·45kg. Other addons such as speech synthesis/recognition available. Price $2295. **R. B. Robot Corp.,** 18301 West 10th Ave., Suite 310, Golden, Colorado 80401.




**Armdroid I** has 5 axes plus 3-finger gripper (6 stepper motors with open loop control) capable of lifting 300g. Supplied with PSU and software for BBC, Commodore 64 or Spectrum, but will interface to any micro with 8-bit parallel port. Microswitches to aid positional sensing are optional. Hand-held manual control box is available. Overall dimensions: 150 × 230 × 310mm with reach of 340mm. Price £495 + VAT (assembled), £445 + VAT (kit). An alternative 2-fingered gripper is available for £35 + VAT. Colvis solid state vision system allowing 32 × 32 pixels can be added. Price £899 + VAT. **Colne Robotics Co. Ltd.,** Beaufort Rd., East Twickenham, Middx TW1 2PQ. ✆ 01-892 8197.

**Teach Robot (TR2)** is powered by 6 d.c. motors with optical shaft encoding for position sensing. It has 5 axes plus gripper, the main bearing comprising two ball races. The kit can be assembled in 6 hrs (spanners are provided). The robot may be manually activated from 'Action Box', or each motor micro driven by a Euro-board interface on a system bus allowing up to 9 boards. Vert. reach 760m, hor. reach 460mm. Prices: TR2 £185 (kit), 90-page manual £12·50, Action Box (kit) £41, 6-board interface/bus kit (without i.c.s) £180. Prices exclude VAT. **Remcon Electronics Ltd.,** PO Box 81, Chislehurst, Kent BR7 6LP. ✆ 01-467 7377.





**Fischertechnik** telescopic robot arm is one of 6 micro controlled devices that may be built using their highly educational 'Computing Kit'. Each peripheral may be broken down and reassembled as another, to make such things as a plotter, a sun-seeking solar cell and a sorting machine. The robot incorporates 2 motors with potentiometer position sensing, and an electromagnetic pickup. Available from major toy stores. Price £64·95. **Artur Fischer (UK) Ltd.,** Fischer House, 25 Newton Rd., Marlow, Bucks SL7 1JY. ✆ Marlow 72882.

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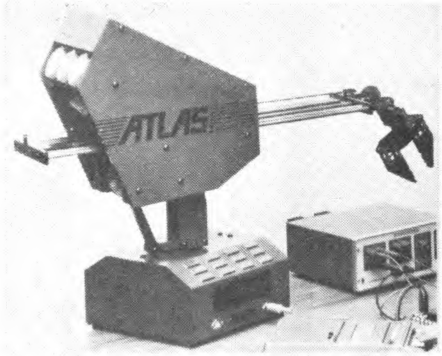
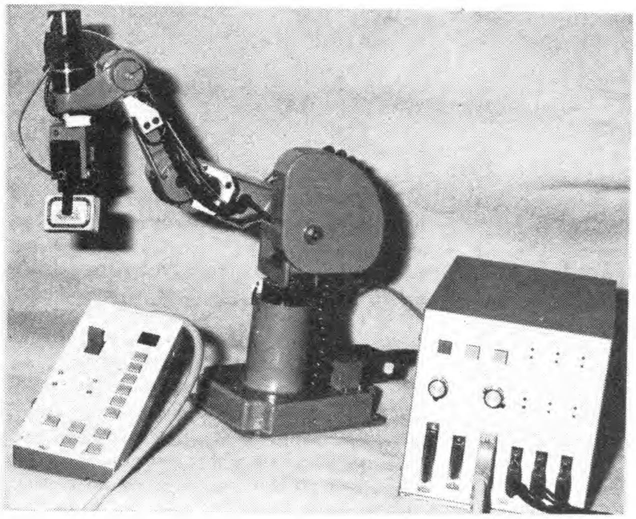
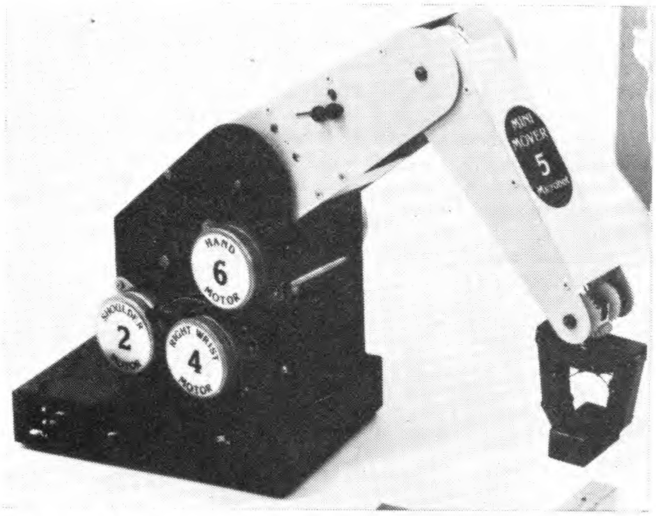
## SMALL ROBOTS



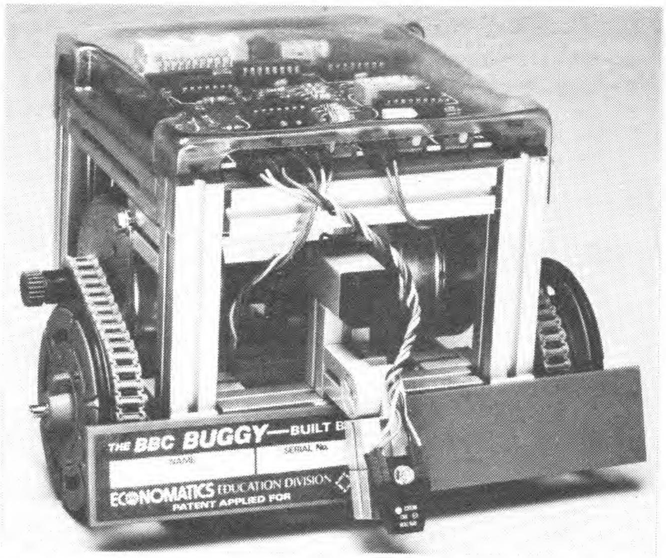

**Atlas** is a self-contained stepper motor driven robot with onboard micro. It has 5 axes plus one supplementary function. The teaching console provides automatic editing. The robot is readily dismantled to allow students to study its mechanisms. Maximum payload is 1kg, Resolution better than 0·1mm and repeatability better than 1mm @ full load. Price £1,950. Test & Diagnosis module £250 (kit). **L. J. Electronics Ltd.,** Francis Way, Bowthorpe Industrial Estate, Norwich NR5 9JA. ✆ 0603 748001.



**Teach Mover** has 5 axes of movement (plus gripper) using stepper motors with open loop control. This unit has been specifically designed to simulate industrial robot operations in the laboratory or classroom; it has an on-board microprocessor. Via the teach control unit an operator can put together complex routines by positioning the arm with the various keys and pressing the 'Record' key. Up to 53 positions can be recorded in this way. An auxiliary 12V/4A power supply is required (£170). The price, £2,280, includes teach control unit, user manual and Apple II software package. Accessories include an experimenter's kit. **Syke Instrumentation Co. Ltd.,** Syke House, 117/119 Station Road, Liss, Hants. GU3 7AJ. ✆ 0730 893821.

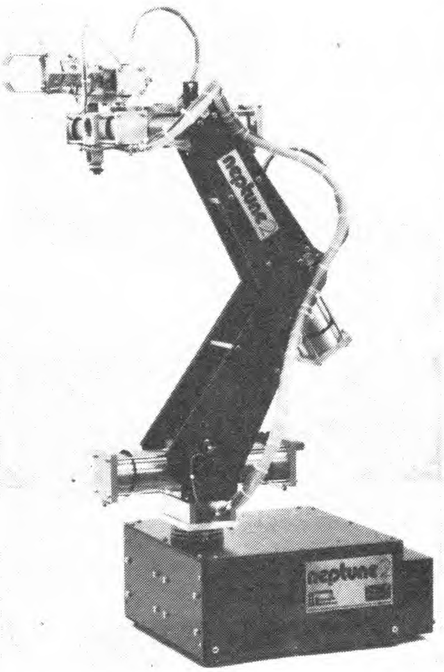



**Minimover** has 5 axes of movement using stepper motors with open loop control, it has an 'intelligent' gripper that can sense if it is holding something and judge its size to within 1·5mm. Will interface directly to Apple II, TRS 80 and Pet computers or any 8 bit parallel port machine. Max. payload at full extension is 445g. Auxiliary power supply required, 12V, 4A, from manufacturer, £130. Robot price £1788 including cable and user manual (prices exc. VAT). Accessories available include; Reference and applications manual; Pneumatic gripper (two finger) with mount adaptor kit; Pneumatic accessory kit with 4-way valve and speed control; Also various software packages. **Syke Instrumentation Co. Ltd.,** Syke House, 117/119 Station Road, Liss, Hants. GU33 7AJ. ✆ 0730 893821.

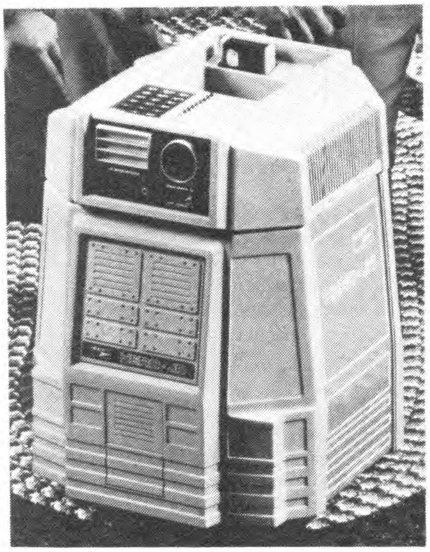



**BBC Buggy** kit is based on modular Fischer Technik parts, prewired stepper motors and assembled circuit boards, and may be modified during experimentation. Only a screwdriver is required for assembly. Interfaces are available for Spectrum and RML (Commodore 64 in pipeline) which include onboard ADC and 7-seg. display of control lines status. The Buggy accommodates a full range of sensors and is sold with a 13 program cassette. These are: *Test & Familiarisation, Switch* (direct computer control), *Memory Switch, Recorder* (route display), *Snail* (screen route planning), *Routeplanner, Bar Code Routeplanner, Explore* (seeks out object, defines its shape and returns to base), *Explore Wall* (maps boundaries), *Sunseeker* (maze lightfinder), *Man vs Buggy, Line Follower,* and *Tin Pan Alley* (composing music by barcode). A 'Grab Arm' is available. Price (BBC version £164·35 + VAT. **Economatics (Education) Ltd.,** Epic House, 9 Orgreave Rd., Sheffield S13 9LQ. ✆ 0742 690801.

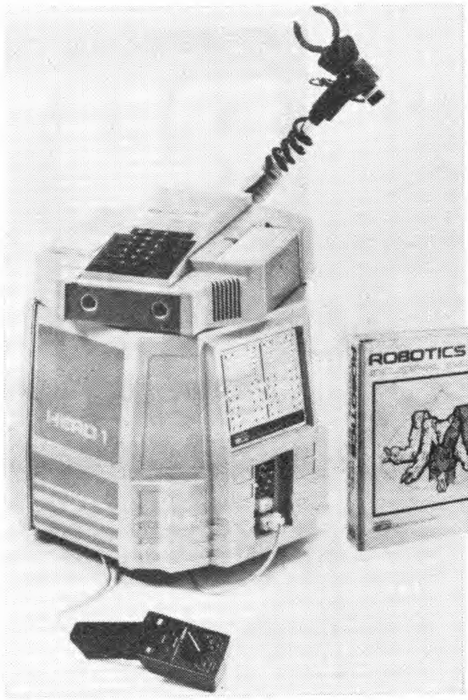
# BUYER'S GUIDE... SMALL ROBOTS



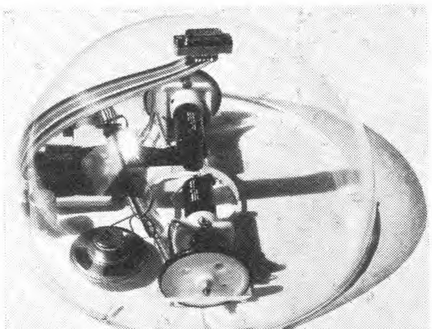

**Neptune Models I and II** (currently published in Practical Electronics) are electro-hydraulically powered robots. Neptune I has 6 servo-controlled axis movements and Neptune II has 7. These systems use water as the hydraulic medium; they are sold in kit form. Assembly time is minimised by the use of a preformed wiring loom, pre-assembled and tested electronics and pre-assembled cylinders which are leak-proof and incorporate inertial compensation. Suitable for the BBC, VIC 20 and Spectrum computers, Neptune I has 8-bit control and II has 12-bit control. Both robots are, with ADC option, controllable via a hand-held simulator (£45/£52). Maximum payload is 2·5kg. Prices: Neptune I: £1,732·50 including ready-built control electronics (optional), Neptune II: £2,530 including ready-built control electroncs (optional). ADC option £109; ready-built hydraulic power pack £500; gripper sensor £43; optional three-fingered gripper £86; connector leads extra. **Cybernetic Applications,** Portway Trading Estate, Andover, Hants. SP10 3PR. ✆ 0264 50093.



**Hero Junior** is fashioned visually on Hero 1 but intended for domestic and entertainment use. It can sing, recite poetry, follow human beings around, and wake up its owner in the morning with a personalised alarm, detecting whether or not the reposer has stirred before taking appropriate action. Battery life is 4-6 hours. Hero JR can patrol a security round and activate the Heath burglar alarm upon detecting an intruder. Unfortunately, this and other wireless features are not suitable for use in the UK. A range of cartridges give JR a choice of personalities to suit situations, e.g. games and songs for a party, quizes for education etc. JR has no arm. Price £499·95 (kit); £999·95 (assembled). **Maplin Electronic Supplies.**



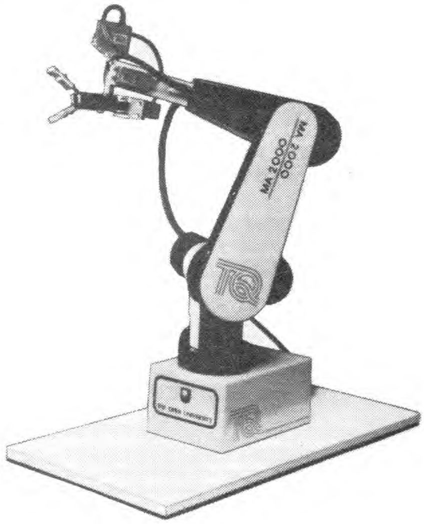

**Hero 1 (ETW-18)** is a mobile incorporating an extending arm (up to 127mm) plus a further 3 axes and gripper. The head rotates 350° to position the arm and sensors, the entire machine being powered by 8 motors, 7 of which are steppers. An optical encoder measures distance travelled, and there is a breadboard for experimental circuits. Also includes: Voice synthesiser, ultrasonic motion detector, sound detector, light detector, 7-seg. display and keyboard for program entry, ultrasonic rangefinder, cassette interface, realtime clock/calendar, battery charger, and a teaching pendant which provides an easy way to program movements. Includes 1200 page robotics course. Price £1,995 + VAT & p.p. Available ready-built from **Zenith Data Systems Ltd.,** Bristol Rd., Gloucester GL2 6EE. ✆ 0452 29451. Available in kit (ETS-18) from **Maplin** (see advertisers' Index). Price £999·95.



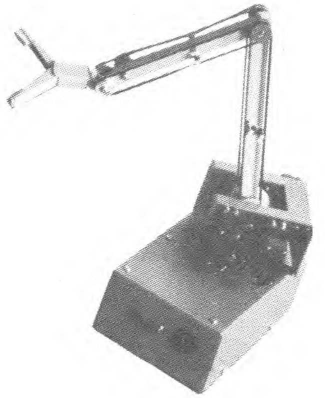
**Edinburgh Turtle** is a production version of that produced by the a.i. department of Edinburgh University. It may be programmed to move a fixed distance in any direction, or to turn a specific number of degrees. Incorporates a retractable pen, which, using the language LOGO may be used to draw shapes and remember how to do it again in the future. Two types available: TURTLE-SERI with serial interface, PSU and EPROM for use with any micro, and TURTLE-PARA in which a specific interface for the micro used is supplied. In the latter, disc or cassette software is downloaded. **RC4** Turtle does not require a cable link because it has an onboard rechargeable battery, and communicates via a two-way radio control link. Therefore its movements are not restricted, and additional sensors can feed data back to the micro. Prices: Edinburgh Turtle £350 (SERI), circa £170 (PARA). RC4 £175. To all prices add p&p and VAT. **Jessop Microelectronics Ltd.,** Unit 5, 7 Long St., London E2 8HN. ✆ 01-739 3232.

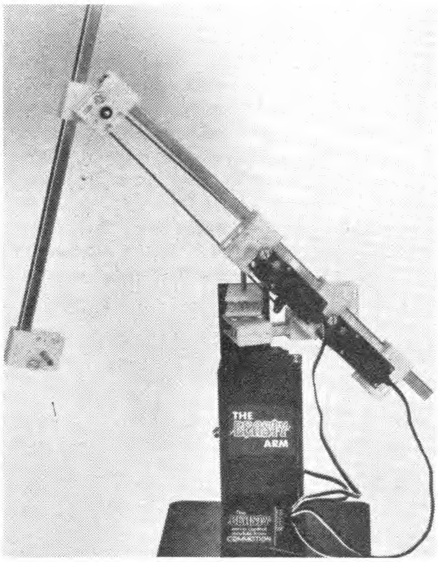
# BUYER'S GUIDE... SMALL ROBOTS

**MA2000** Open University robot has 6 axes, powered by d.c. servo motors, plus a pneumatic gripper (for which a compressed air cylinder, or compressor is required). Supplied in wooden case which converts into operating base, keypad, and controller interface for BBC Model B and the University's Hektor micro. Software (partly BASIC) enables 3 alternative movement programming methods. Experiment kit also available. Arm reach is 500mm, payload 1kg. Price to be announced. **TecQuipment International Ltd.,** Bonsall St., Long Eaton, Notts NG10 2AN. ✆0602 722611.



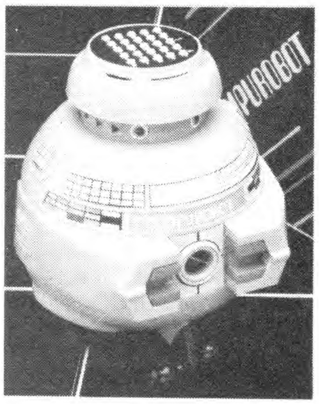

**Alfred** (featured currently in Everyday Electronics) is powered by six servomotors, five of which provide axis control, and one of which is mounted on the forearm (but not shown in photo) to control the gripper. Power is transmitted along the plastic arm by toothed belts, producing a highly articulate arm using simple components. Alfred interfaces to any micro with an 8-bit I/O port, and requires a 12V/2·5A PSU. The arm heralds a range of peripherals including vision and mobile base. Software includes simulated pendant. Arm reach is 380mm, payload 170g. Price £140 + VAT. Available from Robot City Technology, 20 Burners Lane, Kiln Farm, Milton Keynes MK11 3AU. ✆ 0234 750120.

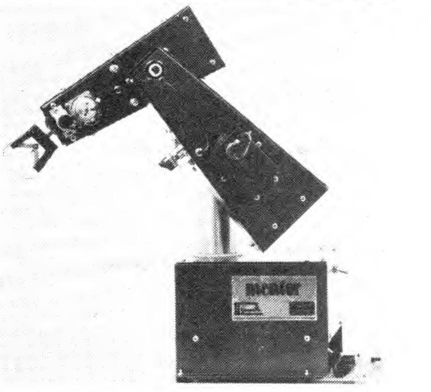





**NOTE:** Prices were correct at time of going to press, but in many cases should only be considered as a guide. The supplement heading picture shows a robot made by ASEA Ltd., spot welding SAAB motor cars.

**Beasty Arm** is powered by 3 radio control type servomotors using the well known 'Beasty'—a matchbox sized motor controller which communicates with a BBC micro serially (theoretically allowing optical, and even radio link-ups). The standard arm uses a hook, although a gripper can be added. Arm lengths, joint leverages etc. are selectable, facilitating custom design. Software supplied on cassette is ROBOL which is a simple control language. Price £110 (basic configuration). Also available: EV1 Electronic Vision of 128 × 256 pixels scanned in 0·05 secs. Price £129·95. Beasty Mobile Base is a caterpillar vehicle measuring 360 × 304 × 225mm high, capable of conveying a 6·5kg load over rugged terrain at up to 5 m.p.h. Price £60. **Commotion,** 241 Green Street, Enfield, Middlesex EN3 7SJ. ✆01-804 1378.

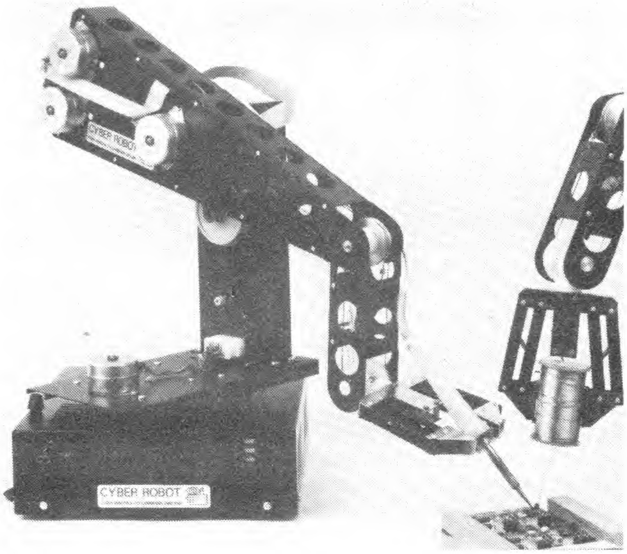


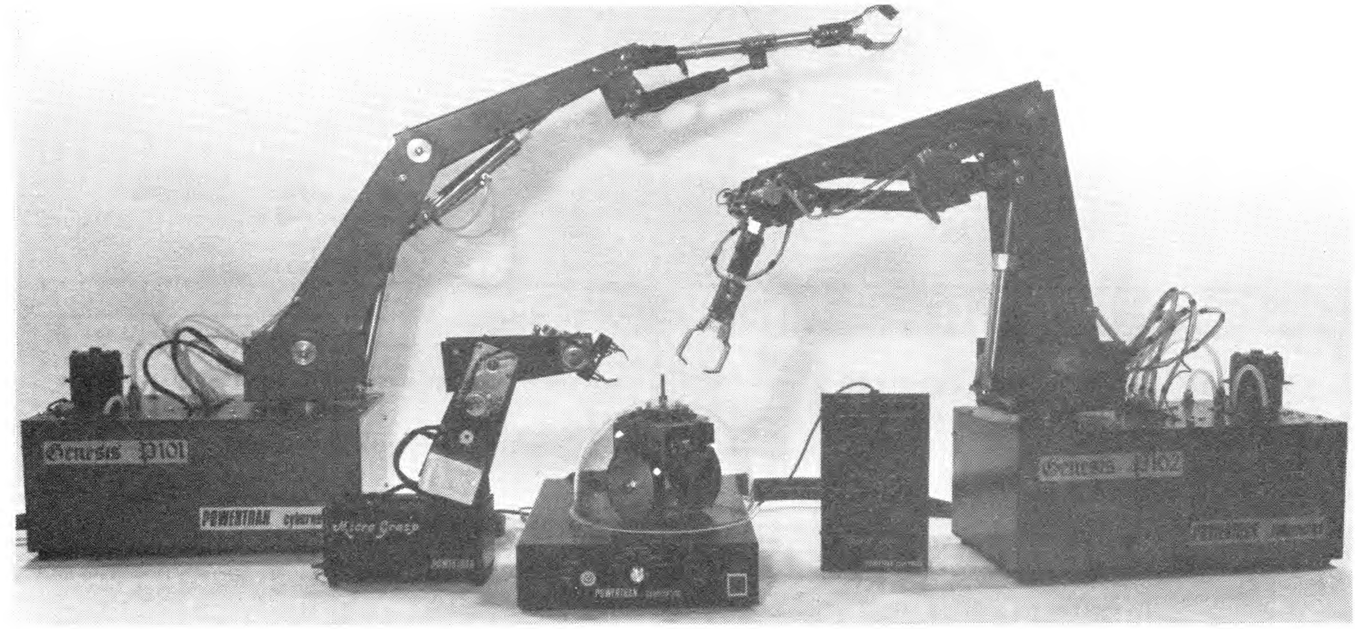
**Mentor** has 6 axes of movement, simultaneously servo controlled. Features integral control electronics and power supply, long life bronze and nylon bearings and inertial compensation circuitry. Optional ADC (on-board) available, also hand-held simulator. Suitable for use with the BBC, VIC 20 and Spectrum computers using BASIC. Mentor is supplied as a kit with ready-built control electronics (optional). Price £552. ADC option £22·50; Simulator (requires ADC option) £48; prices include VAT. Connector leads extra. **Cybernetic Applications,** Portway Trading Estate, Andover, Hants. SP10 3PR. ✆ 0264 50093.

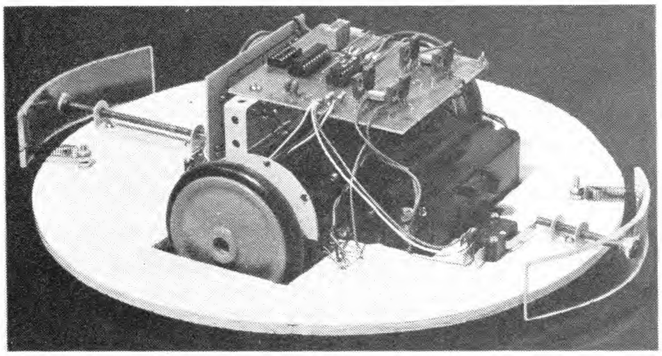
**George** can be programmed with up to 48 steps, and will go forwards, backwards, hold, turn, or curve left, or right, and retract. He has 3 speeds and 9 time intervals, and incorporates a light beam and sounder. A demo' program is provided. George is 168mm high. Price £23·95. Available through retail outlets. **Computer Games Ltd.,** CGL House, Goldings Hill, Loughton, Essex IG10 2RR. ✆ 01-508 5600.

# BUYER'S GUIDE... SMALL ROBOTS




**Cyber 310** has 5 degrees of movement with a programmable gripper (6 stepper motors) and a maximum payload of 250g. It has the rare ability to rotate the shoulder through 300 degrees in the vertical plane to operate on the opposite side with the arm upside down. Ideal for use with BBC micro or 8 bit parallel (centronics) ports; uses ROBOFORT (extension of FORTH) learning system, sub-routines in BASIC (non-learning). Price £772·50. Includes ROBOFORTH software, cable, step by step tutorial. Application software available (£230)—the core of the package is Cartesian co-ordinates (x,y,z,); Cylindrical polar co-ordinates (distance, height plus angle); this (three in one) package allows movement by describing a position in space and the approach angle of the gripper. Also includes Towers of Hanoi using real disks. **Cyber Robotics Ltd.,** 1 Ditton Walk, Cambridge CB5 8QD. ✆0223 210675.



**EE Buggy** (published in Everyday Electronics May 1984) uses a twin motorised gearbox with magnetic clutch. Optoelectronics feedback provides closed loop control, along with 2 collision detectors. For use with micros having 8-bit user port. Price £37 (excluding p.c.b.s which are available from the EE PCB Service). **Greenweld,** 443 Millbrook Rd., Southampton SO1 0HX. ✆ 0703 772501.

**Genesis series: P102** is a hydraulic anthropomorphic arm with 5 axes plus gripper capable of a 3lb payload. It has double-acting cylinders with inductive positional feedback, and 2-speed operation. Dedicated 6802 control box offers 8 programmable sequences of up to 64 steps, but allows greater sophistication by way of an RS232 link to an external computer. 4K of non-volatile memory is incorporated. Price £1,476 + VAT.

**P101** is a simplified version with single-acting cylinders, and 2K of non-volatile memory (8 programmable sequences of up to 32 steps). Price £1,050 + VAT.

**Micrograsp** (also shown in the photograph) is a motor-driven arm of 4 axes plus gripper. Potentiometers provide positional sensing. Can be driven from almost any micro (ZX81 especially) using the interface board supplied. Construction is basic with all those parts subject to wear readily replaced. Price £272 + VAT.

**Hebot II** (shown above) is a turtle type robot featuring independent 2-wheel drive, collision detectors, retractable pen, flashing eyes and a horn. Supplied with this is a universal interface board. Price £95 + VAT.

All these robots are available in kit form from **Powertran Cybernetics Ltd.,** Portway Industrial Estate, Andover, Hants SP10 3BR. ✆0264 64455.

**HRA934** is a ready-built version of P102 (with improved interface). Price £2,726 + VAT. Available from **Feedback Instruments,** Park Rd., Crowborough, Sussex TN6 2QR. ✆08926 3322.

# BUYER'S GUIDE... SMALL ROBOTS

**Movit** Mini Robots range comprises 5 battery powered machines (shown in order).

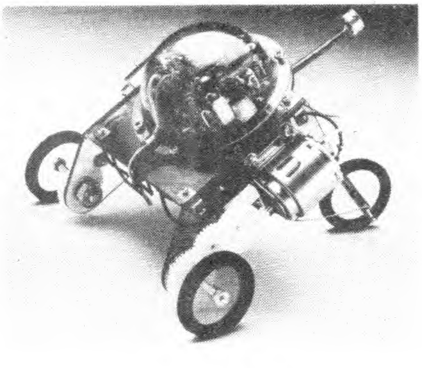
**MV913 Line Tracer** is guided along a line by an infra-red sensor. It has 3 wheels driven by 2 d.c. motors. Price £17·99.

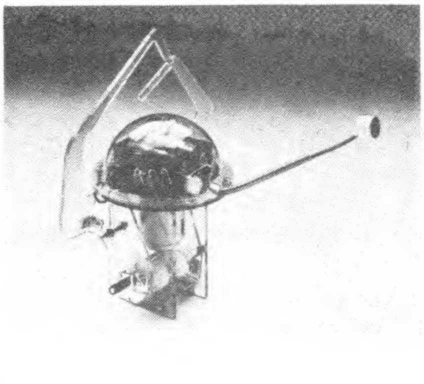
**MV915 Piper Mouse** uses a sound sensor to follow instructions issued by its owner using a whistle. Has 3 wheels driven by 2 d.c. motors. Price £19·99.

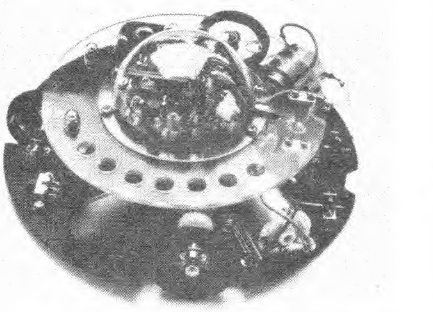
**MV918 Memocon Crawler** contains RAM to remember and follow instructions entered through a keyboard. Has 3 wheels driven by 2 d.c. motors. Price £34·99.

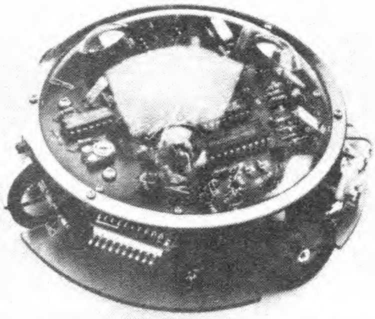
**MN919 Monkey** romps along a tightrope, activated by a clap of the hands, or other fragor. Driven by 2 cranked gripper arms. Price £9·99.

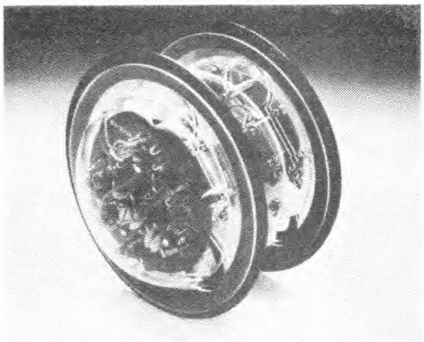
**MN935 Circular** is controlled using a hand held unit, and can wheel around the floor in any direction, or turn on the spot. Has 2 wheels driven by 2 d.c. motors. Price £29·99.





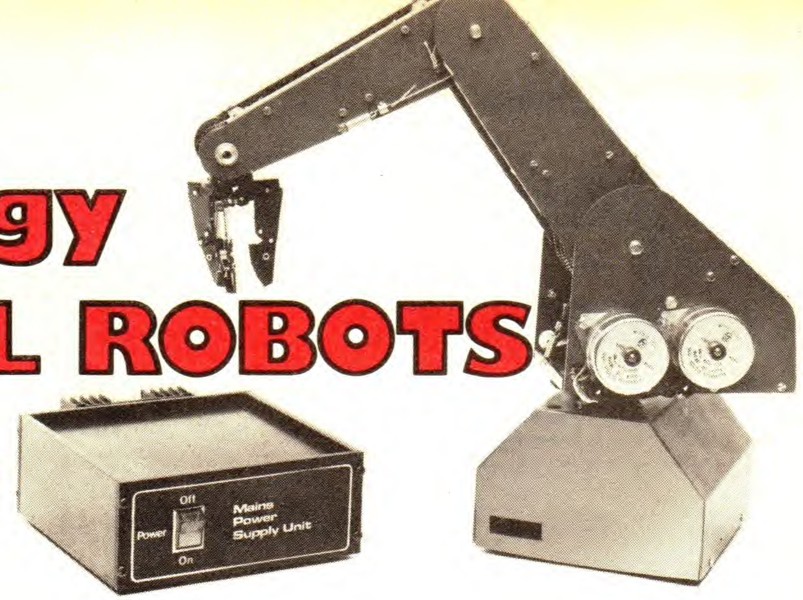






**Prism Micro Products Ltd.**, Prism House, 18-29 Mora St., City Rd., London EC1V 8BT. ✆01-253 2277. Movits are available through High Street hobby and toy stores.

# The Technology of SMALL ROBOTS




**Tom Ivall**

ALTHOUGH the small educational and personal robots are somewhat crude in mechanical design compared with their industrial big brothers, in another respect they are more advanced. Programming by software, and all the operational flexibility it provides, came rather late in the day to industrial robots—when minicomputers and microcomputers eventually arrived in the factory. With the small educational and personal robots it was the other way round.

The means of programming by software—microprocessors and microcomputers with their associated programming languages—already existed in some abundance and variety before the small robots were even thought of. In fact it was the electronics and software that really sparked the mechanics of these devices into existence.

A generalised schematic of a personal or educational robot is shown in Fig. 1. The technology is similar in principle to that of the industrial programmable controller used for sequence control of machines or processes. Such a system can be broken down, as shown, into three main functions: a stored, alterable program, a control section, and whatever device is being actuated (in this case a machine under position control).

To make a single-arm robot perform a required task—say picking up an object, moving it to another place and putting it down there—the various mechanical members of the articulated arm have to be moved through sequences of positions in space. So the electric motors or low-power hydraulic cylinders that drive these members, rotating them about the various joint pivots, have to produce related sequences of angular or linear positions at their drive shafts or rods (depending on the gearing, transmission etc).

In turn this means that the drive motors or cylinders must be energised for specific durations and at specific times throughout the task. The electric or hydraulic power is switched to them in the required pattern by a control system—typically by switching semiconductor power amplifiers on and off.

The power switching is controlled by electrical signals and these in turn are initiated by data from a stored software program. Usually this program is held in one or more semiconductor memory chips. Part of the total storage capacity is a programmable memory, usually a RAM: this holds the user's application programs, which can be loaded and changed as required.

The remaining storage capacity is used for necessary firmware: a permanent (ROM) or semi-permanent (EPROM or RAM) memory holding an internal system program—called an operating system by some manufacturers—which allows the applications software to be conveniently run on a particular arrangement of robot hardware. This internal 'managerial' firmware is, of course, dictated by the design of the robot system's fixed hardware.

In software terms the applications and internal system programs are stored lists of position-control instructions. Electrically they are spatial patterns of binary states in the bit cells of the memory chips. They are written into and read out of memory under the control of a microprocessor. When read out to perform their position-control functions, the static bits become a stream of digital data, which passes out of the 'Program' block in Fig. 1 via a serial or parallel input/output channel.

At this point the program instructions are in binary code, typically a sequence of 8-bit bytes. They therefore have to be decoded to form the switching signals, and this is done in the 'Control' block of the Fig. 1 schematic.

As systems, the small robots now on the market can be divided into two groups. In the first group, the 'Program' digital storage and processing section of Fig. 1 is built into the equipment by the manufacturer, along with the 'Control' section and mechanisms. The programmable part of the memory might be a small capacity RAM (say 8K) and the microprocessor a 6502 chip. Also provided is a purpose-designed control box or keyboard.

In the second group of products, the 'Program' section in Fig. 1 is not built into the robot but has to be provided by the user as an external home or personal computer, as indicated in the diagram.

The important difference between them is this. In the first group of robots, the detailed control and co-ordination of the arm positioning is taken care of automatically by the internal system program, or operating system, stored as firmware. This allows the whole robot to be controlled by a comparatively simple steering keyboard, the keys directly commanding the five or six arm joints to rotate in one direction or the other.

In the second group, however, this system program is not provided as built-in firmware. The user can write it himself by analysis of the whole robot control system, perhaps using machine code, then place it in the home computer's RAM via the computer keyboard. Or he can make use of software already prepared by the robot manufacturer on magnetic disk or cassette and load this into his computer. Such prepared software uses versions of existing programming languages such as BASIC and FORTH.

Fig. 1 and the preceding discussion merely outline the general character of these small robot systems. But when examined in detail the products on the market reveal a bewildering variety of

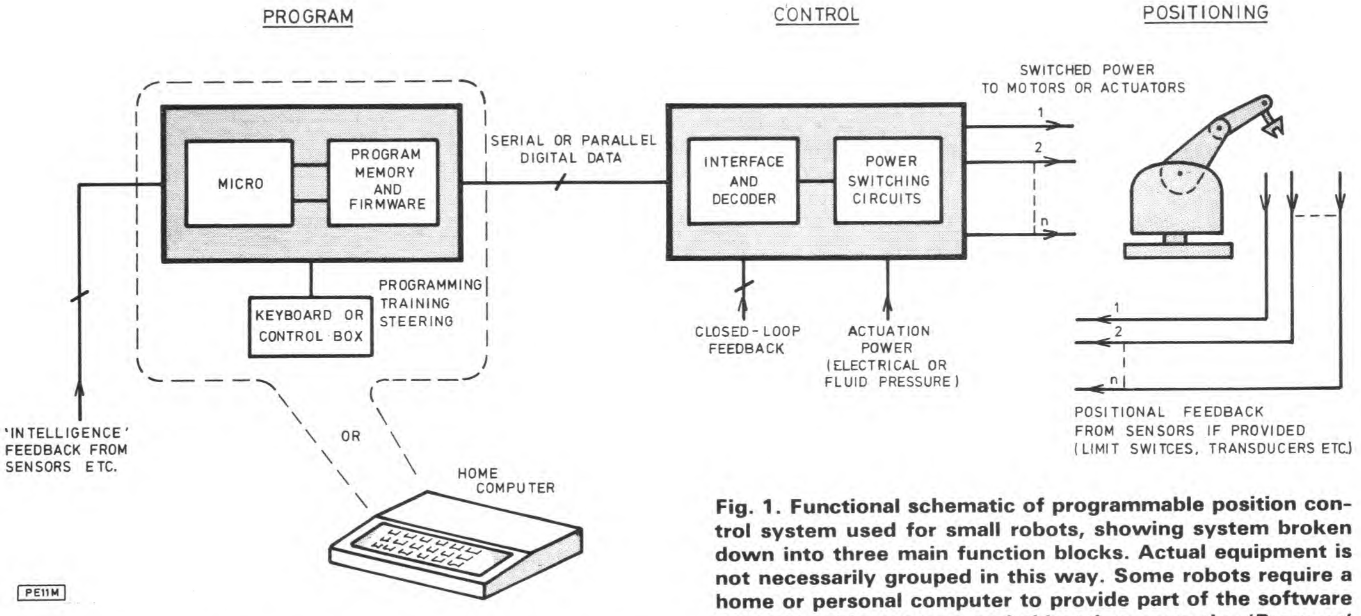



**Fig. 1. Functional schematic of programmable position control system used for small robots, showing system broken down into three main function blocks. Actual equipment is not necessarily grouped in this way. Some robots require a home or personal computer to provide part of the software programmable system, and this takes over the 'Program' functional block as shown**

physical shapes and sizes, design techniques, performance levels, facilities and prices. To get a grasp of what is going on in this technology you have to mentally take the products to pieces and look at the individual parts in some detail. This is what we are doing in the rest of the article.

It's more helpful to divide these robot systems into their functional parts, rather than into the actual pieces of equipment which house them as commercial products. These functional parts are: (1) the mechanical structure of the articulated arm; (2) the drive system, including the electric motors or hydraulic actuators, gearing and transmission; (3) the control system for these drives, including conversion of digital data into control signals; and (4) the software programming and its associated hardware. Let's look at them in turn.

## MECHANICAL STRUCTURE OF ARM

As outlined in the previous article, the articulated single arm consists of five main members, corresponding to the human trunk, upper arm, forearm, hand and (rudimentary) fingers. The vertical 'trunk' part rotates through about 360° at the 'waist', pivoting on a base unit intended to stand on a table. These general features can be seen from Fig. 1 in the previous article.

The extension members are jointed at pivots which allow rotation in one plane at any given point in the arm (e.g. forearm rotation relative to the upper arm, at the elbow). At the wrist, however, a more complex double pivoting arrangement, usually based on a differential gear, allows rotation of the hand in two planes relative to the forearm carrying it.

One axis allows the hand to pivot as in bending the wrist to wave good-bye (called pitch). The other allows the hand to rotate axially, as in using a screwdriver (called roll)—even when the wrist is well bent, which is more than human anatomy can do (try it!).

The wrist differential gear has two input bevel gears driven by separate motors and a planetary output bevel gear which moves the hand in the two ways described. When the two input gears are rotated equal angular distances in opposite directions, the output gear simply rotates on its own axis, producing the 'roll' wrist rotation. When the two input gears are rotated in the same direction through a given angular distance, the output gear moves as a whole in planetary fashion round the input gears (without axial rotation) producing the 'pitch' motion, up or down according to the input drive direction.

At the extremity of the articulated arm the rudimentary 'fingers' take the form of grippers, which can be closed and opened to grasp and release objects. These are short members on pivots corresponding to 'knuckles': a pair for gripping square objects or three for gripping round objects.

In the manufacturers' literature, the versatility of the arm for manipulation is specified as the number of joints at which distinct rotations are possible (e.g. forearm relative to upper arm) in the articulation system. This is expressed as a number (typically 5 or 6) of 'degrees of freedom', or 'degrees of motion' or 'axes of rotation' or 'axes of movement'.

Don't be confused by these different terms: they all mean the same thing. ('Degrees of freedom', a term borrowed from physics and chemistry, is particularly unfortunate because it has nothing to do with the *angular* degrees of rotation at the joints but might be thought to mean this.)

But the mechanical versatility of the structure also depends on the angular distances through which the various members can be rotated, so these figures should be studied in the literature as well.

## DRIVE SYSTEMS

The extension members of the articulated arm are rotated on their joint pivots in a variety of ways. In the electrically driven robots, the motors are either mounted directly on the various members, at or near the joints, or some distance away—usually in the 'trunk'—transmitting their drive to the joints by arrangements of cables and drums or toothed plastic belts and gear wheels.

The second, remote method has a double advantage. It does not have to lift the weight of the motors added to that of the arm members, and it keeps the centre of gravity low so that the robot doesn't have a tendency to topple over.

Gearing down is used in all arrangements, both to reduce the motor shaft speed to the comparatively slow rotation required at the joints and to obtain the necessary torque or force at the joints. This is done by direct meshing of metal or plastic gear wheels, by cables and drums or by belt drive gearing, depending on the transmission requirements of the structure.

In the hydraulically operated robots, the arm members are rotated about the pivots by lever action given by low-pressure hydraulic cylinders coupled between pairs of members (for example between upper arm and forearm to give elbow movement). The cylinders provide a linear thrust. To obtain the two directions of motion required for 'push' and 'pull' at a given joint, either a spring-return cylinder or a double-acting cylinder must be used. In some parts of the arm mechanism the linear motion of the cylinder is converted into rotary motion by a rack-and-pinion system.

Some electrically operated robot arms use d.c. motors in closed-loop systems (see Fig. 2(b) in previous article) for position control. But many of the products use stepping motors, of the low-cost kind mass-produced for video recorders.

In broad principle the stepping motor is rather like an a.c. synchronous motor, in so far as the angular movement is locked to pulses of current. In the synchronous motor these current pulses are half-cycles of a.c. and arrive repetitively from the mains to produce continuous rotation. In the stepping motor they are square pulses (switched d.c.) which can be sent to the motor singly, whenever required, to produce discrete steps of angular motion.

For example, in one widely used stepping motor each incremental pulse fed to the windings results in a precise angular movement of $7\frac{1}{2}$ degrees. Thus 48 steps are needed to complete 360 degrees of rotation. So a known number of current pulses fed into a stepping motor will result in a known angular displacement. In conjunction with a known gear ratio between the motor and the arm mechanism, this offers a very precise means of position control.

Most of these stepping motors are four-phase types. They have four stator windings and the rotor is moved round, one step at a time, by applying current pulses to the windings in a cycle of events as shown in Fig. 2, with a 90 degrees phase difference between successive pulses. So the complete 360 degrees electrical cycle is made up of 4 × 90 degrees.

Different methods of drive are chosen to meet particular product design requirements. The main considerations are performance, cost, size and operational convenience. For example, the stepping motors in common use are chosen because they are cheap, they suit the pulse type of output given by digital electronic systems, and their incremental action allows precise positioning without the extra complexity and cost of closed-loop control systems.

Their main disadvantages are their limited torque (typically 85mNm holding torque), which restricts the load handling capacity of the robot, and their vulnerability to slip, which affects positional accuracy. In addition, to remain stationary in order to hold a given arm position they need continuous application of electric power—which can make them get rather warm.

Hydraulic cylinders are chosen because, for a given force output, they are more compact than the majority of electric motors. Consequently for a given size of robot they can drive larger loads than electric motors can. This is because the mechanical power (fluid pressure) is supplied directly to the actuator, whereas an electric motor has to include an electromagnetic system to convert electricity to mechanical power.

For linear movements the hydraulic actuator is faster than the (rotary) electric motor. To hold a static position under heavy load the cylinder requires no consumption of power at all: the piston simply rests on a stationary volume of virtually incompressible fluid shut into the cylinder by a valve.

One disadvantage of the hydraulic cylinder is that it needs a closed-loop system for accurate position control. An hydraulic system also needs a central motor driven hydraulic pump to provide the necessary fluid pressure, whereas electric motors receive their electric power directly without conversion. Finally, hydraulic connections and other components may prove rather messy if they leak.

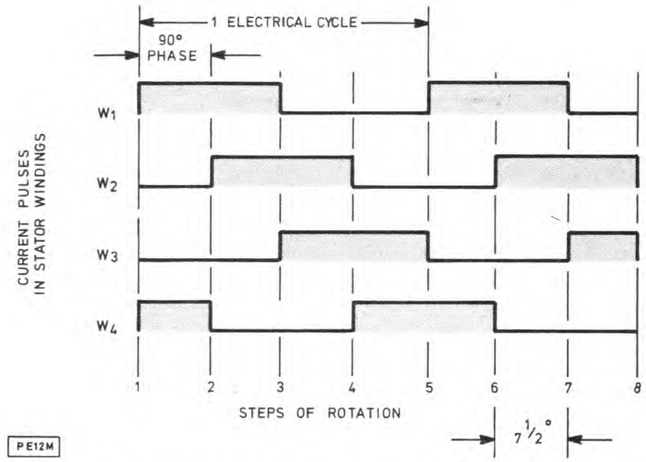



**Fig. 2. Energising current pulses applied to the windings, $W_1$ to $W_4$, of a four-phase stepping motor, showing phase relationships between pulse sequences for steady incremental rotation in $7\frac{1}{2}$° steps**

## CONTROL SYSTEMS

The purpose of the 'Control' block in Fig. 1 is to control the energisation of the various drive motors or actuators in accordance with a sequence of positioning commands coming from the 'Program' section. These commands arrive as binary coded data, typically a stream of 8-bit parallel bytes output from a parallel interface unit (PIU).

Position control systems in small educational and personal robots follow the general principles of those in large-scale industrial robots. Both open-loop and closed-loop systems are employed (see previous article). Open-loop systems (Fig. 2(a) in previous article) are widely used in the small robots because they are simpler and in principle cheaper to manufacture than closed-loop systems. Perhaps a more important reason is that they can take advantage of stepping motors as very convenient positioning devices which can be directly driven from digital signals (see 'Drive' section).

Here the task of the open-loop control system is to take the binary coded position commands from the program memory and convert them into pulses of current to drive the stepping motors. The general method shown in Fig. 3 is used in several small robots.

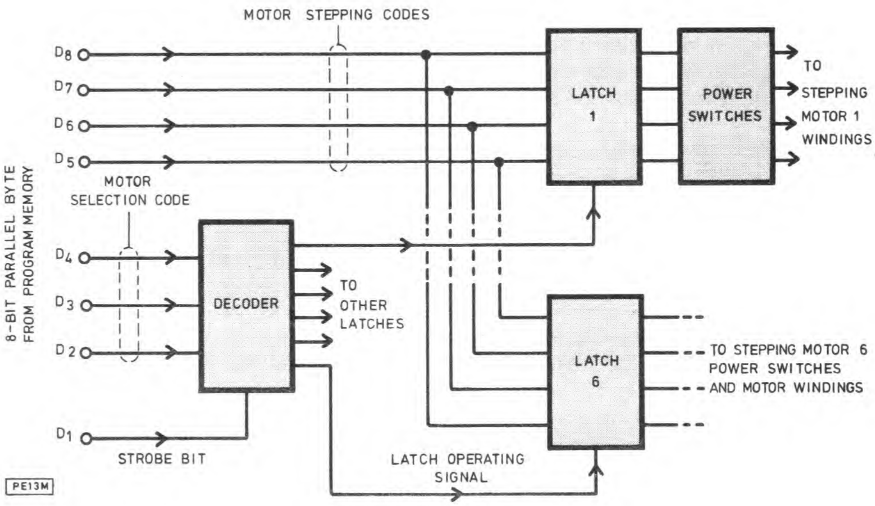
Encoded position-control data arrives as 8-bit parallel bytes on lines $D_1$ to $D_8$. Each 8-bit byte contains three distinct groups of information. $D_2$ to $D_4$ is a three-bit code which tells the control system which one of the six stepping motors to select. $D_5$ to $D_8$ is a four-bit code which causes the selected motor to be stepped round a required number of steps. Finally, $D_1$ provides a one-bit strobe pulse (logic 0 or 1) which causes the selected motor to receive the stepping code then present on $D_5$–$D_8$.

The $D_2$–$D_4$ motor selection code is decoded in an i.c. which produces a signal on one of six lines to bring in one of the six motor circuits. The general form of the decoding process is like this:

| $D_4$ | $D_3$ | $D_2$ | Motor selected | Joint driven |
|---|---|---|---|---|
| 0 | 0 | 1 | 1 | Gripper |
| 0 | 1 | 0 | 2 | Wrist roll |
| 0 | 1 | 1 | 3 | Wrist pitch |
| 1 | 0 | 0 | 4 | Elbow |
| 1 | 0 | 1 | 5 | Shoulder |
| 1 | 1 | 0 | 6 | Waist |

Stepping-code bits $D_2$ to $D_8$ are fed simultaneously in parallel to six i.c. latches for the six motors. For each 8-bit input byte arriving, the decoder emits a control signal which causes one of

**Fig. 3. Simplified version of system used to actuate stepping motors in open-loop position control systems. Input 8-bit parallel codes from the Fig. 1 'Program' block are the positioning commands, and are translated into switching signals which select and energise the four-phase stepping motors**




| $D_8$ | $D_7$ | $D_6$ | $D_5$ | Step | Angular movement |
|---|---|---|---|---|---|
| 0 | 0 | 1 | 1 | 1 | $7\frac{1}{2}°$ |
| 0 | 1 | 1 | 0 | 2 | 15° |
| 1 | 1 | 0 | 0 | 3 | $22\frac{1}{2}°$ |
| 1 | 0 | 0 | 1 | 4 | 30° |
| 0 | 0 | 1 | 1 | Repeat | $37\frac{1}{2}°$ |
| etc. | | | | etc. | etc. |

these six latches to hold the stepping code and apply it through power switches to the windings of the corresponding motor. This occurs if the decoder has received the appropriate strobe pulse from $D_1$. If the motor turns in $7\frac{1}{2}$ degree steps, the stepping code could operate in the following manner:

In closed-loop position control (Fig. 2(b) in previous article) the drive electric motors or hydraulic actuators operate continuously until the sensed 'actual position' equals the commanded 'desired position' and then stop. For electrically operated robots, d.c. motors are used. In hydraulically operated robots the hydraulic cylinders are energised by fluid under pressure (oil or water) which is switched to them by solenoid valves controlled by on/off electrical signals.

Whatever the type of drive, the system needs a transducer to continuously sense the actual angular or linear position reached by the output shaft or rod. With d.c. motor drive the transducer is usually a potentiometer, the wiper terminal giving a d.c. voltage proportional to the angular position of the control spindle. This voltage is the 'actual position' signal which is compared with the 'desired position' signal to generate an error signal in the closed-loop system.

In hydraulically operated robots, some models use an inductive transducer, a linear variable differential transformer (LVDT). This takes the form of a cylinder holding inductively coupled primary and secondary coils, and this structure slides over the hydraulic cylinder as a whole. Fed with an audio frequency a.c. voltage, it senses the position of the cylinder's piston because this metal component acts as a moving core within the transformer coils and so alters the flux linkages and inductive coupling between the primary and secondary windings.

The a.c. output signals of all the LVDT transducers are rectified to give d.c. voltages (typically in a 20-50mV range) which are proportional to the positions of the pistons and hence cylinder output rods. In one model these d.c. voltages are sampled repetitively at a rate of 200kHz and thus multiplexed for the whole robot arm. The multiplexed voltage signals are then fed to an A to D converter, which converts each analogue value into an 8-bit code, thus giving a resolution of 1 part in 256 for each position measured in this way.

Some closed-loop position control systems include refinements such as two-speed movement or three-term control to improve the dynamic performance of the system and its ability to match the requirements of the manipulation task. Three-term control, a technique widely used in industrial process control to avoid overshoots, hunting (oscillations) and other undesirable effects, modifies the error signal characteristic as a function of time. The 'three terms' mean terms of an equation expressing the overall control behaviour. They are called 'proportional' (linear term), 'integral' (integration term) and 'derivative' (differentiation term), and these three modifying components, pre-adjusted by the user, are added to form the overall control characteristic.

When studying the manufacturers' literature on robot control systems, one often meets the term 'continuous path' as a description of the method of arm positioning. This can be confusing, because it is used differently in small robot technology and in industrial robot technology. In the small robot field 'continuous path' usually means that all the arm joints are driven simultaneously, instead of one after the other, to accomplish a total arm movement from one programmed position to another.

In the industrial robots field, 'continuous path' means that the path taken by, say, the gripper in moving from point A to point B is continuously controllable by the program—and hence by the programmer—over the whole of its length. Perhaps a specially shaped path, rather than a straight line, is needed for welding along a seam, spraying paint to follow a contour or to avoid some obstacle presented by the production process or machine. 'Continuous path' industrial robots are so named to distinguish them from 'point-to-point' robots, in which the user can program the required positions of point A and point B but has no control over the path taken by the gripper in moving between them.

## SOFTWARE PROGRAMMING

As in other computer technology, the program which orders the robot arm to perform a sequence of actions is a list of instructions, stored in binary form in a semiconductor memory. The user writes it for the particular task concerned, often with the aid of a software package supplied by the robot manufacturer. In practice the programmable memory usually has enough capacity to hold several tens of program steps.

The manufacturers' software employs algorithms that take account of the design of the particular robot system and so open up this specialised piece of hardware to the user's more general requirements. For example, the user may wish to steer the robot by simple electrical signals commanding the various joint positions. These signals could come from a manually operated keyboard or control box, or they could arrive automatically as in factory automation systems.

Software packages from some of the manufacturers make it a straightforward matter to write programs relating to the geometry of the space in which the robot functions. The algorithms start from required positions in three-dimensional space (of, say, the robot's gripper), as defined by Cartesian co-ordinates ($x$, $y$ and $z$), by cylindrical co-ordinates (angle and two distances), or other co-ordinate systems.

As already mentioned, there are two kinds of program in general use: application programs written by the user and internal system programs (or operating systems). Some robots on the market have system programs already built in as firmware. These often contain positional control information that allows the robot to be steered manually from a keyboard, and the maker supplies a control box for this purpose.

Other robots do not have such 'managerial' firmware built in, but the same purpose is served by the user writing his own system programs on an external home computer perhaps with the aid of manufacturers' software. In this case, if manual steering is required the computer's keyboard is used as a control box.

The robot makers normally supply their software on cassette or magnetic disk. It is often prepared in a special version of some existing programming language, such as a mixture of BASIC and machine code. The user loads it into the RAM of his home computer and then, using the VDU and keyboard, writes a program by the interactive process of responding to options displayed on the screen in menu form.

One manufacturer, for example, offers software packages in a version of FORTH, which is particularly suitable for control applications in any case. The instructions take the form of:

```
E 80 MOVE
```

where E is a mnemonic that selects the elbow joint in the arm, 80 is the number of steps chosen by the user to advance this joint relative to its existing position, and MOVE is the command to perform this instruction. Another type of instruction, for absolute, rather than relative, positioning has the form:

```
300 W 200 S GO
```

which means that the waist (W) and shoulder (S) are instructed to move to absolute positions of 300 and 200 respectively. These numbers are parameters identifying particular positions within a finite range of numbered positions fixed by the engineering design of the arm.

What makes software programming of robots particularly interesting for educational purposes is the possibility of using conditional branching or jump instructions in programs. These give the robot the power to 'decide' on a particular course of action in response to a situation in the manufacturing environment which it doesn't 'know' in advance—for example, whether an object presented to it on a conveyor is the correct size or not.

Of course, the robot doesn't really decide. It implements a generalised decision made in advance by the human programmer: e.g. that the instruction sequence in branch A of the program will be carried out if, say, a certain sensed value is greater than $x$, or the instruction sequence in branch B if this value is less than $x$. (The process is a mechanisation of the truth-functional operator *implication* in deductive logic.)

Such 'decisions' by the robot require an information input sensed from the environment by some transducer (indicated by 'intelligence' feedback in Fig. 1). This could be a simple switch built into the gripper to detect whether it has closed on an object or not, or it could be a whole vision system giving more complex information.