Hobby Electronics

AUGUST '82

ISSN 0142-6192

70p

Project Electronics For Everyone

ZX Interfaces Explained

POPULAR COMPUTING PROJECT

PROJECT: MUSIC- Audio Analyser

TEST EQUIPMENT- LED Millivoltmeter

INTO RADIO-SWR Meter

Introduction to Electronics

Beginner's Guide to Construction

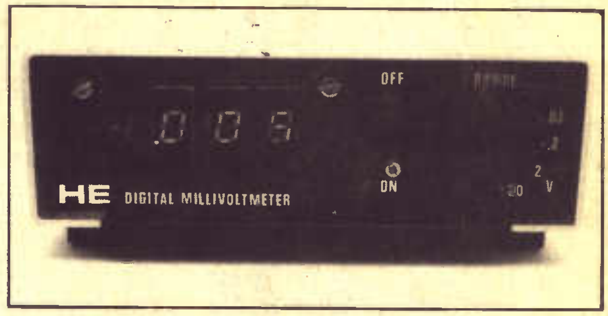
Hobby Electronics

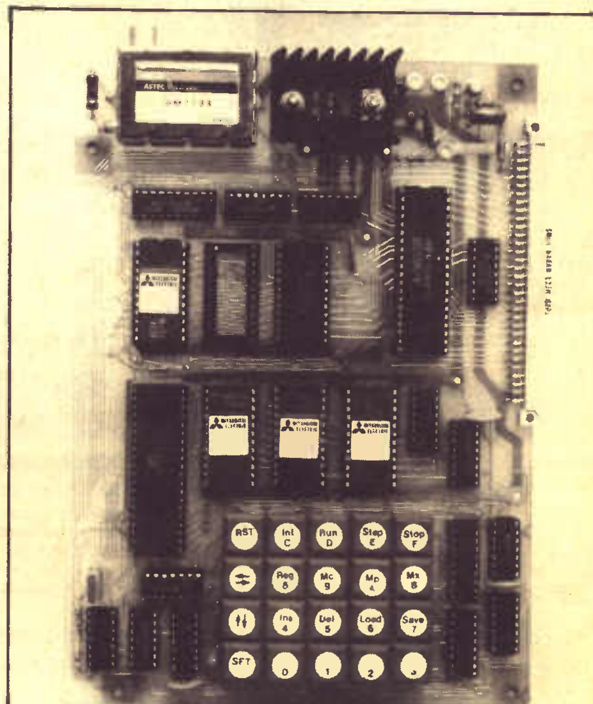
AUGUST 1982
Vol 4 No 8

PROJECTS

FEATURES

REGULARS





Editor: Ron Keeley
Editorial Assistant: Paul Coster BSc
Advertisement Manager: Gary Price
Managing Editor: Ron Harris BSc
Managing Director: T.J. Connell

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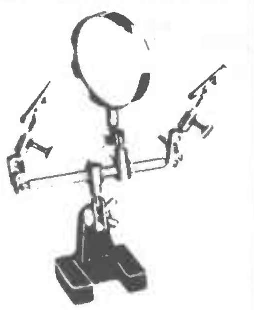

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by Tom Duncan

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MONITOR

IN NOVEMBER, the 5th Breadboard Exhibition comes to London. The most successful show of its type, it will offer electronics enthusiasts the opportunity to see for themselves what they have been reading about in their favourite magazine (that's us of course!). This year, a series of lectures and demonstrations will allow the visitor to learn at first hand how some of these circuits and projects work — and how they may be modified to suit personal needs.

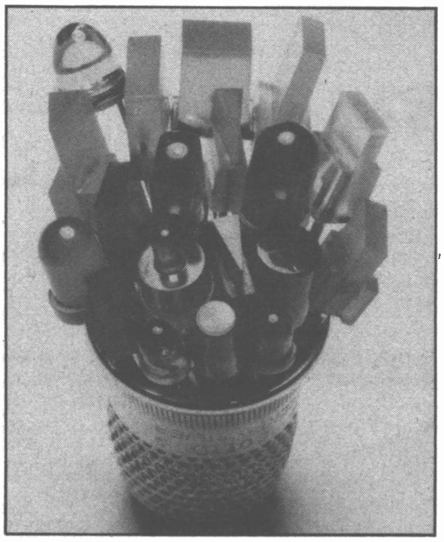
There is also the opportunity to see mail order firms display the contents of their catalogues, and the latest on offer from firms that are "household names" to the electronics buff.

This year, too, a number of exciting competitions are being planned, to fire the imagination and interest of the competitive visitor . . . so, whatever your interest in the hobby of electronics, don't miss BREADBOARD '82!

One of the greatest problems for the amateur electronics constructor is the availability of accurate, reliable and (most importantly) reasonably priced test equipment. The catalogue from **Lawtronics**, recently arrived on the Monitor desk, offers quite a few items which meet this requirement.

The range includes dual-trace oscilloscopes from £223, hand-held digital meters from £37 (analogue meters for less than £15), bench meters from £92, plus logic analysers, signal sources and other, more specialised equipment. The full range is described in the catalogue from **Lawtronics**, 139 High Street, Edenbridge, Kent TN8 5AX; 'phone 0732 865191.

The listed prices do not include either VAT or p&p, and the company offers a 14-day 'Sale or Return' evaluation period.



Let there be LEDs! A complete new 'family' of these devices have been recently introduced by **Zaerix Electronics.** As the picture (**above**) shows, they have rectangular, square, domed, dot and arrow shapes, as well as the standard 3 mm and 5 mm types. Altogether the range comprises 30 lens shapes, three lead frame designs and seven basic colours, diffused or transparent. Typical power handling is 105 mW. For details, contact **Zaerix Electronics Limited**, Electron House, Cray Avenue, St Mary Cray, Orpington, Kent BR5 3QJ; 'phone 0732 460424.

An interesting development in remote control around the home has been made by TK Electronics. The system allows control of up to 16 appliances plugged into receiver units, which are themselves plugged into the mains. The transmitter is hand-held (more than one may be used) and transmits a coded signal which may be altered to prevent interference with other units.

Possibly the most interesting aspect of the system is that the transmitter may be controlled by external logic, enabling automatic control of appliances from a single, central controller such as a digital timer, or microcomputer, thus providing a convenient interface between the control system and the controlled elements.

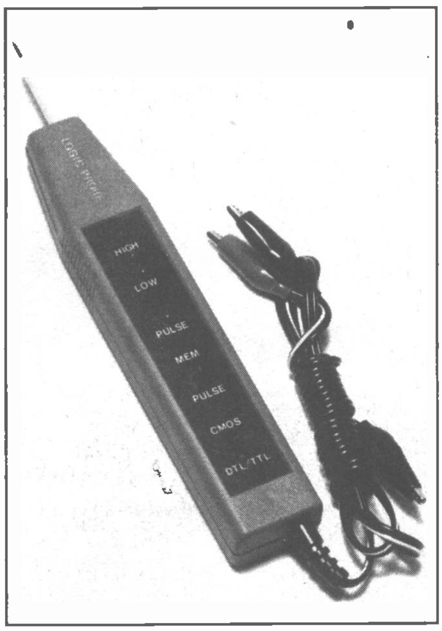
The system is supplied as a kit, consisting of a transmitter and two receivers and is priced at around £48, including VAT. The transmitter is housed in a black plastic hand-held box while the receivers (additional units are also available seperately) are not supplied with a case, allowing it to be installed inside the controlled appliance.

As a new service for customers, TK Electronics have arranged a simple telephone number for orders placed on Access or Barclaycard. The number is: 01 567 8910 - easy enough to remember, isn't it! Finally, TK's new free short-form catalogue is also available in return for a large SAE addressed to **TK Electronics**, 11 Boston Road, London W7 3SJ. A full sized technical and information brochure is planned for later this year.

The only item missing in the range of activities supported by the **Technical Leisure Centre** appears to be — electronics! However, they do offer an interesting range of tools and materials for model and precision engineers, clock and jewellery makers, and they also offer 'home computer items'. The centre is located at 1, Grangeway, Kilburn, London NW6 2BW; Tel; 01 328 3128. Further news of their activities will be included in their free newspaper, Technical Leisure News, which is available on receipt of a large stamped and self addressed envelope.

Monitor has become quite a conniseur of catalogues, of late. **Greenweld's** 1982/83 number, just published, promises 'a veritable cornucopia of components' and at both first and second glances, it certainly seems to contain quite a large range, consisting of just about everything needed for hobby electronics. The catalogue is available by mail for 50p plus 25p postage and includes a free Bargain list, five 12p discount vouchers and a First Class replypaid envelope. Write for the catalogue to **Greenweld**, 443 Millbrook Road, Southampton SO1 0HX. Don't forget that the listed prices include VAT.

Speaking of test equipment (well?) **Stotron Ltd** have a new 10 Mhz Logic Probe by **Sabtronics.** The LP-10 is a high speed probe with the capability of detecting pulses down to 50 nS. The input impedance is 100k, to avoid loading the circuit under test, and it will detect 'floating' inputs caused by open lines, dirty contacts, etc. Two LEDs indicate '0' and '1' logic levels while a third LED displays logic transitions detected by the pulse stretching circuitry. The probe is powered by the circuit under test via clip leads and pulls approximately 35 mA. For further details, contact **Stotron Ltd** Haywood Way, Ivyhouse Lane, Hastings, Sussex; 'phone 0424 442160.



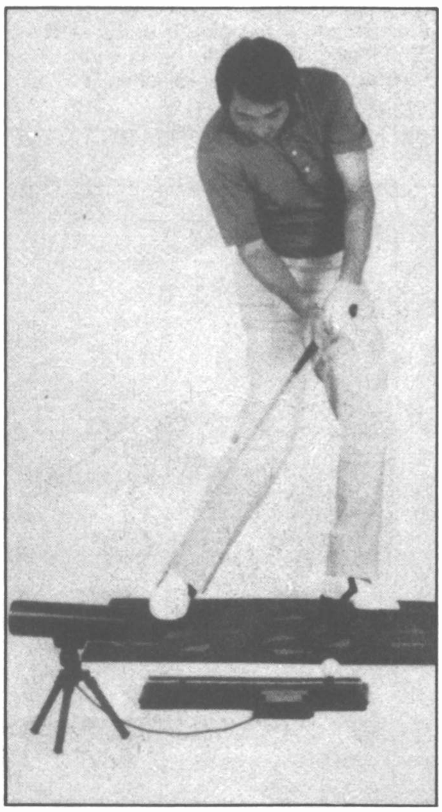
MONITOR

Martello Sound, better known to Monitor as the makers of the Rello range of compact and versatile radio microphones, have now produced a CB rig suitable either as a mobile, hand portable OR as a base station. The Spirit (**right**) is powered by 9 AA size dry or rechargeable batteries (which fit into the integral compartment) or from a standard 12 V vehicle battery or power supply unit. The non-polarised chassis allows installation in either positive or negative earth cars.

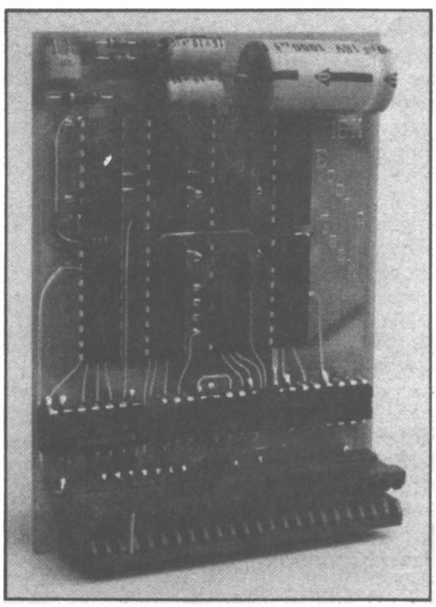
Facilities include 40 PLL synthesized channels, on/off volume, squelch, LED channel selector, battery check and saver, anti-cross modulation control, an 'S' meter and high SWR indicator. Standard equipment includes a lightweight dynamic mic, locking mobile mounting bracket, stainless steel mobile aerial, DC power lead and a carrying strap.

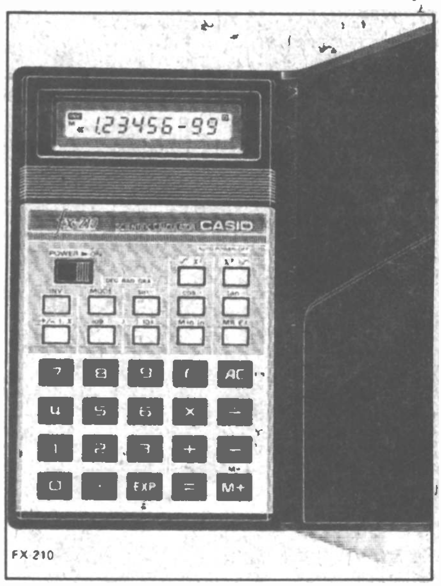
Priced at £143.75, the Spirit contains just about everything needed to get you on the air at once, in any situation. It is available by mail-order (post free) from Martello Sound Limited, Haywood Way, Ivyhouse Lane, Hastings, East Sussex.

This one is almost — but not quite — too good to be true. Welcome to computerised golf! The GL-500 has been developed by Mitsubishi Electric to help golfers improve their stroke-making by measuring and displaying a multitude of esoteric information (club head speed, face angle, swing arc, direction, distance and much more), all of which add up to indicate whether Jack Nicklaus should be keeping an eye on your game, too. The press release didn't mention a price and we haven't asked!



The latest ZX81-related product to come to our notice is a 'no-frills' 16K RAM pack, **below**, from **EconoTech**. The price (£19.95, including VAT plus £1.50 p&p worldwide) is the result of cost-effective design and manufacturing methods. The chips are industry standard 4116 16K NMOS Dynamic RAMs, and the board is powered from the edge connector's +9 V line and the internal 5 V regulator. The board uses a 44-way connector with gold plated contacts and fits against the back of the computer in such a way as to prevent wobble — and inadvertant loss of memory. It is fully compatible with the ZX Printer and is supplied complete with comprehensive instructions and a six month guarantee. Further information is available from EconoTech, 30 Brockenhurst Way, London, SW16 4UD, Tel: 01 764 8671.





Does anyone remember when a pocket calculator, of any kind, was a rare and very expensive toy? The times, they do change! Now Casio's latest, the FX210, provides '23 useful scientific functions' for just £12.95 (recommended retail price).

The functions include the usual trig and log, powers, roots and reciprocals. The memory is independent and elements within equations can be partitioned, with up to three levels of bracketing (now if they'd used Reverse Polish, that wouldn't have been necessary . . .).

The FX210 is powered by a lithium battery which will run for about 570 hours of continuous use before replacement is required. Battery life is enhanced by the use of an LCD display (eight digits total) and an automatic power-down feature which operates five minutes after the last keystroke. **HE**

TTLs	
7400	11p
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7402	12p
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7404	12p
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7406	20p
7407	20p
7408	14p
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7440	16p
7441	70p
7442A	32p
7443	90p
7445	50p
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74251	70p
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74LS251	35p
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74LS283	40p
74LS298	90p
74LS323	175p
74LS324	160p
74LS348	120p
74LS352	80p
74LS353	80p
74LS363	140p
74LS364	140p
74LS365	30p
74LS367	30p
74LS368	30p
74LS373	60p
74LS374	60p
74LS375	45p
74LS377	60p
74LS378	60p
74LS390	60p
74LS393	45p
74LS399	160p
74LS540	75p
74LS541	75p
74LS670	140p
4000 SERIES	
4000	10p
4001	10p
4002	12p
4006	50p
4007	15p
4008	40p
4009	24p
4010	24p
4011	11p
4012	16p

4013	23p
4014	48p
4015	45p
4016	20p
4017	36p
4018	45p
4019	25p
4020	48p
4021	48p
4022	45p
4023	15p
4024	32p
4025	15p
4026	50p
4027	22p
4028	45p
4029	50p
4030	20p
4031	125p
4033	120p
4034	140p
4035	60p
4036	275p
4039	275p
4040	48p
4041	60p
4042	44p
4043	48p
4044	48p
4076	48p
4047	45p
4048	50p
4049	24p
4050	24p
4051	45p
4052	60p
4053	50p
4054	90p
4055	90p
4056	90p
4059	450p
4060	55p
4063	85p
4066	27p
4067	280p
4068	14p
4069	14p
4070	14p
4071	14p
4072	14p
4073	14p
4075	14p
4076	48p
4077	16p
4078	16p
4081	14p
4082	15p
4086	55p
4089	150p
4093	24p
4094	90p
4095	75p
4096	75p
4097	340p
4098	90p
4099	100p
40085	90p
40097	50p
40098	50p
40102	180p
40103	180p
40106	40p
40109	100p
40163	60p
40173	48p
40174	60p
40175	75p
40193	75p
40257	160p
4502	60p
4503	40p
4507	35p
4508	140p
4510	50p
4511	48p
4512	48p
4514	120p
4515	120p
4516	60p
4518	40p
4520	60p
4521	120p
4526	60p
4527	60p
4528	50p
4532	70p
4534	450p
4536	300p
4538	90p
4539	90p
4543	75p
4553	290p
4555	35p
4556	35p
4560	150p
4568	300p
4569	180p
4572	30p
4583	90p
4584	40p
4585	100p
14495	400p

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LF357	120p	TCA220	350p
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LM389	95p	TL094	200p
LM391	150p	TL170	50p
LM393	100p	TL340C	70p
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24V 1A	7824	55p	7924	60p
5V 100mA	78L05	30p	79L05	60p
12V 100mA	78L12	30p	79L12	60p
15V 100mA	78L15	30p	79L15	60p

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LM317K	325p	78HD5KC	550p
LM317T 1A Adj	140p	78MGT2C	140p
LM337T	225p	78GUIC	200p
LM323K 3A 5V	500p	79GUIC	225p
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78S40	300p	LM305AH	250p

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ILQ74	240p	TIL116	90p
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TIL209 Red	9p	TIL222 Gr	12p
TIL211 Gr	12p	TIL228 Yel	14p
TIL212 Ye	14p	Rectangular LEDs (R, G, Y)	30p
TIL216 Red	18p	NS85881	570p
		TIL311	600p
DISPLAYS		TIL312/3	110p
3015F	200p	TIL321/2	130p
DL704	140p	TIL330	140p
DL707 Red	140p	7750/60	200p
FND357	120p	**DRIVERS**	
FND500	90p	9368	250p
FND507	90p	9370	300p
MAN3640	175p	UDN6118	320p
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* MICROTRAINER *

(as described in June/July/Aug issue)

- Hobbyists can now learn and explore the workings of microprocessors. This project opens the mystical field of computers to enthusiasts.
- A truly low cost teaching aid useful for training centres, schools and industries. In fact a short step towards developing new ideas and systems. Gives effective insight into micros to engineers, technicians, etc. not directly involved in the computer field.

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Square PCB Switch	65p

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BD135/6	40p	MPF102	40p	ZTX752	70p	2N5194	90p
BD139	40p	MPF103/4	30p	VN46	75p	2N5245	40p
BD140	40p	MPF105	30p	VN10KM	60p	2N5298	65p
BD189	60p	MPSA06	30p	VN66	80p	2N5401	60p
BD232	95p	MPSA12	50p	2N697	25p	2N5457 8	30p
BD233	75p	MPSA13	50p	2N698	45p	2N5459	40p
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BD241	60p	MPSA42	50p	2N708	30p	2N5485	40p
BD242	60p	MPSA43	50p	2N918	45p	2N5875	250p
BD677	40p	MPSA56	32p	2N930	18p	2N6027	48p
BF244B	35p	MPSA70	50p	2N1131 2	36p	2N6052	300p
BF256B	50p	MPSA93	40p	2N1613	25p	2N6059	325p
BF257/8	32p	MSPU06	63p	2N1711	25p	2N6107	65p
BF337	30p	MPSU07	60p	2N2102	70p	2N6247	190p
BFR39	25p	MPSU45	90p	2N2160	350p	2N6254	130p
BFR40/1	25p	MPSU65	78p	2N2219A	25p	2N6290	65p
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BFX29	40p	TIP30C	40p	2N2646	45p	2SC1957	90p
BFX30	27p	TIP31A	40p	2N2904/5	30p	2SC1969	195p
BFX84/5	40p	TIP31C	45p	2N2906A	30p	2SC2028	120p
BFX86/7	27p	TIP32A	40p	2N2907A	30p	2SC2029	250p
BFX88	27p	TIP32C	45p	2N2926	9p	2SC2078	200p
		TIP33A	70p	2N3053	30p	2SC2335	250p
						2SC2612	250p
						3N128	120p

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3N141	110p
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3N204	120p
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- **SOFTWARE COMPATIBILITY** Capable of executing Z80/8080/8085 machine language program
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ZX INTERFACES EXPLAINED

Mike Lord

The ins and outs of Sinclair's ZX81 and ZX Spectrum computers.

ADVERTISEMENTS for Sinclair's original ZX80 said that is could be used to control a power station. We doubt whether many readers will be that ambitious! On a more practical level, the ZX81 and the new ZX Spectrum can be used to control activities such as model train layouts, a robot arm, or a sophisticated burglar alarm/deterrent system. Many entrants in recent 'micromouse' competitions have used a ZX to control their mouse's progress through the maze. And in the 'professional' world, many laboratories are now using ZX computers to control simple experiments and record the results.

The main attraction of the Sinclair machines for these applications is, of course, their low cost. But their small size can also be an advantage on a crowded workbench, as well as their ability to survive the rough and tumble of life outside the hallowed precincts of a computer room — an important feature if, like the author, you are prone to dropping pieces of equipment on the floor or spilling cups of coffee over everything.

Input and Output

To be of any use, a computer has to be able to communicate with the outside world. It has to be able to take in data (and remember that a computer sees your program as just another form of data that it has to deal with), and it also has to be able to put out the results of its computations.

Normally, the input signal to your ZX come from the kyboard or from a cassette recorder, and it sends outputs to the TV display or to a cassette recorder. This article will show you how to make your ZX81 or Spectrum able to accept signals from other sources, and how to make it generate signals which can be used for purposes other than driving a TV set or tape recorder.

Because the ZX is an electronic device (and because this is an electronics magazine), we shall only be considering electrical inputs and outputs. Most real applications, however, will also have a mechanical aspect, such as how to actually move the robot's arm, or how to sense that a train is passing through the station. Solving these problems will have to be left to your ingenuity!

The Key To Input

Each key on the ZX keybord is — electrically speaking — a normally open single pole switch. Pressing the key closes the switch and this can be detected by routines built into the computer's ROM. The function INKEY$, for example, can be used in a BASIC program to detect if a single key has been pressed and to tell which key it was.

So, if we wire a normally open switch or relay contact in parallel with one of the ZX's keys, then the operation of the switch or the closing of the relay contact will appear to the ZX exactly as if that

a

	Y1	Y2	Y3	Y4	Y5
X1	1	2	3	4	5
X2	Q	W	E	R	T
X3	0	9	8	7	6
X4	A	S	D	F	G
X5	P	O	I	U	Y
X6	shift	Z	X	C	V
X7	n/1	L	K	J	H
X8	space		M	N	B

Each keyswitch connects between one X connector point and one Y connector point as shown in the table above.

b

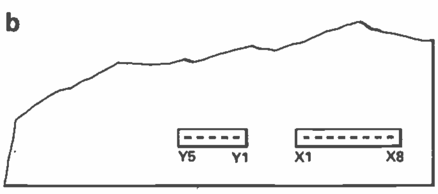


Figure 1(a). The ZX81 keyboard connections ; (b) component-side view of the ZX81 board, showing the keyboard sockets.

a

	Y1	Y2	Y3	Y4	Y5
X1	1	2	3	4	5
X2	Q	W	E	R	T
X3	A	S	D	F	G
X4	0	9	8	7	6
X5	P	O	I	U	Y
X6	caps shift	Z	X	C	V
X7	enter	L	K	J	H
X8	space	symbol shift	M	N	B

Each keyswitch connects between one X connector point and one Y connector point as shown in the table above.

b

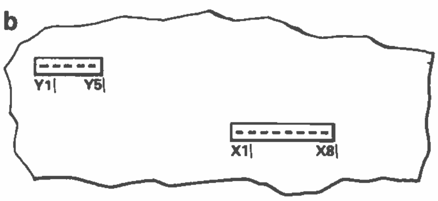


Figure 2(a). The Spectrum keyboard connections; (b) the keyboard sockets from the component side of the Spectrum PCB.

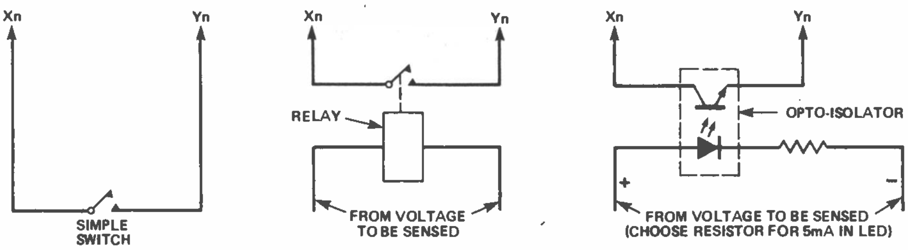


Figure 3. Inputs to the ZX keyboard matrix.

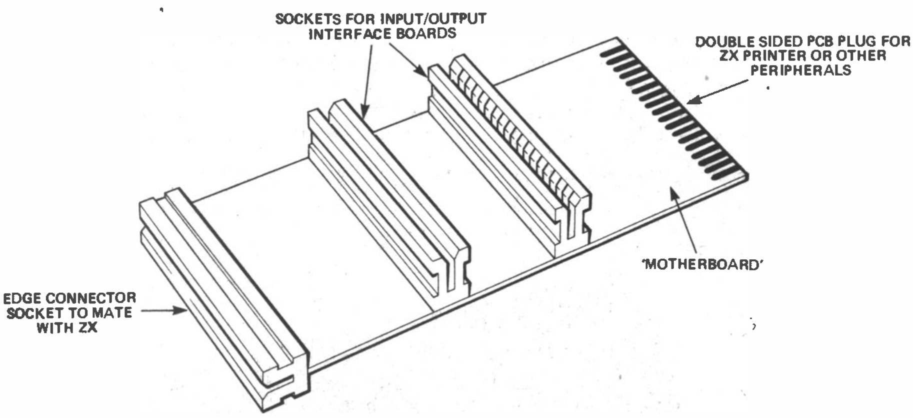


Figure 5. A mother board with sockets for I/O interfaces, connections for a ZX printer or Rampack, etc.

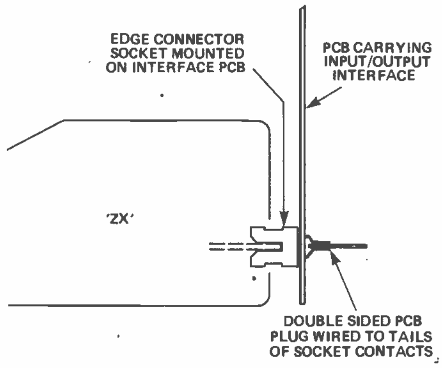


Figure 4. An add-on board must allow access to the ZX socket contacts.

key had been pressed, and it can be detected by your program.

You can't get at the actual switch contacts themselves on the ZX81 or Spectrum keyboards as they are sealed units, so you will have to connect your added switche(s) to the 5 and 8 way film-cable sockets mounted on the computer PCB. One contact of each keyboard switch is connected to one lead in the 5 way cable, the other contact is connected to one lead in the 8 way cable, so that the 40 keys are arranged in a 5 x 8 matrix. The actual connections for each key are shown in **Figures 1 and 2**, so if you wanted your added switch to appear to the computer as key '2', it would have to be connected between connector points X1 and Y2.

This technique is usefully simple, but there are a few points to watch. Any leads connected to the keyboard must be relatively short — say less than 30 cm — or they are liable to confuse your ZX by picking up stray noise. Also, INKEY$ will refuse to recognise any of them. And, of course, you have to be sure that any contacts you may add are open-circuit whenever you want to use the normal keyboard.

A simple joystick can be made using this technique to add interest to games programs. Four normally open switches should be used, mechanically connected to the joystick so that one switch is closed when you move the stick in a particular direction. The switches could be wired in parallel with the four cursor control keys (numbered 5 to 8), corresponding to movements of the stick as Up, Down Left and Right.

Since neither side of the keyboard switches can be connected to ground (doing so would prevent the ZX from working properly), some form of isolating device is needed if you want the ZX to sense an electrical signal. As illustrated in **Figure 3**, a suitable relay could be used, or perhaps a phototransistor/LED opto-isolator. If an opto-isolator is used, the emitter of the phototransistor should be connected to the 8 way keyboard connector, and the collector to the 5 way connector.

The Rear Connector

If we want our ZX to provide outputs — for controlling motors, lights or whatever — or if we want it to be able to detect more than one input signal at a time, then we have to add an interface circuit to the ZX's rear connector.

This connector consists of two rows of contact pads spaced 0.1" apart along the rear edge of the ZX's printed circuit board. Row A is on the top surface of the PCB and row B is immediately underneath. The ZX81 connector has 23 contact positions on each side, the Spectrum has 28; in both cases a slot has been cut into the PCB in one of the contact positions to locate a polarising key fitted to the mating socket. Suitable sockets are readily available from a number of specialised ZX hardware suppliers.

The connector carries the computer's address, data and control signals as well as power lines and was intended for use with add-on devices such as the ZX81's 16K Rampack or the ZX printer; but, as described in the remainder or this article, it also allows you to plug on your own Input/Output interface board. One point to remember when building any add-on for the ZX is that it doesn't prevent you from adding other extensions. This means, in effect, that it should include a double sided PCB plug which is wired to carry the same signals as the actual ZX connector, and to which other extensions can be fitted. One way of achieving this is illustrated in **Figure 4**. Alternatively, you could make up a 'motherboard' as shown in **Figure 5**. This would have sockets for accepting I/O interface boards and a double sided PCB plug at the end for connecting to the ZX printer or Rampack. Again, suitable PCB plugs are available from some ZX hardware suppliers.

Pin No.	Signal Side A (top)	Signal Side B (bottom)
1	A15	A14
2	A13	A12
3	D7	+5V
4		+9V
5	Slot	
6	D0	0V
7	D1	V
8	D2	CK
9	D6	A0
10	D5	A1
11	D3	A2
12	D4	A3
13	INT	IORQE
14	NMI	0V
15	HALT	VIDEO
16	MREQ	Y
17	IORQ	V
18	RD	U
19	WR	BUSRQ
20	−5V	RESET
21	WAIT	A7
22	+12V	A6
23	−12V	A5
24	M1	A4
25	RFSH	ROMCS
26	A8	BUSACK
27	A10	A9
28		A11

Figure 6. The Spectrum rear connector signals.

Pin No.	Signal Side A (top)	Signal Side B (bottom)
1	D7	+5V
2	RAMCS	+9V
3	Slot	
4	D0	0V
5	D1	0V
6	D2	0
7	D6	A0
8	D5	A1
9	D3	A2
10	D4	A3
11	INT	A15
12	NMI	A14
13	HALT	A13
14	IORQ	A11
16	RD	A10
17	WR	A9
18	BUSACK	A8
19	WAIT	A7
20	BUSREQ	A6
21	RESET	A5
22	M1	A4
23	REFSH	ROMCS

Figure 7. ZX81 connector signals.

The signals on the ZX rear connectors are shown in **Figures 6 & 7.** The ones which are most useful for an Input/Output interface are:

The Power supplies; The +9 V line comes directly from the unstabilised output of the ZX mains adaptor. It can vary between about 7V5 and 11 V, and has 1 to 2 volts of 100 Hz ripple on it. Depending on what else is connected to your ZX, you should be able to draw about 200 mA from this line. The +5 V line comes from the ZX's internal 5 volt regulator, which runs hot at the best of times, so don't try to take more than about 100 mA from this supply. The Spectrum also provides a +12 V output, which can supply about 30 mA, and a −5 V line from which you shouldn't take more than a couple of milliamps. Also on the Spectrum rear connector is a point labelled '−12 V'. In fact this is not actually a negative 12 V DC supply, but rather a high frequency square wave of about 13 V peak-to-peak. It can be used to generate a low current (10 mA) negative rail of approximately 12 volts by adding a suitable rectifier circuit such as that shown in **Figure 8.**

Other useful lines on the connector are the signals which come from the Z80 microprocessor at the heart of the ZX computer. They are:

The Microprocessor Data Bus lines D0 to D7. These carry data to and from the Z80, one 8-bit byte at a time. The voltage levels are TTL compatible, but not more than one LSTTL (Low Power Schottky TTL) input should be

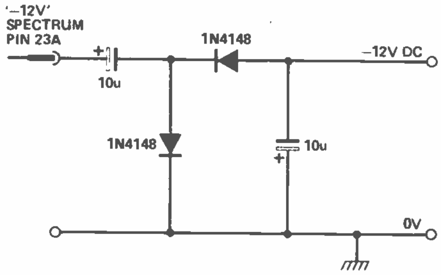


Figure 8. Deriving a negative DC supply from the Spectrum '12 V' output.

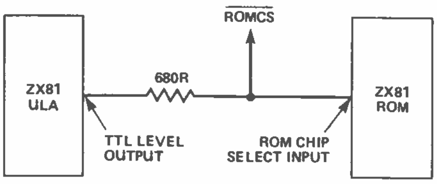


Figure 9. The $\overline{ROMCS}$ circuit of the ZX81.

connected to each line. To input signals to the ZX computer, you have to put signals onto the data bus and this should be done using a device which has tri-state outputs, so as not to load the bus lines when data is not being input.

The Microprocessor Address lines A0 to A15. These carry address information from the Z80 and can each drive one or two LSTTL inputs.

The Z80 Control lines $\overline{RD}$, $\overline{WR}$, $\overline{MEMRQ}$ and $\overline{IORQ}$. These are all outputs from the Z80, used to control the reading and writing of data to and from memory and I/O devices; they are all TTL compatible, capable of driving one or two LSTTL inputs. These lines are normally 'high'; the $\overline{RD}$ line goes low when the Z80 wants to read data from memory or I/O, the $\overline{WR}$ line goes low when it wants to write. The $\overline{MEMRQ}$ line going low signifies that the Z80 wants to read or write to memory, similarly a low level on the $\overline{IORQ}$ line indicates that the Z80 is reading or writing to I/O. (Note that the term 'I/O' is used in a special sense, as will be discussed later).

Finially, there are two interesting lines called $\overline{RAMCS}$ and $\overline{ROMCS}$ ($\overline{RAMCS}$ only appears on the ZX81; not on the Spectrum). These are signals generated within the ZX to select its internal RAM or ROM memories, but are brought out to the rear connector to allow an externally applied signal to over-ride this selection. For example, the ZX81's 16K Rampack uses the $\overline{RAMCS}$ Line to disable the ZX81's internal 1K RAM. As will be described later, we can use these lines to make the ZX81 communicate with an external I/O interface rather than with its internal memory. The levels on these lines are somewhat non-standard, being TTL output levels fed through a 680R resistor. This is illustrated in **Figure 9** which shows, as an example, how the $\overline{ROMCS}$ signal is generated in a ZX81. To enable the internal ROM, the ULA chip in the ZX81 presents a 'low' output level which

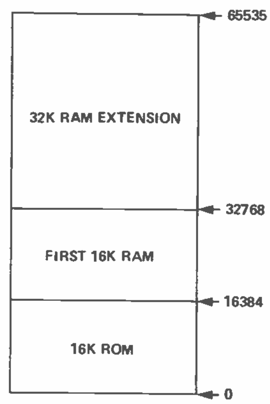


Figure 10. The Spectrum memory map.

normally passes directly to the ROM chip-select input without being significantly affected by the 680R resistor, as the ROM input is a very high impedance. We can, however, connect an external circuit to the $\overline{ROMCS}$ line to prevent the voltage at the ROM chip select input from going low enough to enable the ROM. We would then be free to feed signals from an external interface onto the data bus lines. Similarly, on the ZX81, we can disable the RAM memory by pulling the $\overline{RAMCS}$ line high.

Memory Addressing

If the ZX is to be able to communicate with an Input/Output interface, it must be able to select that interface when it wants to write to or read from it, but the interface mustn't interfere with the ZX's normal communications with its ROM and RAM memories or other Input/Output devices such as the keyboard and printer.

One way of doing this is to see if there are any memory addresses that the ZX doesn't normally use. If there are any such 'free' addresses, then we can allocate some of them to the Input/Output interface. The interface can then be designed to look to the computer like added memory, appearing at the otherwise free locations, and can be accessed by using the ZX BASIC's PEEK and POKE commands.

Since the ZX has 16 address lines (A0 to A15), it can theoretically handle 65536 (64K) different memory locations. The 'memory map' for the Spectrum is shown in **Figure 10,** and it can be seen that a fully expanded Spectrum equipped with 16K of ROM and 48K of RAM does not have any room left in its memory address space for an Input/Output interface.

The ZX81, however, is different. Normally only 8K of ROM and a maximum of 16K of RAM are fitted, which would appear to leave plenty of room for an Input/Output interface. But, because the circuits in the ZX81 which select the ROM and RAM don't decode the address lines as fully as they could, 'echoes' of the ROM and RAM appear throughout the memory map, as shown in **Figure 11.** Thus the 8K ROM not only occupies ad-

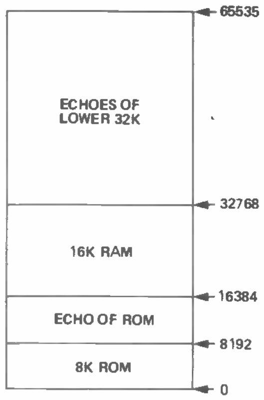


Figure 11. The ZX81 memory map.

dresses 0 to 8191, but it also *appears* to occupy addresses 8192 to 16383. Similarly, multiple echoes of the RAM appear throughout the address space. In fact, one of these RAM echoes, which starts at address 49152, is essential to the circuits in the ZX81 which produce the TV display. There are, however, a lot of unnecessary echoes which could be removed — by holding the $\overline{RAMCS}$ or $\overline{ROMCS}$ lines high when required — to make room for our interface. In practice, because it interferes least with the use of really large RAM expansions such as the Memopack 64K (reviewed in the June issue of HE), the best address to put an interface is just above the ROM, at address 8192.

Z80 I/O Addressing

As well as 64K of memory, the Z80 processor can also handle 64K special 'I/O' addresses. From a hardware point of view, these use the same 16 address lines (A0 to A15) as memory, but are accessed when the Z80 $\overline{IORQ}$ output goes low, whereas a normal memory access is signalled by $\overline{MREQ}$ going to a low level. We could, therefore, design an Input/Output interface so that it responded to these special 'I/O' addresses, rather than appearing in the normal memory map. From a software point of view, the Z80's I/O addresses are handled by a special class of Z80 machine code instruction. There is no equivalent instruction in ZX81 BASIC, so a special machine code routine would have to be written to handle an Input/Output interface mapped into the 'I/O' address space. Spectrum BASIC, however, includes IN and OUT commands which act like PEEK and POKE — but on this 'I/O' space, rather than on memory. This is fortunate because, as we have seen, there is no room in the Spectrum's memory map for an Input/Output interface.

Some of the I/O address space is already used by the keyboard and cassette ports, and other parts have been allocated to Sinclair add-ons such as the printer and the eagerly awaited Spectrum disc drive. Instead of allocating specific blocks of the I/O address space for these functions, the ZX designers have, instead, used the state of individual address lines to select individual 'I/O' functions. For example, bringing A1 low, while leaving the other address lines high, would select the ZX printer. Overall, lines A0 and A8-A15 are allocated for ZX peripherals. In all cases a 'low' level on an address line selects the function. This means that if we want to put our Input/Output interface in the 'I/O' map, we must chose an address which as A0-A4 and A8-A15 all '1'.

Theory and Practice

Many different kinds of interface have been designed for the ZX81, ranging from straightforward I/O boards for controlling relays, lights etc, through joystick controllers and full-sized keyboards to analogue-to-digital converters. No doubt similar products for the Spectrum will appear in due course. Now that we know what signals are available at the rear connector of a ZX computer, and how we can use them to communicate with the outside world, we are better able to understand how these work.

There's nothing like hands-on experience, though, so the next practical step is to consider such a circuit or, better still, to build it! Accordingly, next month's HE will contain a simple, effective I/O Board project, providing eight TTL-level input and output lines and suitable for use with either a ZX81 or a ZX Spectrum.

HE

SPOTLIGHT ON THE SPECTRUM

" . . . an excellent machine, it offers by far the best performance of any computer in its price range . . . ".

Mike Lord

THERE IS no doubt that Sinclair's new Spectrum has already caused a lot of interest among potential customers — and a lot of consternation among his competitors! We were lucky enough to have a prototype machine on loan for a week and so able prepare this review for HE readers.

The Spectrum is suprisingly small (233 x 144 x 30 mm) but has a nice 'chunky' feel to it; it looks robust enough to withstand a lot of rough treatment yet simple enough to be reliable. The keyboard is a great improvement over that used on the ZX80 and 81, as the keys are spaced further apart and they actually *move* when you press them. Perhaps the word 'collapse' would be better, as the keytops are made of hollow rubber mouldings which act as their own return springs. The effect is a bit disconcerting at first — it's rather like typing with galoshes on your hands.

As with the ZX80 and ZX81, BASIC words are entered by pressing a single key but, because the Spectrum has so many functions (most keys have up to 5 meanings), a complicated sequence of shift keys has to be used to select the least frequently used commands. This can be annoying for the beginner, and one wonders occasionally whether Sinclair were right in keeping with 'one touch' keyword entry. Some symbols on the prototype's keys were difficult to read, being very small dark red print on a grey background, but we have been informed that the lettering on production models will be better. All keys have a useful 'auto-repeat' facility, and a click is given by the internal loudspeaker when a key is pressed.

Sound Spectrum

Yes, the Spectrum does have sound. The BEEP command will generate a note of specified frequency and length, and it is quite easy to program simple tunes or space invader type noises.

The TV display is the usual Sinclair standard of 24 rows of 32 characters each,.the bottom two rows being reserved for keyboard input or reports from the computer. The display is always present — there is no equivalent of the ZX81's FAST mode, as the TV signal is generated by special hardware which frees the Z80 processor to work full time at your program.

The character set includes both upper and lower case letters, block graphics characters familiar to ZX81 users, an assortment of miscellaneous symbols, including the copyright symbol, ©, and no less than three distinct types of brackets! You can also define your own characters; each character on the screen is made up of dots in an 8 x 8 matrix and there are 21 spare character codes which you can program to whatever shapes you want. Alternatively, you can even redefine the complete set of 133

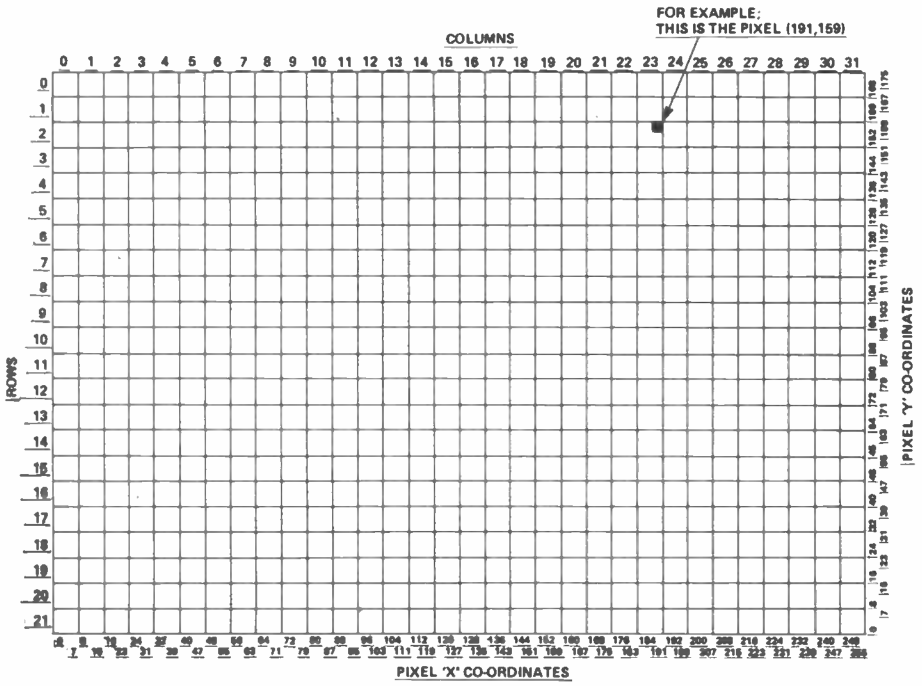


Figure 1. The Spectrum display map.

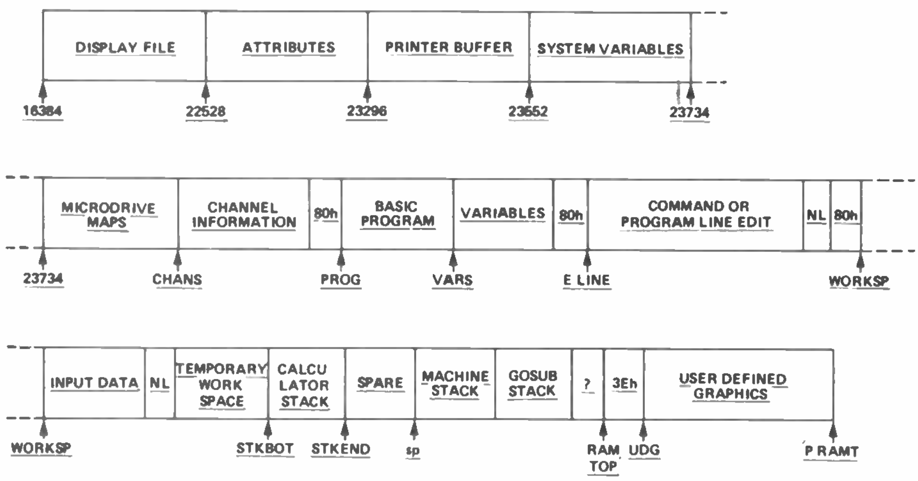


Figure 2. The memory map of the RAM area — RAMT (RAMTOP) is normally 32768.

displayable characters! This is ideal for moving graphics games, as you can define characters to look like — say — different types of spaceship, then move the ships rapidly around the screen by PRINT AT commands.

Then there is the matter of colour. For each of the 32 x 22 programmable character positions on the screen, you can control the background (PAPER) and foreground (INK) colours; also, whether or not the character will appear flashing or steady and whether it is displayed at normal or bright intensity. Six colours, plus black and white are available and they all showed up clearly and distinctly on the author's television, except for a slight 'fringing' which may have been due to the model under test being a much worked-on prototype. The colour of the border around the edges of the screen can also be controlled by your program.

The Spectrum also has PLOT, DRAW and CIRCLE commands which let you plot points and draw straight lines, circles or parts of circles on a 256 x 176 grid. This grid is made up of the 8 x 8 dot matrices used for each of the 32 x 22 programmable character positions on the screen, so that while you can use colour with the PLOT, DRAW and CIRCLE commands, you are limited to a single foreground colour and a single background colour in each of the character positions.

Spectrum BASIC is essentially ZX81 BASIC plus a number of new features. It is not the fastest BASIC around, but it is quick enough for most applications. As well as the plotting, colour and sound commands mentioned earlier, it now has READ, DATA and RESTORE instructions for handling lists of fixed data, and can include user defined functions in the programs. The new BIN function allows you to express a number in binary form as eight '1's or '0's, which must be useful sometimes! The functions ATTR, POINT and SCREEN$ will be valuable in programming moving action games, as they allow you to find out exactly what is being displayed at any point or character position on the screen. Hardware freaks will be pleased by the IN and OUT instructions, which act like PEEK and POKE but on the Z80's I/O space rather than on memory locations.

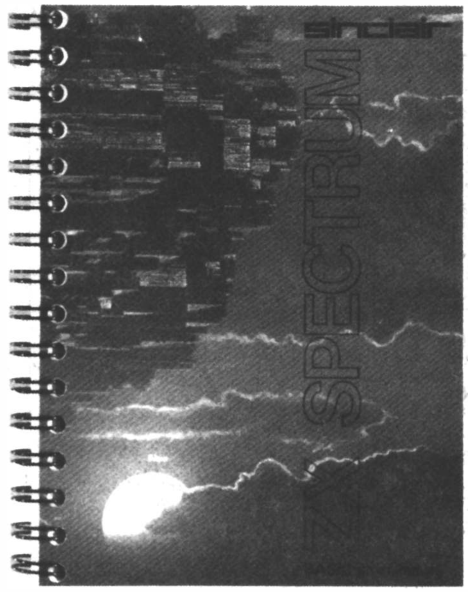


Figure 3. The Spectrum BASIC programming manual is clearly written and well illustrated, as usual.

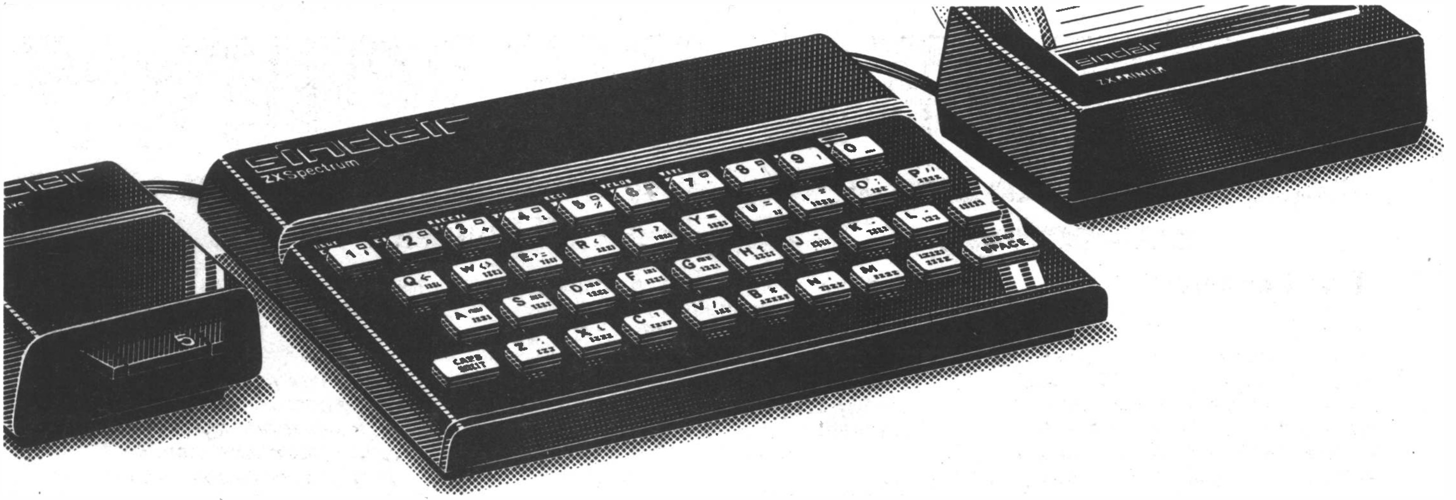
SAVE It

The rate at which programs and data can be SAVEd to tape is now 1500 bits per second (five times faster than the ZX81) and the cassette interface has been made more tolerant of imperfections in the cassette recorder. A new VERIFY command allows you to check a program or block of data, in the Spectrum's memory, against information stored on tape, which is a useful safeguard but surely a checksum added to the saved data would have been more practical. You can also MERGE data and programs from tape with those already present in the machine, which allows the Spectrum to handle masses of data by taking in a chunk at a time, or you could MERGE previously written routines from tape into a new program.

The most tantalising aspect of the Spectrum's launch was the mention of new add-ons to be available "later this year". They are a RS232/Network interface which will allow the Spectrum to be connected to a whole range of standard computer peripherals, including printers and modems, and the ZX Microdrive. The Microdrive will be Sinclair's answer to the floppy disc drives found on more expensive computer systems. For only £50, it will hold up to 100K bytes on an interchangeable microfloppy, and transfer data or programs to and from the Spectrum at 16K bytes per second. This will turn the Spectrum into a serious business machine as well as greatly extending the possibilities for the hobbyist. We can't wait!

In Conclusion

The Spectrum is an excellent machine. It offers by far the best performance of any computer in it's price range, and seems to be easy to use without any particular 'vices'. Place your order now! **HE**



"...the quality of the colour display is excellent". Popular Computing Weekly.

"The graphics facilities are great fun". Personal Computer World.

"...the Spectrum is way ahead of its competitors". Your Computer.

"The world's best personal computer for under £500."

Clive Sinclair

Sinclair ZX Spectrum

16K RAM £125, 48K RAM £175.

This is the astonishing new ZX Spectrum – a powerful professional's computer in everything but price!

There are two versions – 16K or a really powerful 48K. Both have a full 8 colours, sound generation, a full-size moving-key keyboard and high-resolution graphics. Plus established Sinclair features such as 'one-touch' keyword entry, syntax check and report codes!

Key features of the Sinclair ZX Spectrum

Full colour – 8 colours plus flashing and brightness-intensity control.

Sound – BEEP command with variable pitch and duration.

Massive RAM – 16K or 48K.

Full-size moving-key keyboard – all keys at normal typewriter pitch, with repeat facility on each key.

High resolution – 256 dots horizontally x 192 vertically, each individually addressable for true high-resolution graphics.

ASCII character set – with upper- and lower-case characters.

High speed LOAD & SAVE – 16K in 100 seconds via cassette, with VERIFY and MERGE for programs and separate data files.

The ZX Printer – available now

The printer offers ZX Spectrum owners the full ASCII character set – including lower-case characters and high-resolution graphics.

Printing speed is 50 characters per second, with 32 characters per line and 9 lines per vertical inch.

ZX Microdrive – coming soon

Each Microdrive will hold up to 100K bytes on a single interchangeable microfloppy – with a transfer rate of 16K bytes per second. And you'll be able to connect up to 8 ZX Microdrives to your ZX Spectrum – they're available later this year, for around £50.

How to order your ZX Spectrum

BY PHONE – Access, Barclaycard or Trustcard holders can call 01-200 0200 for personal attention 24 hours a day, every day.

BY FREEPOST – use the coupon below. You can pay by cheque, postal order, Access, Barclaycard or Trustcard.

EITHER WAY – please allow up to 28 days for delivery. And there's a 14-day money-back option, of course. We want you to be satisfied beyond doubt – and we have no doubt that you will be.

sinclair ZX Spectrum

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Stanhope Road, Camberley, Surrey, GU15 3PS. Tel: Camberley (0276) 685311.

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	Sinclair ZX Spectrum – 48K RAM version	101	175.00	
	Sinclair ZX Printer	27	59.95	
	Printer paper (pack of 5 rolls)	16	11.95	
	Postage and packing orders under £100	28	2.95	
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POINTS OF VIEW

Topics this month are CB, the MEMOPAK 64K RAM, and a point concerning our "Scaling the HiFi Heights" series.

CB vs Computers

Dear Sir,
Firstly, in answer to N. J. Treacher's letter (HE, June '82) re CB circuit diagrams; the only one presently obtainable from the makers is the Amstrad 900-901. This is really a super service sheet, including junction voltages, parts list and numbers for spares. The circuit is printed on a large folded sheet and is available from Amstrad to anybody for £2.50 plus 20p p&p. Hope this helps.

Now, my comments. I have taken HE from issue No. 1 and I think is has been a very good mag. It was even better when you included a bit of CB (which must have helped your sales) but this was stopped when CB mags appeared. So how about finishing up the section on computing when this session comes to an end, as there are plenty of computing mags now, and stick to basic electronics.

How about articles on wind generator control circuits, charging car batteries by solar cells and other energy savers — but please stick to what HE is about; basic, useful projects and teach-ins.
B. J. Shelford,
Sheerness,
Kent.

Firstly, then, thanks for your Point of View, and also for the tip on CB service sheets. Let's hope N. J. Treacher is still in touch!

Your comments on CB radio and computing are interesting. We don't see this as a straight-forward contest, though. As a long-term regular reader, you will be aware that we did as much as anybody else to publicise CB radio in the UK — but when CB magazines (including our own Citizens' Band Magazine) began to appear, it seemed that the dedicated CB nut would be better served by those specialist publications. This was confirmed by the lack of response (best described as 'underwhelming') to the demise of our Breaker One-Four page. Nevertheless, we know that many readers are still interested in CB, and that many more would like to learn more about radio generally, so we introcuded the 'teach-in' series, Radio Rules, together with regular CB/radio projects and features, under the title 'Into Radio'.

We also felt that the best way we could contribute to a better understanding of computers was to devote a number of pages to the basic electronics of micro computers — the 'nuts and bolts', as we like to say. We are still the only magazine to deal with computer technology on this level.

Lastly, our July issue contained a number of projects which could be 'solar-powered' (for further information on sources of relatively inexpensive cells, see the Monitor pages), and other energy-saving projects are being planned!

Memopak

Dear Sir,
We have read your review of our MEMOPAK 64K on page 65 of Hobby Electronics for June 1982. May I say we thought it very fair? There are, however two points I would like to make.

The first concerns the amount of RAM available in our pack. There is 64K RAM physically present, but as the ZX81 can only address 56K locations above the 8K of its own ROM, we can only provide an additional 56K to the Sinclair user. However, the MEMOPAK 64K was not intended solely for use on the ZX81, and it would provide 64K of RAM to any Z80 processor that could address it. It might, for example, be used in conjunction with the Spectrum (with paging). Another possibility is that it could be combined with a disc operating system for use with the ZX81.

Secondly, the ZX81 arrays are not restricted to the upper 32K of RAM, as your diagram indicates. What happens is that the ZX81 allocates space to the instruction file, the display file and the arrays (in that order) from about 16K onwards. Although the instruction file cannot climb above the 32K address limit, the arrays may start lower down — an array of 45K is possible.

We take your point about the sticky tabs and we are considering replacing them with Velcro tabs.

Perhaps you would consider publishing this letter in the interests of clarification for the ZX public.
Yours Faithfully,
D. J. Jay,
Technical Consultant,
Memotech Ltd.

We are only to happy to oblige, and hope that this clears up any misconceptions concerning the MEMOPAK 64K.

Hi-Fi Heights Revisited

Dear Sir,
I bought your magazine for the first time last week, solely to read your article on "Makin' Tracks", which was well set-out for first-time PCB etchers. Reading further into the magazine, I noticed some comments about 'Gremlins' (Letters, page 23), then further still, in 'Scaling the Hi-Fi Heights', a reference to Centrifugal Force throwing the cartridge away from the centre of a circle. Was this the Gremlins in action again, or have I just misunderstood your meaning?

This was, of course, that the frictional force between the stylus and the groove walls tends to drag the cartridge in the direction of travel of the groove. Where there is an offset angle in the cartridge mounting (you don't offer much background to this in your paragraph on Tracking Error!) this frictional force has a component inwards, at right angles to the arm and this is compensated for by a bias outwards, which varies according to the load on the stylus.

Perhaps you could have a word with your printers and get them to sort out their Gremlins?
B. A. L. Morgan,
Ledbury.

A month (or two) in publishing, as in politics, is a long time (with apologies to Sir H. Wilson); apologies also to D. G. Parker of Stroud in Gloucestershire, for our late comments on this subject.

Remembering that the series was, after all, an introduction to hi-fi and not a thesis, we admit that the explanation was less than complete. In fact, there are two mutually opposed forces acting on the cartridge. The first, due to centrifugal force, tends to throw the arm away from the centre of the disc and some compensation for this force (which is readily observable when using a flat, ungrooved test disc) must be applied. The second force is, as the writers correctly point out, due to the drag of the stylus tip against the groove wall and it tends to pull the arm into the centre of the disc. Once the effects of centrifugal force, or any misalignment of the arm tending to reinforce this, have been corrected, a small adjustment to the bias can then be made to compensate for the inwards-acting force. As with all measurements and adjustments, it is first necessary to have a stable reference point; this is the reason for the first adjustment, made using a test record. We hope this explanation has not been a drag.

Lastly, lest our printers feel gravely insulted, we must also admit that the Gremlins (or 'the fairies at the bottom of the darkroom', as a colleague calls them) mostly reside in our typewriters, here at the lavish offices of A.S.P.

HE

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160V: 10nF, 12n, 100n 11p; 150n, 220n 17p; 330n, 470n 30p; 680n, 38p; 1μF 42p; 1μ5 45p; 2μ2 48p.
1000V: 1nF 17p; 10nF 30p; 15n 40p; 22n 36p; 33n 42p; 47n 48p; 100n 50p; 470n 99p.

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15V	7815	40p		7915	45p
18V	7818	40p		7918	45p
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6V	78L62	30p		—	
8V	78L82	30p		—	
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15V	78L15	30p		79L15	60p

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OA85	15
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OA91	8
OA95	8
OA200	8
OA202	8
IN914	4
IN916	5
IN4001/2	5
IN4003	6
IN4004/5	6
IN4006/7	7
IN4148	4
IN5401	15
IN5404	16
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BT116	180
C106D	38
TIC44	24
TIC45	29
TIC47	35
2N5062	32
2N5064	38
2N4444	130

TRIACS

3A 100V	48
3A 200V	54
3A 400V	56
8A 100V	60
8A 400V	69
8A 800V	115
12A 100V	78
12A 400V	82
12A 800V	135
16A 100V	103
16A 500V	115
25A 800V	220
25A 1000V	480
T28000D	120

DIAC

ST2 25

TTL74

7400	11
7401	11
7402	11
7403	12
7404	13
7405	15
7406	20
7407	20
7408	14
7409	14
7410	14
7411	16
7412	18
7413	18
7414	20
7416	20
7417	20
7420	15
7421	20
7422	20
7425	24
7426	28
7427	22
7428	25
7430	14
7432	22
7433	22
7437	25
7438	25
7438	25
7440	15
7441	68
7442	32
7443	90
7444	90
7445	55
7446	60
7447	35
7448	40
7450	16
7451	16
7453	16
7454	16
7460	16
7470	30
7472	24
7473	24
7474	20
7475	32
7476	30
7480	40
7481	120
7482	65
7483	38
7484	70
7485	60
7486	20
7489	205
7490	20
7491	35
7492	25
7493	25
7493	35
7495	35
7496	40
7497	90
74100	80
74104	50
74105	55
74107	20
74109	25
74110	35
74111	56
74112	170
74116	50
74118	60
74119	80
74120	60
74121	25
74122	40
74123	40
74123	35
74126	35
74128	35
74132	28
74135	40
74136	28
74141	55
74142	175
74143	210
74145	50
74147	90
74150	50
74151	40
74153	40
74154	55
74156	40
74157	30
74159	80
74160	60
74161	48
74162	48
74163	48
74164	48
74165	48
74166	48
74167	150
74170	125
74172	275
74173	54
174174	54
74175	50
74176	40
74177	45
74178	80
74180	40
74181	115
74182	60
74184	90
74185	95
74186	470
74188	250
74190	48
74191	46
74192	46
74193	45
74194	45
74195	46
74196	46
74197	46
74198	84
74199	84
74221	64

74LS

LS00	11
LS01	11
LS02	11
LS03	12
LS04	12
LS05	13
LS08	12
LS09	12
LS10	13
LS11	13
LS12	12
LS13	20
LS14	30
LS20	13
LS21	12
LS22	13
LS26	12
LS27	12
LS28	14
LS30	12
LS32	13
LS33	14
LS37	14
LS38	15
LS40	13
LS42	28
LS47	35
LS48	45
LS55	14
LS63	120
LS73	18
LS74	18
LS75	20
LS76	18
LS83	36
LS85	48
LS86	16
LS90	24
LS92	32
LS93	23
LS95	40
LS96	40
LS107	40
LS109	23
LS112	22
LS113	16
LS114	22
LS122	36
LS123	36
LS124	90
LS125	24
LS126	35
LS132	40
LS133	30
LS136	26
LS138	28
LS139	28
LS145	70
LS147	150
LS148	85
LS151	40
LS153	40
LS155	30
LS157	30
LS158	30
LS160	37
LS161	37
LS162	37
LS163	37
LS164	43
LS165	60
LS166	62
LS170	70
LS173	55
LS174	50
LS175	40
LS181	95
LS190	36
LS191	36
LS192	36
LS193	37
LS194	33
LS195	33
LS196	38
LS197	48
LS221	55
LS240	55
LS241	55
LS242	55
LS243	55

CMOS

4000	10
4001	10
4002	12
4006	50
4007	14
4008	32
4009	24
4010	24
4011	10
4012	16
4013	20
4014	46
4015	40
4016	20
4017	32
4018	45
4019	25
4020	42
4021	40
4022	40
4023	13
4024	32
4025	13
4026	80
4027	20
4028	39
4029	45
4030	15
4031	125
4032	80
4033	125
4034	140
4035	45
4036	275
4037	115
4038	110
4039	290
4040	40
4041	40
4042	40
4043	40
4044	40
4045	105
4046	45
4047	40
4048	40
4049	25
4050	25
4051	45
4052	60
4053	50
4054	85
4055	85
4056	85
4057	1915
4059	435
4060	45
4061	1195
4062	995
4063	85
4066	24
4067	245
4068	14
4069	13
4070	13
4071	13
4072	13
4073	13
4075	13
4076	50
4077	13
4078	15
4081	13
4082	13
4085	50
4086	60
4089	125
4093	20
4094	70
4095	75
4096	70
4095	290
4097	190
4098	75
4099	190
4160	75
4161	99
4162	99
4163	99
4175	105
4194	105
4408	790
4409	790
4410	725
4411	690
4412	790
4415	480
4419	280
4422	770
4433	770
4435	850
4440	999
4450	350
4451	350
4490	350
4500	675
4501	28
4502	60
4503	35
4504	75
4506	35
4507	35
4508	130

ICs

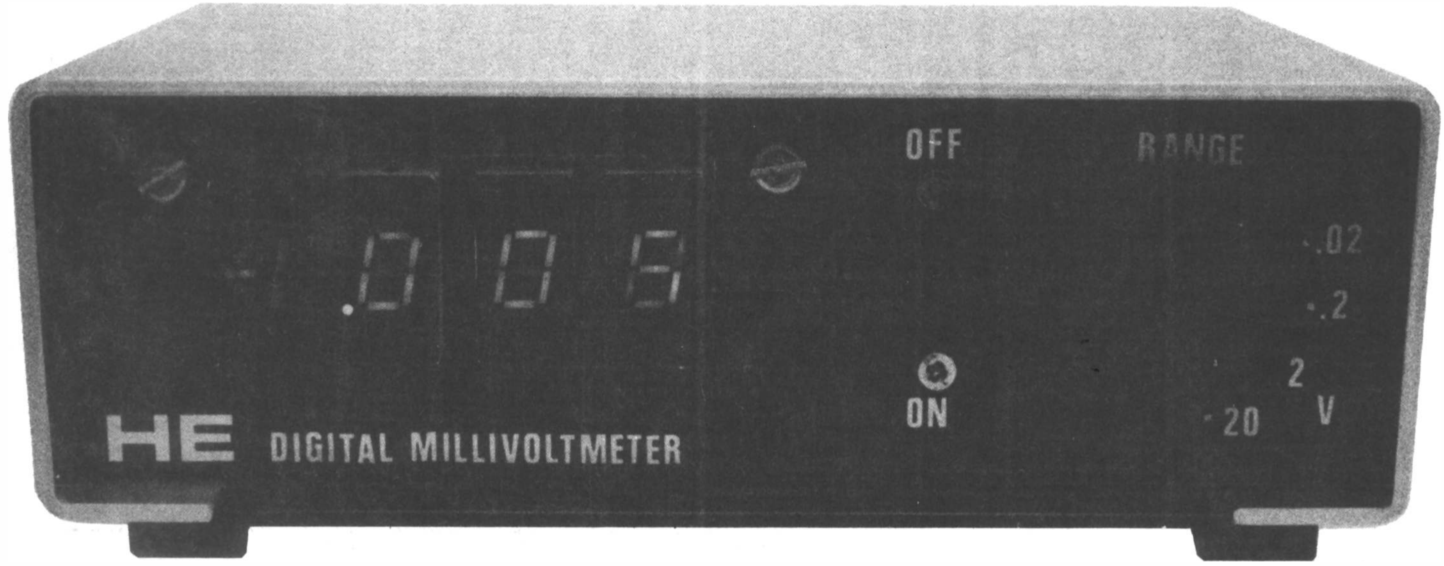
2114L-2	70
2708	225
2716	215
4116	70
4816 (BBC)	225
6116	390
6502	325
6522	320
6800	275
709C 8 pin	35
733	100
741 8 pin	74
747C	65
748C	36
753	185
810	159
81LS95	85
81LS96	85
81LS97	85
9400CJ	350
AY-1-1320	225
AY-1-5050	99
AY-1-5051	160
AY-3-8910	438
AY-5-1230	450
AY-5-1350	388
CA3011	130
CA3018	86
CA3020	210
CA3023	210
CA3028	95
CA3035	255
CA3045	365
CA3046	70
CA3048	220
CA3059	285
CA3075	213
CA3080E	70
CA3081	190
CA3085	95
CA3089E	200
CA3090AQ	375
CA3123E	150
CA3130	90
CA3140	40
CA3160	95
CA3161	160
CA3189	295
HA1336W	240
ICL7106E	750
ICL7107	975
ICL8038CC	300
ICM7204	550
ICM7205	1150
ICM7216A	1950
ICM7217A	790
ICM7224	785
ICM7555	80
ICM7556	150
LA3350	250
LA4031	340
LA4032	295
LA4400	440
LC7120	300
LC7130	340
LC7137	395
LF347	150
LF351	48
LF353	50
LF355	85
LF356	90
LF357	110
LF398	475
LM301A	24
LM308	95
LM311	70
LM318	150
LM319	215
LM324	30
LM339	47
LM348	64
LM349	115
LM358	60
LM377	175
LM379	480
LM380	75
LM381	145
LM382	115
LM384	140
LM386	90
LM387	120
LM389	95
LM393	100
LM394	290
LM733	100
LM1458	40
LM2917	195
LM3900	50
LM3302	90
LM3900	50
LM3909	85
LM3911	125
LM3914	210
LM3915	220
LM3916	220
LS7220	280
M252	625
M253A	1150
MC1303	88
MC1304P	260
MC1310	150
MC1455	150
MC1458	55
MC1488	55
MC1458	40
MC1469	300
MC1488	40
MC1489	55
MC1495	350
MC1496	70
MC1596	225
MC1648	290
MC1709G	90
MC1710	79
MC3302	150
MC3340P	120
MC3360P	120
MC3401	66
MC3403	75
MC3403	110
MFC6040	75
MK50398	635
ML924	250
MM5303	635
MM5307	1275
MM5387	47
NE529	225
NE531	14
NE543	225
NE544	210
NE555	16
NE556	45
NE560	325
NE561	398
NE562	410
NE564	420
NE565	120
NE566	155
NE567	140
NE570	410
NE571	400
NE5534	225
RC4136	69
S566B	225
SAB3209	425
SAB3210	325
SAB3271	485
SAB4209	595
SN76013	350
SN76023	350
SN76477	450
SN76488	480
SN76660	120
SL490	350
SP8629	299
TAA621	295
TA7120	150
TA7130	150
TA7204	200
TA7205A	90
TA7222	150
TAD100	159
TBA120	70
TBA641	290
TBA800	80
TBA810	95
TBA820	80
TCA965	120
TDA1004	290
TAD1008	310
TDA1022	499
TDA1024	105
TDA1490	325
TDA2004	495
TDA2020	320
TLO61	40
TLO63	80
TLO71CP	24
TLO72	45
TLO74	100
TLO81	24
TLO82	45
TLO83	75
TLO84	90
UAA170	170
UAA180	170
UA2240	120
XR2206	300
XR2211	575
Z80CPU	299
Z80A CPU	350
Z80A CTC	290
Z80 CTC	290
Z80PIO	260
Z80APIO	275
ZN414	80
ZN424E	130
ZN425E	345
ZN426E	300
ZN427	590
ZN428	410
ZN429	210
ZN1034E	200
ZN1040E	675

TRANSISTORS

AC125	35
AC126/7	35
AC128	30
AC141/2	30
AC176/87	30
AC188	30
ACY17/18	70
ACY20/1	75
ACY22	60
AD140	120
AD149	79
AD161/2	42
AF115	60
AF139	40
AF178	75
AF180/6	70
AF239	55
BC107/8	10
BC108B	12
BC108C	12
BC109	10
BC109B	12
BC109C	12
BC117/8	20
BC119	38
BC137	40
BC140/3	30
BC147/8	9
BC149	9
BC153/4	27
BC157/8	10
BC159	11
BC160	45
BC167A	10
BC168C	10
BC169C	10
BC170	15
BC171/2	11
BC177/8	16
BC179	20
BC182/2L	10
BC813/L	10
BC184	10
BC184L	10
BC186/7	26
BC212	10
BC212L	10
BC213	10
BC213L	10
BC214	10
BC214L	10
BC307B	14
BC328	95
BC338	15
BC441	34
BC461	34
BC477	40
BC516/7	40
BC547/8	12
BC549	14
BC556/7	15
BC558/9	15
BCY70	18
BCY71	18
BCY72	20
BD131/2	48
BD133	60
BD135	45
BD136/7	40
BD138/9	40
BD140	40
BD695A	99
BD696A	99
BDY17	195
BDY60	160
BDY61	160
BF115	35
BF167	29
BF173	27
BF177	25
BF178	30
BF179	35
BF180	38
BF194/5	12
BF196/7	12
BF198	18
BF200	30
BF224A	25
BF244	28
BF256	35
BF257/8	32
BF259	35
BF594/5	40
BFR39/40	23
BFR41/79	23
BFR80/81	25
BFX29	28
BFX81	45
BFX84	28
BFX85/6	28
BFX87/8	28
BFY50/1	23
BFY52	23
BRY39	40
BSX20	20
BSY65	35
BSY95A	25
BU105	170
BU205	190
BU208	200
E113	45
E176	50
E421	250
MJ2955	70
MJE340	54
MJE370	100
MJE371	100
MJE520/1	95
MJE2955	70
MJE3055	70
MPF102	40
MPF103	30
MPF104	30
MPF106	40
MPSA05/6	25
MPSA12	30
MPSA55	30
MPSA56	30
MPSU06	55
MRSU56	60
OC35	125
OC36	120
OC41/2	75
OC44	75
OC45/70	40
OC71/2	40
OC76	50
OC81/2	50
OC83/4	40
OC170/1	50
TIP29A	32
TIP29C	38
TIP30	48
TIP30A	35
TIP30C	37
TIP31A	38
TIP31C	37
TIP32A	38
TIP32C	42
TIP33A	65
TIP33C	78
TIP34A	74
TIP34C	88
TIP35A	110
TIP35C	128
TIP36A	130
TIP36C	140
TIP41A	50
TIP41B	52
TIP42A	55
TIP42B	58
TIP120	70
TIP121/2	73
TIP141	105
TIP142	105
TIP147	120
TIP2955	60
TIP3055	60
TIS43	32
TIS44	45
TIS88A	50
TIS90	30
TIS91	32
VK1010	80
VN10K	55
VN46AF	78
VN66AF	80
VN88AF	94
ZTX107/8	11
ZTX109	12
ZTX300	13
ZTX301/2	16
ZTX303	25
ZTX304	17
ZTX314	25
ZTX326	30
ZTX341	30
ZTX500	14
ZTX501/2	15
ZTX503	18
ZTX504	25
ZTX531	25
ZTX550	25
2N526	58
2N696	30
2N697	23
2N698	40
2N699	48
2N706	19
2N918	35
2N930	20
2N961	65
2N1132/2	24
2N1304	65
2N1305	60
2N1306/7	65
2N1671B	120
2N2160	350
2N2219A	28
2N2220A	23
2N2222	25
2N2369A	18
2N2476	58
2N2483	27
2N2497	63
2N2646	45
2N2894	30
2N2904	28
2N2905A	26
2N2906/7	26
2N2926G	10
2N3053	26
2N3054	58
2N3055	48
2N3121	30
2N3133	45
2N3135	30
2N3252	46
2N3442	140
2N3568	25
2N3663	15
2N3702/3	10
2N3704/5	10
2N3706/7	10
2N3708/9	10
2N3710/11	10
2N3713	140
2N3771	179
2N3772	195
2N3773	210
2N3819	22
2N3820	38
2N3822/3	45
2N3866	90
2N3903/4	15
2N3905/6	15
2N4037	46
2N4058	10
2N4061/2	15
2N4069	45
2N4859	78
2N4871	55
2N5135/6	20
2N5138	18
2N5179	45
2N5180	45
2N5191	75
2N5305	24
2N5457/8	30
2N5459	30
2N5485	30
2N5777	45
2N6027	32
2SA636	250
2SA671	250
2SA715	60
2SC495	70
2SC496	70
2SC1061	250
2SC1096	85
2SC1173	125
2SC1306	100
2SC1307	150
2SC1449	85
2SC1923	50
2SC1945	225
2SC1953	90
2SC1957	90
2SC1969	140
2SC2028	85
2SC2029	210
2SC2078	170
2SC2091	85
2SC2314	85
2SC2166	165
2SC1679	190
3N128	112
3N140	112
40311	60
40313	130
40316	95
40317	80
40324	100
40326	60
40327	70
40347	90
40348	120
40360	60
40361/2	70
40407	60
40408	70
40411	285
40412	90
40467	130
40468	85
40594	105
40595	110
40603	110
40636	175
40673	85

Digital Millivoltmeter

Owen Bishop



A high precision bench instrument based on a single VLSI chip.

THIS IS an item of precision test equipment which will be in constant use on the electronics work-bench, as well as being frequently called on for jobs around the home. It is battery-powered, to give it portability, and its compact layout makes it almost pocket-sized. In spite of the fact that it is built from only two ICs, its detailed specification (see box) includes most of the features found in an instrument costing appreciably more to buy ready-made.

Compared with its analogue counterpart, a digital voltmeter is an instrument of considerable complexity. To assemble an analogue voltmeter, you need only a milliammeter, a set of precision resistors and a rotary switch. An essential part of a digital voltmeter is the ingeniously designed circuit which converts the analogue voltage input into its digital equivalent. This, in itself, is a fairly complex operation if it is to be performed with precision (see **How It Works**). The final stage of conversion consists of the output from a series of decimal counters, one for each digit. The next step is to convert the counter output to a decimal number to be shown on a set of 7-segment displays. When the number of digits in the display is 3 or greater, it is more economical to use a multiplexed display, where the digits are each illuminated, in turn, for a very short period. The rate of turning the digits on and off is so high that, to the eye, it appears that they are continuously lit. As each digit is illuminated, the output from the corresponding counter is decoded to produce the correct figure for that display. Only one decoder IC is needed to serve all the digits, instead of one for each digit. This saves expense on decoder ICs but the multiplexing circuit requires a pulse generator (or clock) to time its opeations, plus the switches required to connect each counter, in turn, to the decoder.

To build such a circuit using MSI (Medium Scale Integration) ICs requires 2 dual counters, a decoder, a clock IC, another IC for the multiplexing counter and 2 or more for the multiplex switches, making a total of 7 ICs — as a modest estimate! The complexity of the wiring, and the difficulties of setting up and testing each stage, make the assembly of a circuit of this kind a daunting project for the inexperienced constructor. Fortunately, VLSI (Very Large Scale Integration) has made it possible to put all of the above (and more) on to a single slice of silicon!

Although it costs only as much as the total cost of the individual ICs listed above, the 7107 chip carries a complete digital millivoltmeter, including the analogue-to-digital converter, the counter, and all the circuitry required to multiplex and drive the display. All the constructor needs to do is to provide the circuits which cater for the various ranges of input voltage, to add the few external components which the 7107 requires, and to assemble the display digits on a panel. This is still plenty enough to do, so VLSI does not rob the constructor of the interest and satisfaction of building a useful and attractive instrument.

Circuit Details

The input potential dividers consist of R1, together with RV1 and R2 (2 V range) or RV2 and R3 (20 V range). These are set to divide the input voltage by 10 and 100 respectively. The dividers are brought into action by grounding the lower resistor of each, using switch SW2b. The voltage from the potential dividers is selected and passed to the IC by SW2a. For the 200 mV range, neither potential divider is grounded, so only the 10M resistor (R1) comes between the input socket and the IC. It might be thought that such a high resistance would seriously reduce the voltage reaching the IC, however, the current needed by the +ve or −ve inputs for a full-scale reading is only 1 pA (a millionth of a millionth of an amp). With so little current, the maximum voltage drop across R1 is only 0.05 mV, which can certainly be ignored.

The high resistance of R1 also serves to protect the IC from a high voltage, accidentally applied. If, by chance, the +ve socket is connected to 1000 V, say, the current flowing

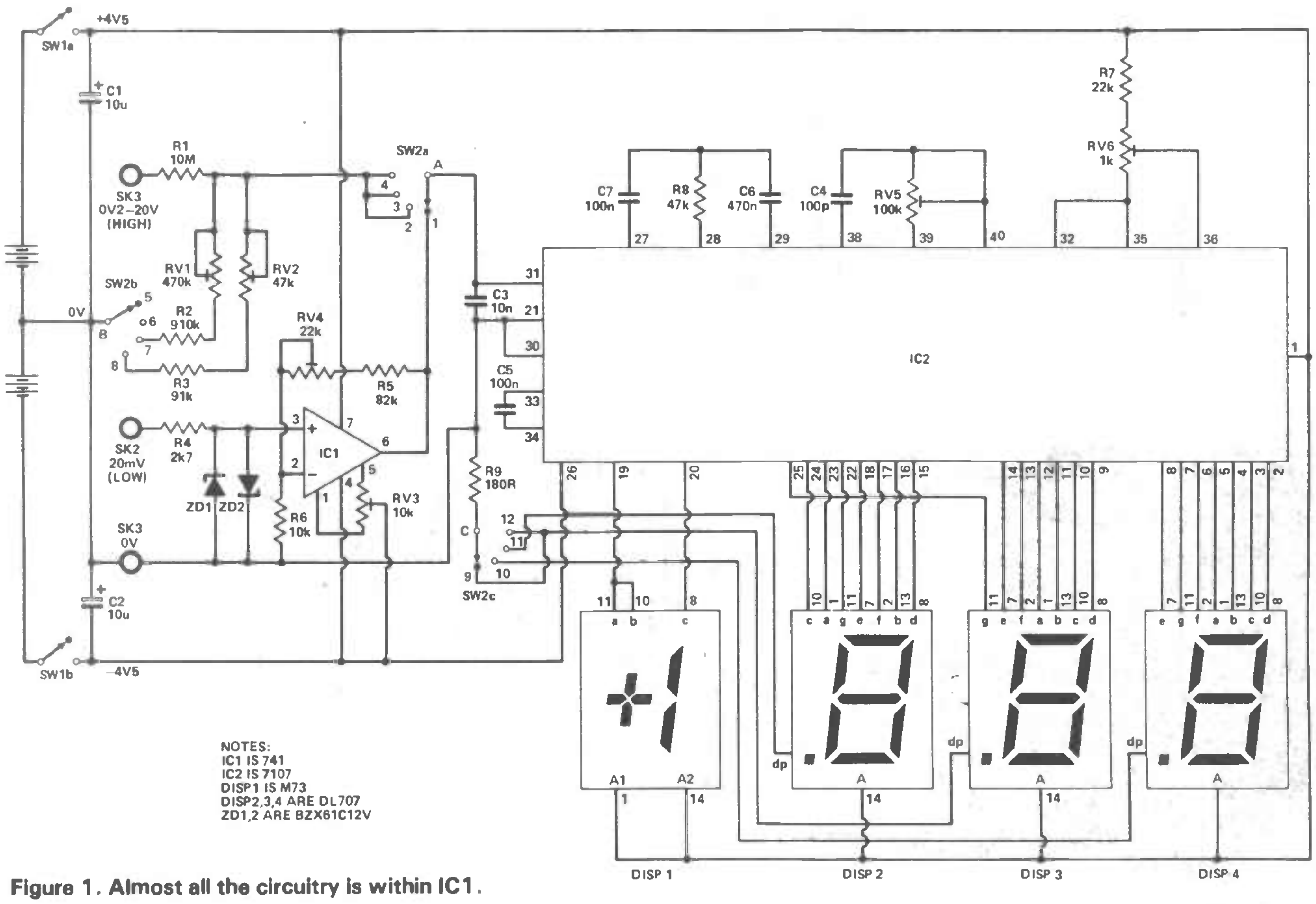
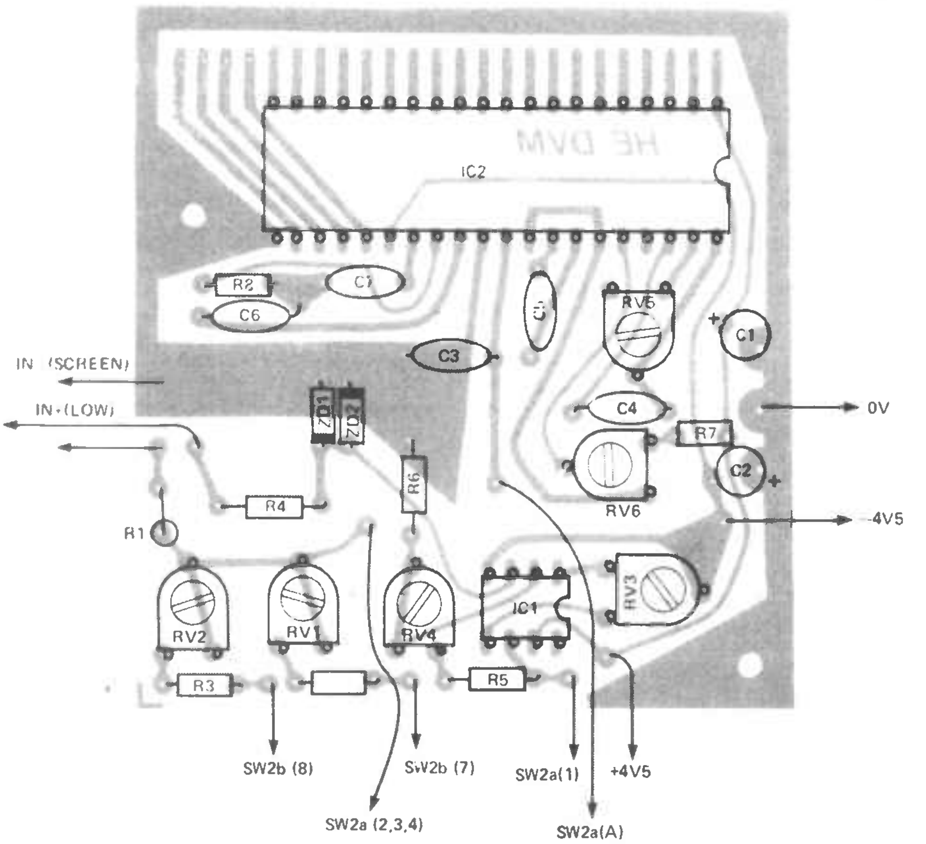


Figure 1. Almost all the circuitry is within IC1.



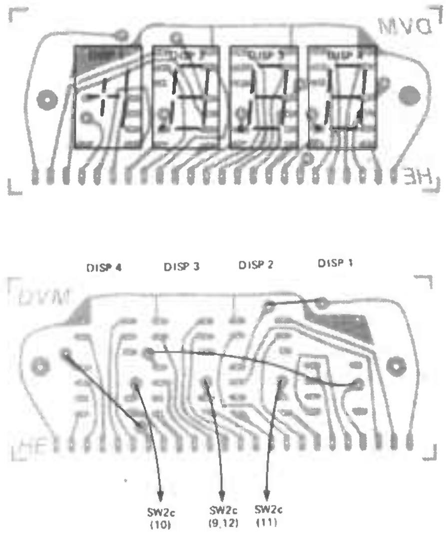


Figure 2. The component layout (Left) is straightforward, but care is needed when wiring the jumper leads to the display board (see Figure 4).

Figure 3. The display board; top, the view from the component side; bottom, the foil side, showing the wire links which must be soldered in place.

through R1 will be only 100 uA. Since the input can take up to this current without damage, R1 gives full voltage protection against ± 1000 V on the three upper ranges. On the 2 V and 20 V ranges, R1 and one of the potential dividers are connected across the input lines. The input impedance on these ranges is therefore a little over 10M . On the 200 mV range, the input impedance is that of the input of IC2 itself, equivalent to $2x10^{11}$ ohms.

The operational amplifier (IC1) used on the 20 mV range is connected in a non-inverting configuration. There is a potential-divider (R5, RV4, R6) connected to the output (pin 6), so that one tenth of the output voltage is fed back to the inverting input. The offset null compensation is provided by setting RV3. Input protection is a little more elaborate on this range; R4 provides part of the protection, the remainder being provided by the zener diodes ZD1 and 2. The diodes are connected with opposite polarity, so that protection is independent of the polarity of the input. The input of IC2 can withstand up to 15 V but before this voltage is reached one of the diodes begining to conduct. The resistor, R4, serves to reduce the current through the zeners when an excessively high voltage is applied. With 100 V on the input the voltage drop across R4 is 88 V, giving a current of 33 mA, which is well within the rating of the zeners. In normal use, R4 presents only a small addition resistance, in series with the input impedance of IC1, so its effect on input voltage may be ignored.

DVM Circuits

The oscillator in IC2 uses the external components RV5 and C4. RV5 is adjusted to give a clock frequency of approximately 48 kHz, which is divided down by internal logic to give a display renewal rate of 3 times per second. RV6 and R7 set the reference voltages; to give 200 mV full-scale reading, RV6 is adjusted until the voltage at its wiper is 100 mV. C7 is the capacitor used in the integrator, while C6 stores the correcting charge required for the auto-zero function. R8 links the input buffer amplifier to the integrator, and is the resistor through which C6 and C7 are charged and discharged during ramp and auto-zero operations.

One of the advantages of the 7107 is that it drives the segments of the displays directly eliminating the need for 23 current-limiting resistors. The displays are of the common anode type, the cathodes of the individual segments being wired to the corresponding pins of IC2. Each of these sinks the right amount of current, to illuminate the segment. The decimal points are switched by the range-change switch SW2c. A single current-limiting resistor (R9) is required in the return connection of the 0 V line.

Construction

If the circuit is to be assembled in a case of the recommended type, keep carefully to the specified dimensions because the individual items fit closely together within the case. Before laying out the etching pattern on the boards, check that all the components have sufficient space, particularly the preset resistors and the polycarbonate capacitors. Both boards may then be etched and drilled.

The LED board (**Figure 3a,b**) is simple to assemble. Insert the teminal pins before soldering the displays in position; they are placed with their heads flush with the display side, with the pins projecting out on the track side of the board. The displays are then pushed into position. Solder the pins of the displays and the terminal pins, then make the wire links as shown in **Figure 3b** — except for the connections to the decimal-point pins, which are best left until later. Connections between the LED board and the main board are by 24 wires. The 20-way jumper cables suggested for this purpose make it very easy to insert the ends of the wires in the row of holes and solder them in position. The standard 20-way jumper cable is only 85 mm long so the relative positions of the boards, as shown in the internal photograph, **Figure 4**, must be closely adhered to. If you wish to mount the boards further apart, use 20-way ribbon cable intead, or even 24 separate wires, though either will take a lot longer to solder, with increased possibility of short-circuits between adjacent wires. Now solder the jumper cables to the LED board; use one complete 20-way cable and split a 5-way or 20-way cable to make the 4-way cable needed for the remaining 4 connections.

To test the board, connect the +4V5 line to a 4V5 or 6 V battery, through a 180R resistor. Then touch a wire, connected to the 0 V terminal of the battery, to each of the other wires of the cable, in turn. Check that each segment lights correctly and, if it does not, inspect the soldering and tracks. In the +1 digit, both segments 'a' and 'b' of the '1' light together. Only segment, c of the '+' sign is used, giving a '−' sign to indicate reversed polarity. When

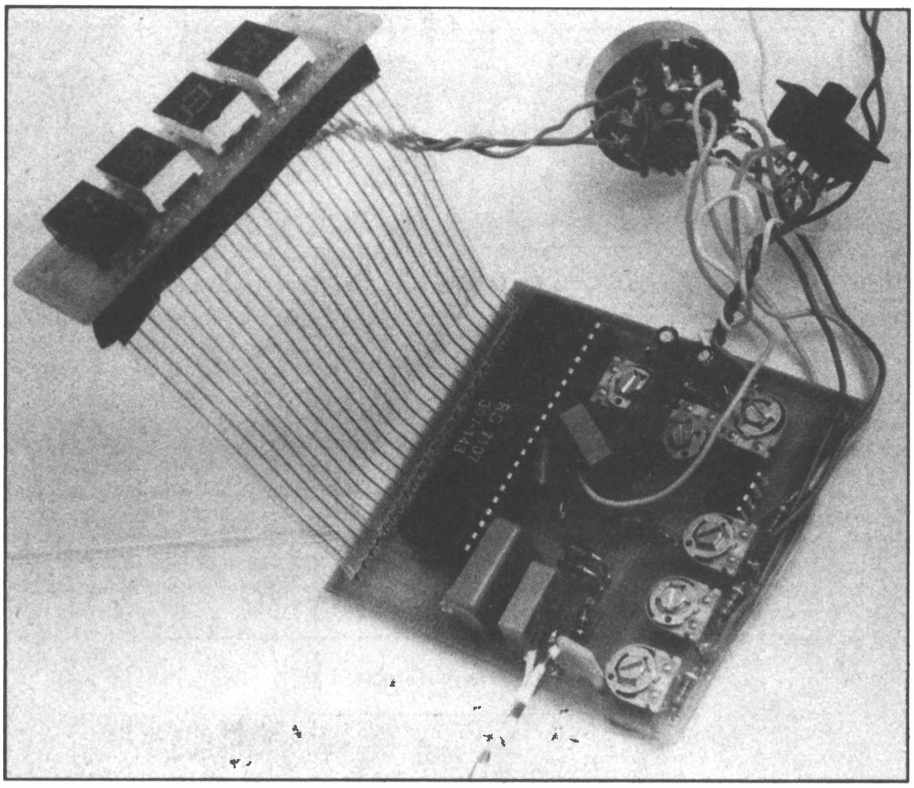


Figure 4. An 'exploded' view of the Millivoltmeter, before final assembly.

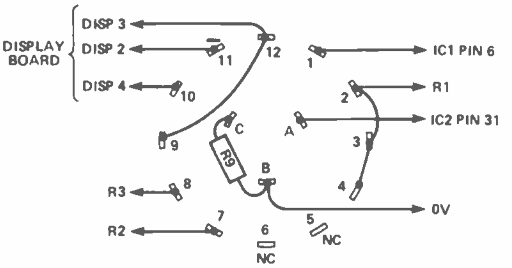


Figure 5. Wiring diagram for the range switch (SW2).

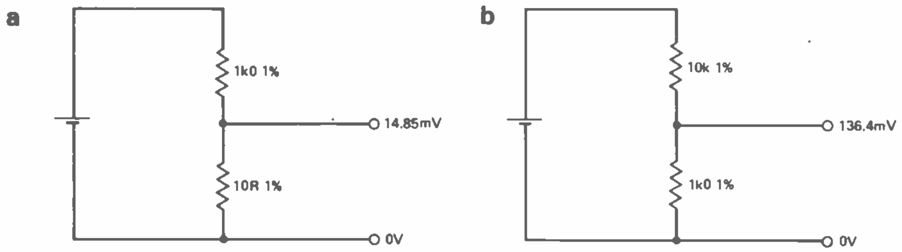


Figure 6. (a) a low voltage source for testing the 20mV input; (b) a battery-based voltage reference.

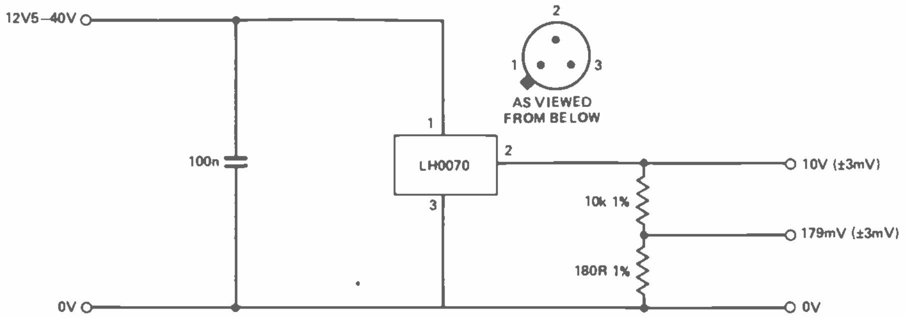
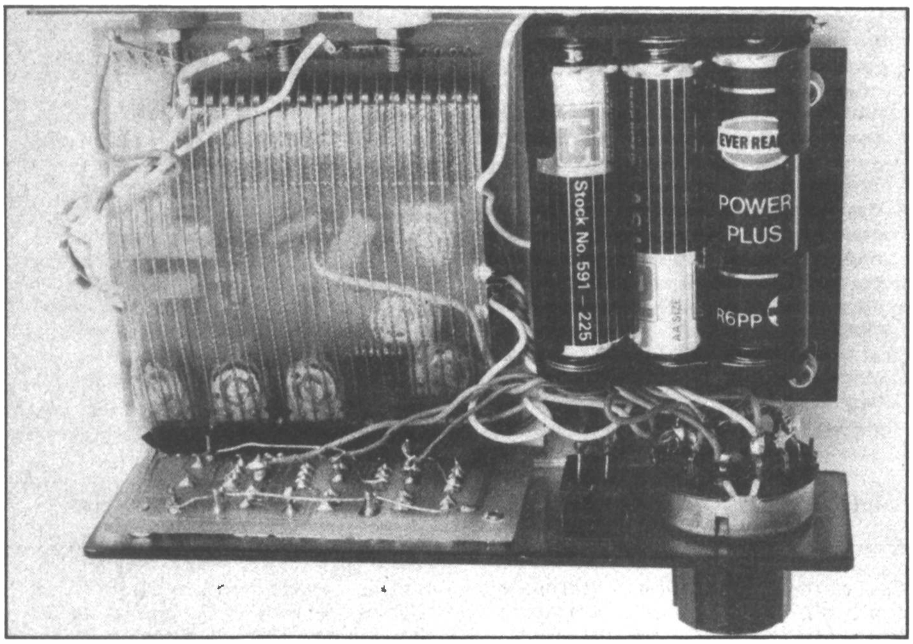


Figure 7. A precision voltage reference is preferable.



polarity is normal, the '+'sign is not lit.

It is highly advisable to use a socket for IC2, but it is not worth while for IC1. Mount the socket and other components, but do not insert IC2 until the whole board has been assembled and tested as far as possible. Solder leads to the power supply pins, the input terminal pins and the leads to the rotary switch, SW2 (**Figure 5**), taking care that these are long enough to run from the board to the intended position of SW2, but not so long that they will take up an undue amount of room in the enclosure. Finally, solder the jumper cable to the board.

Testing The Main Board

To test the input circuits, temporarily connect the power supply and connect a 6 V battery to the +ve and −ve input pins. With SW2 switched to the appropriate range and using a borrowed meter, measure the voltage at its wiper. All voltages are measured with respect to the 0 V line, which is common with the −ve input terminal. Unless your test instrument has very high input impedance, the voltage you find at SW2 will be very much lower than expected. For example, if your test meter has 2M0 input impedance then, since it is in series with R1, five-sixths of the voltage is dropped across R1 and the voltage at SW2a will be only one sixth of the expected value. At this stage, though, the point is simply to check that some sort of signal gets through, showing that none of the soldered joints are 'dry' and that no tracks are incomplete. This is also a check against unintended high voltages (from the power supply) appearing, due to short-circuits between tracks.

To adjust the offset null of IC1, first connect the 20 mV input pin to the −ve input pin. Adjust RV3 until the output of IC1 (read at pin 6 or at the wiper of SW2a) is 0 V. Next, make up a low-voltage source (**Figure 6a**) for testing the 20 mV input circuit. Connect this to the 20 mV and −ve input pins and adjust RV4 until the reading on the test meter is approximately 150 mV, indicating an input voltage of 15 mV. Exact setting can be left until later, but it is worth while getting it approximately correct at this stage. Now position the wipers of RV5 and RV6 to the middle of their tracks.

After a thorough check to see that all components directly connected to IC2 have been correctly mounted and properly soldered, and that there are no broken tracks or short-circuits, plug IC2 into its socket. This is a CMOS IC and the usual precautions, to avoid static charges, must be taken when handling it.

Power Supplies

The specified supply is a battery-pack consisting of six HP7 cells, wired to produce ±4V5. The 7107 is actually designed to operate at ±5V so, if you are a TTL enthusiast or frequent builder of microprocessing systems and already have a bench power supply delivering 5 V DC, it is quite in order to use this instead. You will need a −5 V supply too, a point which is discussed later.

The maximum supply rating for the IC is +6 V and −9 V, so it is also feasible to use an 8-cell split supply, giving ±6 V. The main effect of this is to brighten the display, which could be a useful feature under bright ambient light. You will need a larger case to accommodate the extra cells though, so while you are about it, you might as well adopt 'C' size or 'D' size cells, for longer life.

The negative supply does not need to have exactly the same voltage as the positive supply. The current required on the negative side is much smaller too, since it is from the positive side, only, that the current for the display is drawn. This makes it possible to adopt a different method of providing the negative supply, in which the positive supply comes from a battery (or a mains power-pack), but the negative supply is generated by diode level shifting. There is a very inexpensive inverter IC for doing just this and a very simple project for using it will appear next month. This, in fact, was the method used for the prototype of the DVM, in which three 'C' cells and an inverter gave entirely satisfactory results.

Calibration

The following instructions are for a preliminary calibration, which serves also to check the operation of the circuits and the IC; it is best carried out before mounting the boards in the case. If the circuit fails to respond correctly, switch off the power and check it. This procedure should also be repeated for the final calibration, after the board has been mounted in the enclosure.

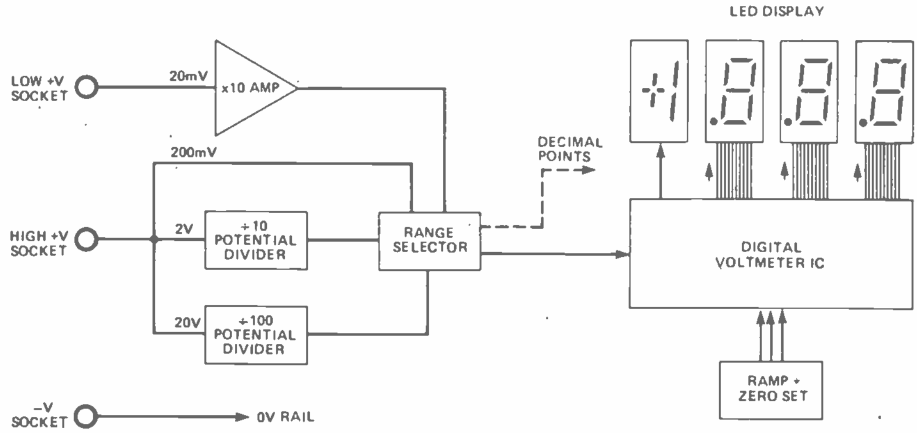
On applying power, the display should light and, after flashing one or two random figures, should settle down and display figures close to '000' and ' – 000'. For accurate calibration it is best to use a precision voltage reference, with a potential divider (**Figure 7**). This IC is relatively expensive and most readers will probably be content with the less accurate alternative, a single dry cell (**Figure 6b**).

Connect the 0V rail of the reference source to the –ve input, turn SW2 to the 200 mV range and connect the +ve input to the 136. 4 mV point. As the reading settles, the display should change about 3 times a second; adjust RV5 so that this rate is obtained, approximately. Alternatively, monitor pin 40 with an oscilloscope and adjust RV5 to obtain a frequency of 48 kHz. You may see the display flash (the last 3 digits extinguished and the '1' flashing); this is the *over-range* indication — but don't worry about it at this stage.

Adjust RV6 until the display reads '1364', (no decimal points, yet), occasionally showing close values between about '1360' and '1370'. Now change the range switch to 2 V and use the 1V5 cell direct. Adjust RV1 until the reading '1500' is obtained, then change to the 20 V range and adjust RV2 until a reading of '0150' is obtained. Change to the 20 mV range and connect the 14.85 mV source to the +20 mV input; adjust RV4 to obtain a reading of '1485'.

It must be stressed that although this is a high-precision instrument, giving a *reading* to 1 in 2000 counts (0.05% of full scale), its *accuracy* depends on the care with which it is calibrated and the accuracy of the sources used. If you have access to a meter of similar high precision and input impedance, it is worth while checking your instrument against this.

How It Works



THE DVM IC requires an input of 200 mV to give a full-scale reading of 2000 counts. The attenuator stages of the cirucit produce an input to the IC of up to 200 mV for each of the input ranges except on the 20 mV range, where there is a x10 operational amplifier. On the 200 mV range, the input goes direct to the IC; on the 2 V and 20 V ranges, potential dividers reduce the input to 200 mV, maximum.

The IC converts an input voltage in the range 0 to 200 mV to a digital count in the range 0 to 2000 counts. The operating principle is known as the 'dual ramp technique'. The IC goes through three stages of operation automatically, three times a second; at the first stage, the input is connected to an integrator circuit, charging a capacitor for a fixed period of time, determined by the internal clock of the IC. The voltage to which this capacitor is charged depends on the input voltage and it is charged positively or negatively, depending on the polarity of the input.

In the second stage of operation, the capacitor is discharged by connecting it to a reference voltage. There are two reference voltages; +REF, which is used when the polarity of the input is negative and –REF, which is used when the polarity is positive. While discharging is occurring, a counter operates at a fixed rate, determined by the internal clock. Discharge is terminated when the charge on the capacitor has reached zero, at which point (the beginning of the third stage of operation) the number of counts registered is a measure of the original input voltage. This count is then decoded and sent to the LED display.

In the third stage, the +ve and –ve input lines are connected together and a special auto-zero capacitor is charged with a small

DVM Specification

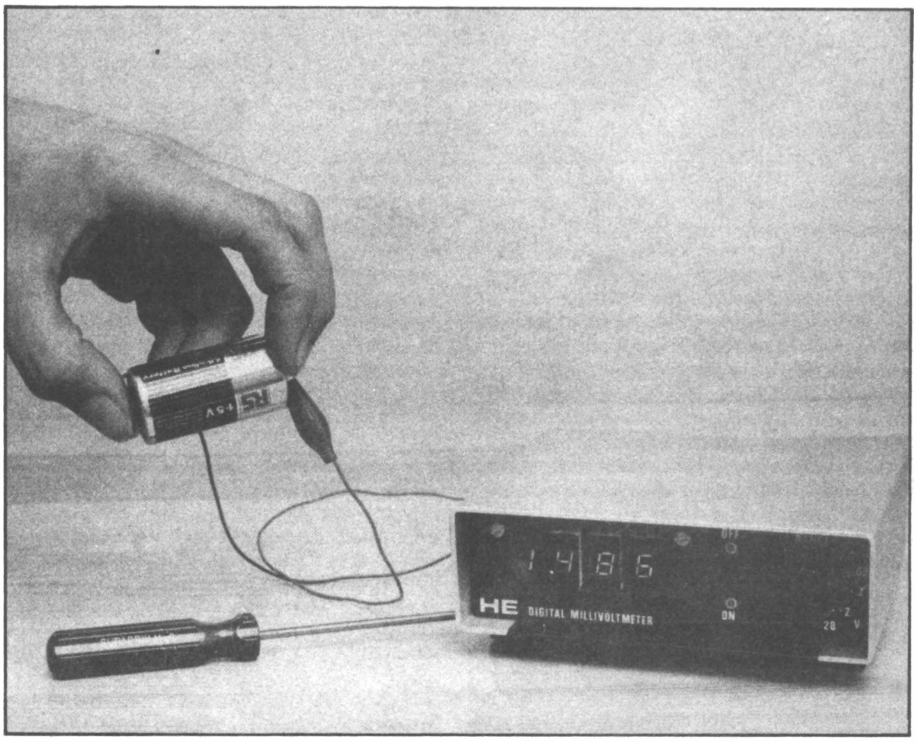
Four switched DC ranges with 0.05% counting precision on all ranges:
- 0 — 20.00 mV
- 0 — 200.0 mV
- 0 — 2.000 V
- 0 — 20.00 V

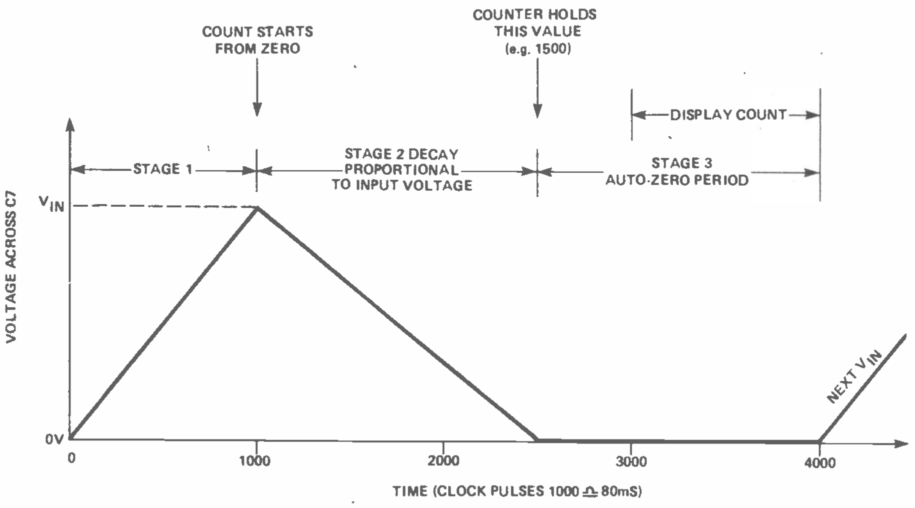
High-impedance input: Over $2x10^{11}$R on 200 mV range, over 10M on 2 V and 20 V ranges, over 2M on 20 mV range.

Conversion rate: display refreshed 3 times per second.

Automatic polarity indication.
Over-range indication.
Auto-zero.

Battery-powered (6 x HP7 cells), allowing measurement of differential voltage levels.





voltage, to compensate for differential voltages appearing at the amplifier outputs; any drift in the output is reflected as a change in the charge on this capacitor. At the next stage-one operation, this charge is used to correct the reading; should there be no input voltage, the charge compensation gives an all-zero reading, but should there be an input voltage, a small value is added to or subtracted from the result, compensating for amplifier drift.

The dual ramp techique gives a precise result yet does not require many high-precision or high-stability components. For example, charging and discharging both involve the *same* capacitor (C7) and resistor (R8), so that their exact values do not matter and there are no problems if these should alter with temperature or with age. In addition, each stage begins and ends at the same voltage, thus cancelling out errors and the effects of drift in the comparator amplifier.

Nor must the frequency of the clock be exact or stable; if the clock is running slow, charging proceeds for *longer,* and a higher voltage is reached, but during the longer discharge stage, the counter counts *more slowly* because it is triggered by the *same* clock. The clocking error cancels out completely, leaving the final count entirely unaffected!

Precison circuits are required only in setting the voltage levels and holding the discharge current constant. Circuits of this kind are relatively easy to incorporate into an IC, making it possible to produce a precise instrument for relatively low cost.

Parts List

RESISTORS (All ¼ watt 5% metal film unless noted)

R1 . . . . 10M (1%)
R2 . . . . 910k
R3 . . . . 91k
R4 . . . . 2k7 (1%)
R5 . . . . 82k
R6 . . . . 10k (1%)
R7 . . . . 22k
R8 . . . . 47k
R9 . . . . 180R

POTENTIOMETERS (All Cermet min. horizontal presets)

RV1 . . . . 470k
RV2 . . . . 47k
RV3 . . . . 10k
RV4 . . . . 22k
RV5 . . . . 100k
RV6 . . . . 1k

CAPACITORS

C1,2 . . . . 10u 6V radial electrolytic
C3 . . . . 10n metallised polycarbonate
C4 . . . . 100p siver mica
C5,7 . . . . 100n metallised polycarbonate
C6 . . . . 470n metallised polycarbonate

SEMICONDUCTORS

ZD1,2 . . . . BZX61C12V zener diode
DISP1 . . . . M73 common anode ±1 LED display
DISP2,3,4 . . . . DL707 common anode seven segment display
IC1 . . . . 741 op-amp
IC2 . . . . 7107 digital panel meter IC

MISCELLANEOUS

SW1 . . . . DPDT miniature slide switch
SW2 . . . . 3P4W rotary switch
SK1,2,3 . . . . . 4mm terminal post

20-way jumper or ribbon cable; 40 pin DIL socket; small knob; case (see Buylines); 9V x 'AA' battery holder; PP3 clip; nuts, bolts, wire, solder etc.

Buylines . . . . page 34

If you are unable to do this, do not rely on the fourth figure of your reading as an absolute indicator of voltage. Even the third figure is suspect when 2% resistors are used in the calibration procedure. However, if you measure two voltages and merely want to know by how much they differ, subtraction of one reading from another, made on the same range, removes many of the inaccuracies of calibration and you can be reasonably confident of the result to the nearest millivolt.

Final Assembly

The first step is to cut and drill the front and rear panels, and to add the legends. Also, cut a notch in the cover of the case, to allow for one of the bolts holding the main board. There is not much room to spare inside the case but, provided that you tackle assembly in the right order, everything will slip smoothly into position. First, mount the main board on its two bolts; take care that the tracks do not contact any metal parts of the case beneath the board. The recommended case has bosses, to which the cover of the case is bolted; one of these projects upward, beneath the board, and may make contact. To guard against this, stick a square of insulating tape on the track side of the board in this region. Next, mount the rotary switch, which is already wired to the board.

The input sockets project from the back panel and come close to IC2. You may find it more convenient to remove the back panel from the case before fitting the sockets to it. Note the V-shaped notches cut in the mounting holes. These align the sockets so that wires may be inserted in a vertical direction. When the sockets are in place, connect them to the main board, remembering that the jumper cable lies across the top of the board, eventually, so make these connections long enough to go around the cable.

Next wire up the power supply and connect it to the board. The easiest way to secure the battery pack in position is to fix it to the bottom of the case, using a 'Sticky Fixer' or a lump of Blu-Tack. At this stage, the circuit is complete and it is worth running through the calibration procedure once again to check that nothing has been altered during assembly. At this stage, the display is still suspended on the end of the jumper cable allowing access to the presets. Before closing up, run a strip of insulating tape across both sides of both ends of the jumper, to guard against short circuits.

When all is working correctly, gently bend the jumper so that the display board comes to its correct location. Fix it to the front panel by its bolts — you may need to use insulating washers to avoid short-circuiting the tracks. Check that nothing is protruding from the top or sides of the case, then slide the cover into position. The digital millivoltmeter is now complete and ready for action!

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Beginners Guide To Construction

Roger Harrison

We continue our occasional series for newcomers with this concise, practical guide to constructing electronic circuits and projects.

THERE ARE several different ways of building electronics projects. The simplest by far is to use a printed circuit board. Other methods of construction include stripboard (Veroboard), matrix board and tag strips. Each method has advantages and disadvantages.

Matrix Board

This is a phenolic material (like very hard cardboard) perforated in a grid pattern. It is a brittle material though quite strong -dont bend it too much or it will fracture. Cutting it to size is a simple matter. Score along a line of holes with a pen knife or similar, clamp it along the score on the edge of a sharp corner, such as the edge of a bench or table, and bend or strike the overhanging portion sharply. It should fracture cleanly along the score.

You use it by inserting the components through the holes and making interconnections by joining the components across the back (non-components side) of the board. It all sounds a bit messy but it's surprising how quickly circuits can be assembled, and with a bit of care they look quite neat.

Another advantage of matrix board is that components and wiring can be placed exactly as shown on the circuit diagram. The main disadvantage is that the back of the board becomes a bit of a rat's nest if you try to build a complex circuit. Another minor drawback is that the finished job doesn't look like a totally professional unit.

Tag Strips

Tag strips consist of a series of metal tags mounted on an insulating strip. The strips in turn are mounted on two or more further metal tags which are used to screw the whole lot down onto a chassis.

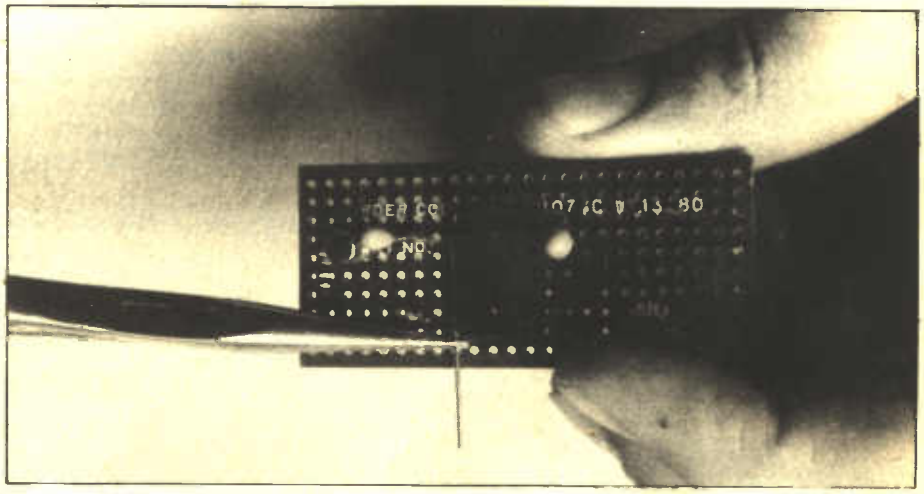
Component leads should never be wrapped more than three quarter-way roung a tag. If you twist them right round you'll have an awful job trying to remove them, if you need to, at a later date.

Tag strip construction is quick, cheap, and simple but the method is only really suitable for small scale projects as inter-tag wiring is otherwise extensive and tedious. This method also wastes space.

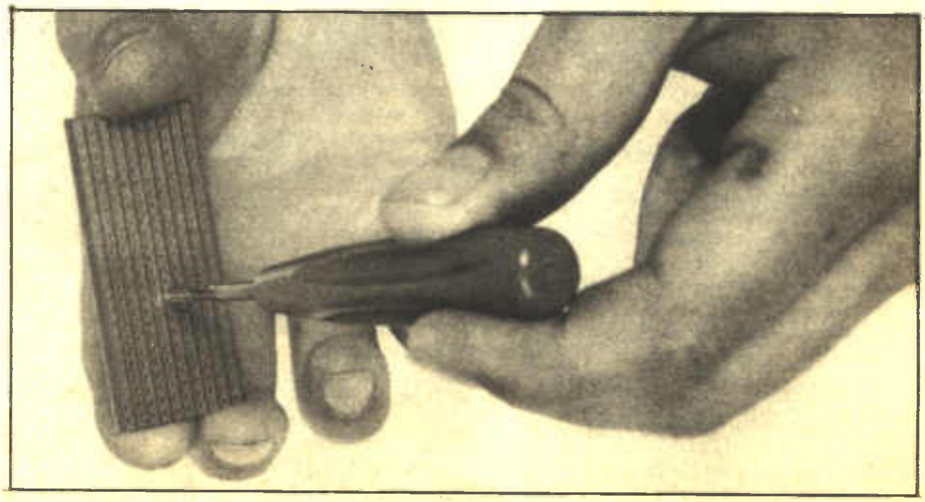
Veroboard

This is made from a material similar to that used for matrix board, but with lines of copper (referred to as 'strips' or 'tracks') embedded in it. The strips are spaced 0.1" apart and the holes in the strips, though which components are inserted, are also at 0.1" intervals.

Veroboard is easily obtainable in large pieces which can be used for a big job, or cut down to suit a smaller circuit. It is simple to use and if the component layout is worked out in advance, it can result in a neat finished appearance. It is fairly easy to make mistakes, though. One very important point to watch is that components which are not meant to be connected are isolated by cuts in the copper strip (these are easily made either with a suitable sized drill bit or with a special tool). A wise constructor will always check the layout against the circuit diagram to make sure that all components are in the right holes, in the right strip, and that the leads of a transistor, for example, are only joined to those components shown on the circuit, and to no others. Two other points to note are that the loose copper which results from cutting the tracks is not joining adjacent strips, and that after soldering, no solder bridges have been accidentally made.



Assembling a circuit on matrix board.



Using the special tool to cut Veroboard tracks. A drill bit is as usefull

Printed Circuits

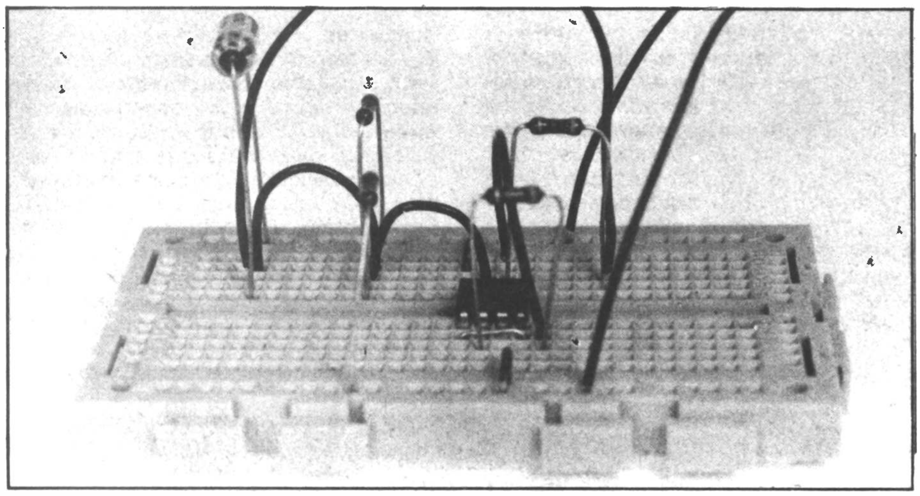
Printed circuit boards simplify electronic circuit building enormously.

The board material is made of phenolic resin or glass fibre with a thin copper sheet bonded to (generally) one face. Intercomponent wiring is formed by etching away the unwanted copper — so that only the tracks and components mounting pads remain.

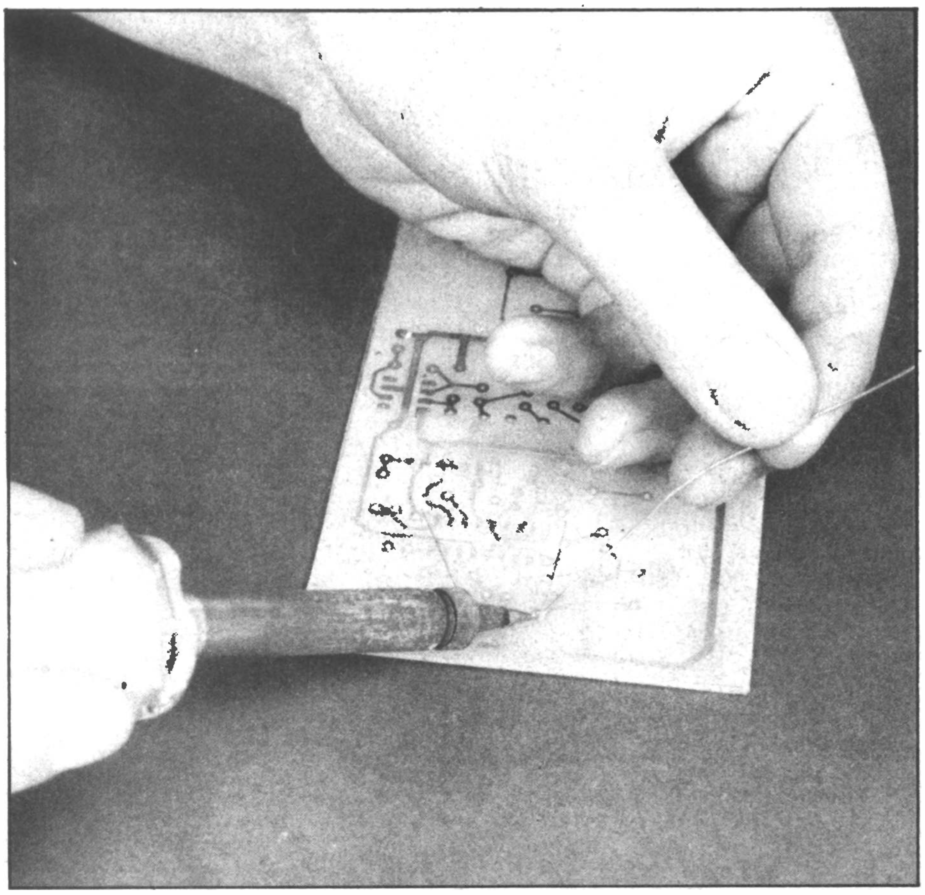
Holes are drilled for the components which are then inserted through from the non-copper side and their leads soldered directly to the copper pads. Printed circuit boards have a number of significant advantages over other methods of construction. The biggest is that mistakes are less likely to occur. Most of the wiring is right there, etched onto the board, and the drilled pattern is such that in many instances components will only fit the right way round. The finished article looks professional — it is how most professional equipment is made.

The disadvantages are that printed circuit boards are more expensive than other methods; there is also less personal involvement.

Most component suppliers stock PCB material for those who wish to make their own. It is not that difficult but may be messy and even dangerous, because of the powerful chemical used to etch away the unwanted copper. A complete description of how to make PCBs is beyond the scope of this article; a detailed description of the method, using a sealed etch kit, appeared in the February issue of Hobby Electronics. Pre-etched and drilled PCBs, ready for assembly, are available for most HE projects from out PCB Service.



A modern 'breadboard' block — useful for prototyping a circuit but not for permanent use!



Soldering components onto a printed circuit board.

Soldering

Good soldering is vital — most of the problems that beginners have with their first projects are due to poor joints. The following hints will aid you to become adept at soldering.

- Purchase a good quality iron with a rating between 15 and 25 watts.
- Use only resin-cored solder (60/40 tin-lead content). Do not use acid flux.
- A new, or worn, iron will need tinning. To do this let the iron get quite hot and file the tip smooth to expose fresh clean copper. Quickly, before the copper has time to discolour, apply resin-cored solder — it should flow all over the tip forming a shiny coating.
- Keep your soldering iron clean. Wipe it frequently with a damp cloth or sponge.
- Make sure the connection to be soldered is clean. Wax, frayed insulation and other foreign substances will result in inferior joints.
- With older components, or copper wire, it will be necessary to clean and tin the individual components before soldering them together.
- Attach the wires to be soldered. Do not make more than a half turn in a lead to be soldered — twisting makes subsequent removal difficult.
- Heat the connection with the iron and apply solder to the joint.
- Keep the iron on the point until the solder just commences to flow on the connection. Too little heat results in a high-resistance joint (known as a dry joint). Too much causes component damage and evaporates the tin component, again causing a poor joint. This step requires practice.
- Let the solder harden before moving the connection. Then check for a smooth bright joint. A joint that has been moved will have a crystalline appearance, may have a high resistance and will fracture easily.

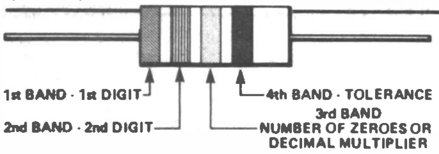
Good soldering is a matter of practice. If you follow the above hints, it will be only a matter of time till you are making professional joints.

Finding Your Way

Most beginners have little trouble identifying components after a little experience, but remembering which way around they go can often prove somewhat confusing! Here's how to avoid the pitfalls and assemble projects knowing you've put the components in correctly and how to make simple substitutions.

Resistors

Resistors are fairly straightforward components. If you see the value and wattage specified for a project, there's little that can go wrong. A colour code chart is a handy guide if you are not completely



STANDARD RESISTOR COLOUR CODE			
COLOUR	DIGIT VALUE	MULTIPLIER (No. OF ZEROES)	TOLERANCE +%
BLACK	0	1	
BROWN	1	10	1
RED	2	10^2 or 100	2
ORANGE	3	10^3 or 1k	
YELLOW	4	10^4 or 10k	
GREEN	5	10^5 or 100k	
BLUE	6	10^6 or 1M	
VIOLET	7	10^7 or 10M	
GREY	8	10^8 or 100M	
WHITE	9	10^9 or 1000M	
GOLD	–	0.1 or 10^{-1}	5
SILVER	–	0.01 or 10^{-2}	10
NONE	–	———	20

HIGH STABILITY (GRADE 1) RESISTORS ARE DISTINGUISHED BY A SALMON-PINK FIFTH RING OR BODY COLOUR

Reading resistance values from a colour-code chart.

familiar with how to read the value from the coloured bands painted on the body of the component.

Resistors are not 'polarised' — that is, it doesn't matter which way round you put them in.

They can be damaged by clumsy handling. Don't bend the leads too near the body of the component, this can fracture the end or the main body — the lead may even come right off. Don't apply excessive heat to the leads when soldering or hold the iron to the joint for too long. It is sufficient just to have the solder flow properly to make a good joint — a 'little extra' may do more harm than good.

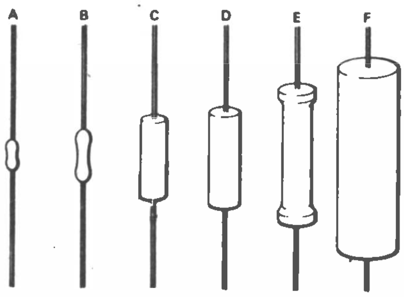
In many instances the exact value of a resistor in a circuit is not too important and you can substitute a resistor one value up or one value down from that specified without causing any great change in a circuit's operating conditions. For example; either a 2k7 or a 3k9 resistor may be substituted where a 3k3 value is specified. Don't do this with high wattage resistors or high stability resistors (1% or 2%). A resistor having a smaller tolerance rating may always replace one of a greater tolerance rating of the same value. For example: a 4k7, 10% resistor may be replaced by a 4k7, 5% type.

Similarly, half-watt resistors may be substituted for quarter-watt resistors, provided they physically fit.

Potentiometers

These are simply adjustable resistors. Commonly, they consist of a resistance 'track' with a moveable 'wiper' connection that can be varied from one end of the resistance track to the other. Thus, they have three terminals.

This is where most newcomers come unstuck. The one in the middle is always connected to the wiper (shown as an arrow on the circuit symbol). This leaves the other two connections to sort out! On a rotary pot, with the shaft pointing at you and the terminals pointing at your feet, when the shaft is rotated clockwise (normal direction for 'up' or 'increase' — whatever the control is doing) the wiper



WATTAGE RATING					
SIZE	TYPE	@40°C	@20°C	LENGTH	DIA
A	CARBON FILM		0.05	4mm	1.5mm
B	COMPOSITION		0.25	6.5mm	2.3mm
	CARBON FILM		0.25	7mm	2.3mm
	METAL FILM		0.25	7mm	2.5mm
	METAL OXIDE		0.125/0.25	7.2mm	2.5mm
C	COMPOSITION		0.5	10mm	3.5mm
	CARBON FILM	0.5	0.33	9mm	3mm
	COMPOSITION	0.35	0.2	10.3mm	4.3mm
D	COMPOSITION	0.5	0.25	11.5mm	4.1mm
	COMPOSITION	0.35	0.2	12.7mm	5.3mm
	CARBON FILM	0.5	0.25	11mm	4mm
	METAL FILM		1.0	12mm	5.5mm
	METAL OXIDE		0.25/0.5	11.2mm	4.2mm
E	COMPOSITION	0.75	0.35	17.8mm	4.1mm
	CARBON FILM		1.0	14mm	4.8mm
F	COMPOSITION	2.0	1.0	30mm	7.8mm
	CARBON FILM		4.0	24mm	8mm

The characteristics of some common resistors.

will be approaching the right hand terminal. If it's a volume control, that'll be maximum volume and therefore the maximum signal point should connect to the right hand terminal. Got it?

Even if you don't get it right in your project, it's easy to correct — simply reverse the connections to the two outer terminals!

The value and 'law' of the potentiometer required for a circuit will be specified with the project. It is not a good idea to substitute. The 'law' of the potentiometer simply refers to the way in which the resistance varies as you move the wiper. The two most common forms are 'linear' and 'logarithmic'. A linear law (or 'curve') pot changes its resistance in a manner directly proportional to the amount the wiper has been moved, whereas logarithmic (or log) law pot varies resistance logarithmically as the wiper is moved linearly.

Log pots are predominantly used as volume controls. Linear pots are used for current or voltage control in circuits. A linear pot will be marked 'A', while a log pot will be marked 'C'.

Capacitors

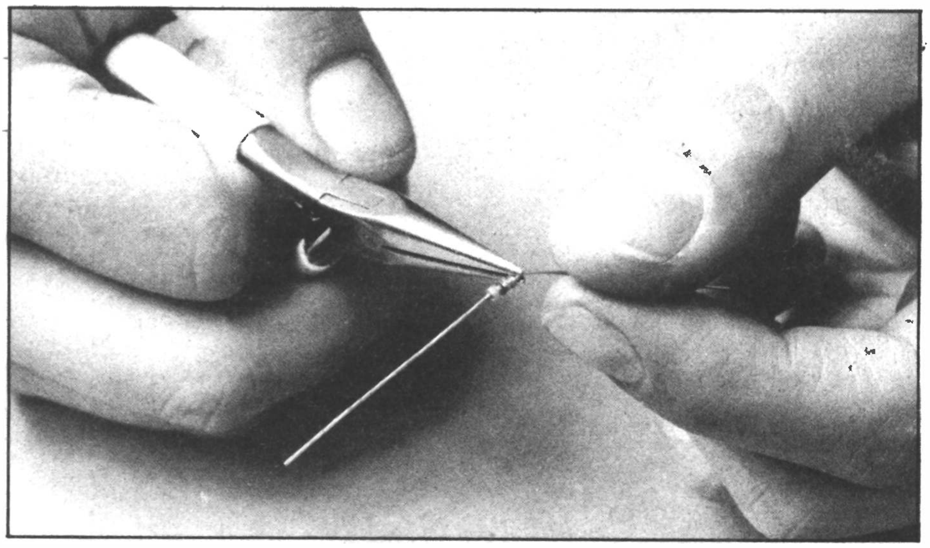
Capacitors come in a wide variety of shapes, and sizes, types and ratings. The important thing to remember is that there are polarised and non-polarised types. Electrolytic and tantalum capacitors are polarised and you must take care which way round they are connected in a circuit. All the others are non-polarised. Of the latter, we mainly specify polyester and ceramic types. These are the most common. They may be inserted either way round.

A polarised capacitor always has some marking to indicate which lead is which. Many are made with a black stripe adjacent to the negative lead. Some have a '+' and a '–' sign near the respective leads. Always check that you have inserted or connected polarised capacitors the right way round. They won't work otherwise — and that's about the worst that will happen in a battery-operated circuit. A wrongly-connected electrolytic in a mains-operated circuit (even at low voltages) may very well explode! Messy . . . . . worse if you have your face nearby when it happens.

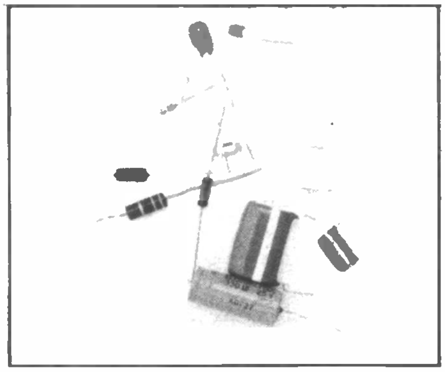
In general, capacitor values should be adhered to; subsititution is not recommended unless you are very familiar with the way a circuit works and the role of the particular capacitor. Voltage rating is important, particularly with electrolytics and tantalums. Never use a capacitor rated at a lower voltage than specified. You can go upwards, though. For example; if a project calls for a 10 uF, 16 V type then a 25 V rated capacitor of the same value may be substituted.

Diodes

Diodes are polarised components. There is always a right way and a wrong way round. If you use it the wrong way round you may well destroy the device. Fortunately, they always have some sort of mark identifying the cathode end. It may be a band around that end of the body ad-

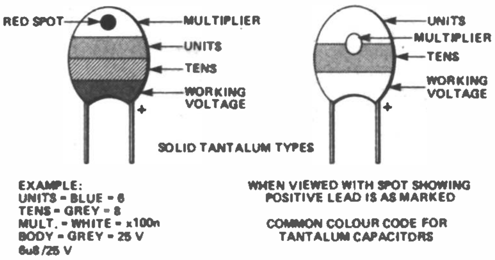


Bend it but don't break it!



A selection of components.

COLOUR CODE FOR TANTALUM CAPACITORS			
COLOUR	VOLTAGE	TENS & UNITS	MULTIPLIER
BROWN	–	1	x10
RED	–	2	x100
ORANGE	35 V	3	–
YELLOW	6V3	4	–
GREEN	16 V	5	–
BLUE	20 V	6	–
VIOLET	–	7	–
GREY	25 V	8	x10n
WHITE	3 V	9	x100n
BLACK	10 V	0	x1u
PINK	35 V	–	–



Interpreting the colour-code of tantalum capacitors.

jacent to the cathode lead, or the body maybe chamfered at the end. We generally indicate on the construction diagram with our projects the polarity of any diodes. Alternatively, a small diagram may accompany either the circuit or the construction diagram showing diode body shapes and markings and how these relate to the diode symbol.

Any substitutes will usually be mentioned in the parts list accompanying a project or in the Buylines page. However, as diodes are generally rated in terms of voltage (maximum reverse voltage, not conducting), it is always safe to substitue a diode with one having a higher rating than specified — never the other way around, and never substitute a silicon signal diode for a germanium signal diode.

Transistors

For most purposes a transistor is either the right one or it's not. It is rarely possible to substitute another type which some one may recommend as 'just the same', though, substitutes or equivalents may be mentioned in the parts list, or in Buylines.

A transistor can only be connected one way round — the right way! The construction diagram or component overlay with a project will indicate which way the pins are to be inserted in a PCB. Connected incorrectly, there's a good chance you'll destroy the device when first switched on.

Incredibly, not all transistors of the same type number have the same pin connection. Sometimes a manufacturer may vary the pin connections of a type at different times! Transistor pin connections and orientations are given in the construction diagram or component overlay.

Transistors (and diodes) may be damaged by excessive heat when soldering. Although, these days, it is no longer really necessary to use a 'heatsink' (pliers or a special tool) when soldering small transistor leads — as has been often recommended in the past — a little care and speed when soldering is a good idea. Just get the solder flowing neatly over the joint, 'wetting' it properly, and things should be fine. Don't overdo it.

Integrated Circuits

Integrated circuits must be soldered in the right way round. They always have some identification — usually in the form of a small scallop in one end of the case or a small indentation adjacent to a pin at one end (this is pin 1). They should be inserted exactly as shown in our overlay drawings. Do make sure they are the right way round before soldering because once in they're very hard to get out again.

Because of this it's well worth while spending a bit more on IC sockets. These are plastic sockets which have identical pin connections to the IC and into which, in turn, the IC is plugged. It's not always worthwhile because some ICs are so cheap that the socket costs more than the IC, but they are worth considering for use with expensive devices.

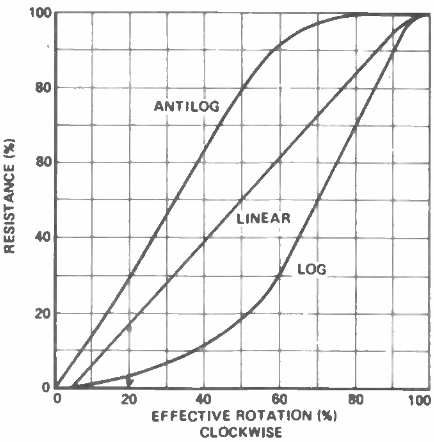
Like transistors, most ICs are stronger than they look, but don't overdo the soldering — it is very easy to get a tiny solder 'bridge' between the pins.

CMOS ICs are a bit different. These are very tough — once soldered in — but are a bit fragile until then.

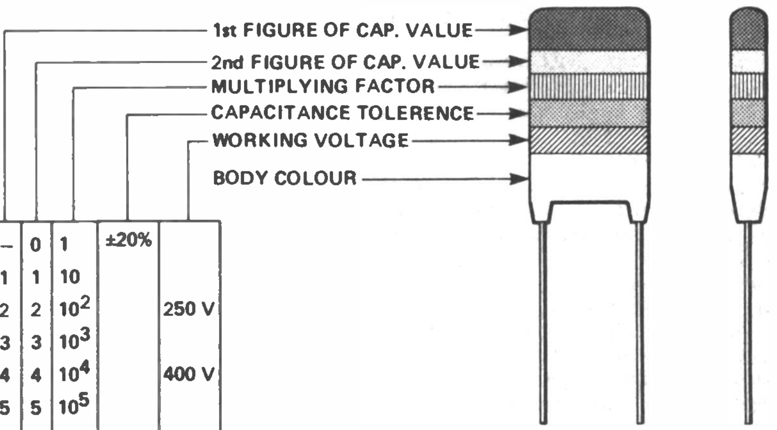
They should be handled with care as they are easily damaged by quite small static charges. CMOS ICs are supplied inserted in a conductive plastic foam or foil-wrapped styrene block. Remove them carefully. Take care to pick them up with your thumb and forefinger grasping the ends of the package, not touching the pins. Make sure you have them correctly oriented before inserting them into a PCB.

When soldering CMOS ICs use an iron having an earthed tip and barrel. If you're unsure about this, use a clip lead to connect the iron's barrel to the negative supply rail on the board. These measures will ensure you don't 'blow' CMOS ICs from either static or leakage currents.

HE



Linear and log are the two most common potentiometer 'laws'. Antilog, though useful in some cases, is not often found in our circuits.



COLOUR	1st FIGURE	2nd FIGURE	MULTIPLYING FACTOR	TOLERENCE	WORKING VOLTAGE
BLACK	–	0	1	±20%	
BROWN	1	1	10		
RED	2	2	10^2		250 V
ORANGE	3	3	10^3		
YELLOW	4	4	10^4		400 V
GREEN	5	5	10^5		
BLUE	6	6			630 V
VIOLET	7	7			
GREY	8	8			
WHITE	9	9		±10%	

The values of polycarbonate and polyester capacitors can be read from the chart.

Always leave CMOS ICs until last when assembling a project. Once removed from the packaging, insert them quickly and first solder those pins connected to the power rails — generally pins 7 and 14 for most 14-pin packages, but check with the diagram beforehand. This ensures any static charges are dissipated by the other components.

LEDs

Light emitting diodes are very handy little solid-state indicators and for that reason are widely used. Common colours are red, yellow and green although orange is available and we believe blue will be available shortly. Some are clear but glow red.

Being diodes they are polarised. They are not usually damaged if incorrectly connected — but they won't work. The polarity of the leads may be indicated in several ways. The most common is to have a flat section on the case adjacent to the cathode lead. Some have one lead shorter than the other — the cathode lead being shorter.

LEDs will last forever. We don't know of any that have worn out yet! They must be used at the correct current rating and if this is exceeded . . . poof! You will generally find a resistor connected in series with a LED in a circuit. Don't ever test a LED by connecting it across a battery. Best way to test one is to wire it into a circuit known to work.

LED connection diagrams generally accompany the circuit or component overlay with our projects.

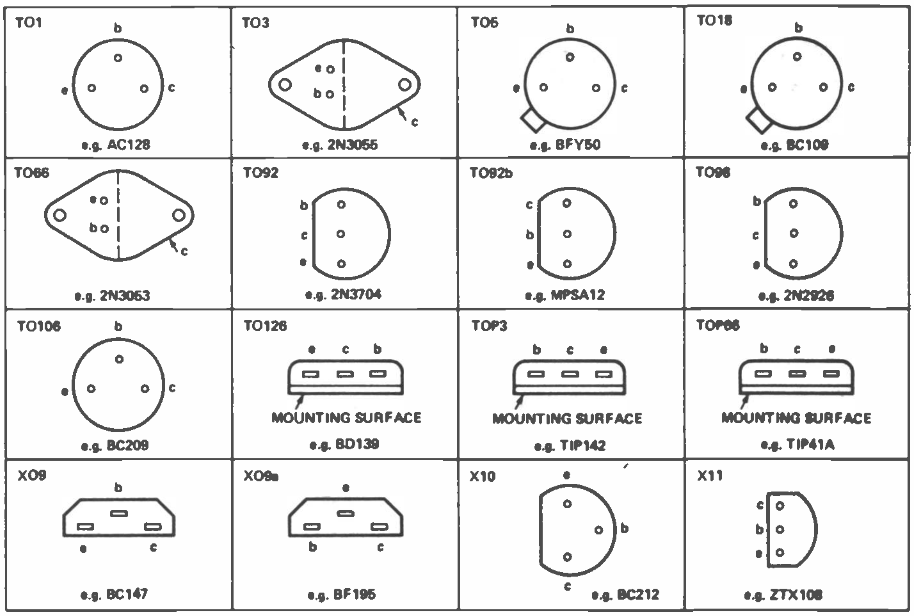
Loudspeakers

Small speakers are a common item in simple projects. In general, the unit chosen is not critical.

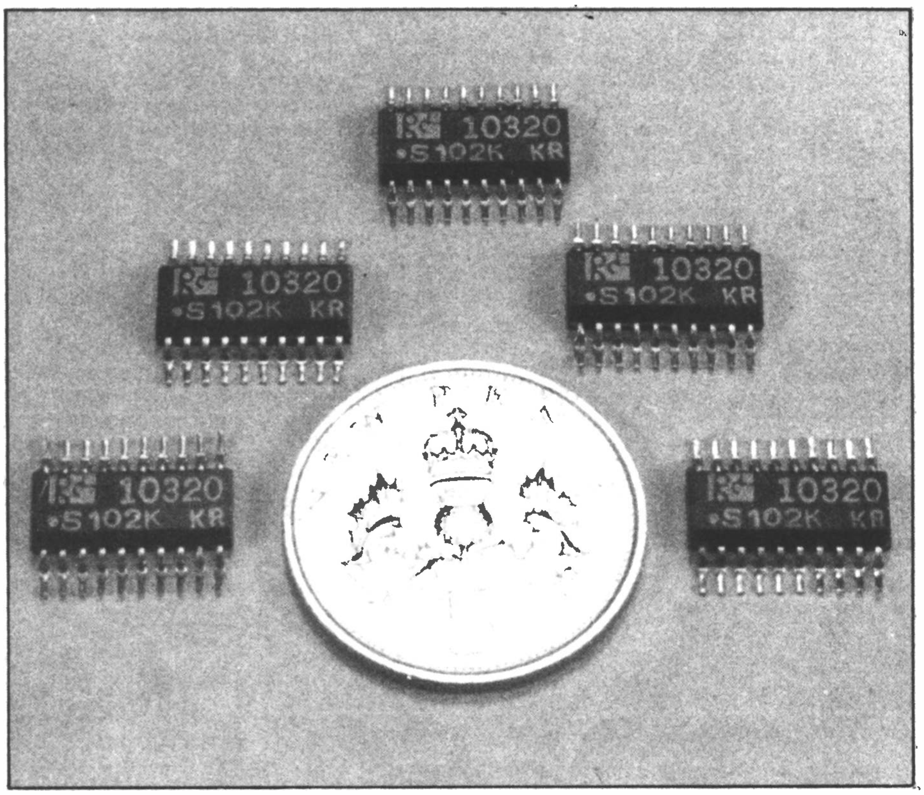
They are made in varying levels of quality, size and impedance. Quality is unimportant. Frankly we'd go for the cheapest you can find! Impedance is specified in each project parts list.

Speakers are not polarised — you may connect them either way round.

If the speaker doesn't make a noise when the project seems to work otherwise it's fairly easy to check if you've got a faulty one. Check by touching the leads momentarily across a 1½ volt cell — not a nine volt battery. If the speaker is working it produces a loud click. Don't leave the cell connected for more than a fraction of a second or you'll end up knowing that the speaker was working but isn't any longer!



The pin configurations of some often-used transistors.



ICs continue to become smaller while packing in more functions.

Conclusion

As a last caution, make sure you connect the battery or power supply to your project correctly, otherwise you may never know whether it worked or not! Most of our battery-operated projects use 9 V batteries. The battery clips used with these have a red and black lead for connections. The red one is the positive lead, the black, negative. This is the colour coding for supply connections. Keep it in mind.

That just about wraps up the majority of things you should learn and keep in mind when it comes to constructing basic projects, and you will learn a whole host of other interesting and useful things as you progress. The best teacher is experience, as they say in the classics!

Light Blue Touchpaper

Electronic circuits are not fireworks but they sometimes share a tendency to do the unexpected — or simply not to perform as expected. If a circuit doesn't work, the most probable causes of the trouble are:

(a) Components inserted the wrong way round or in the wrong place.
(b) Faulty soldering.
(c) Solder bridges between tracks.
(d) Faulty components.

These are simply the *most* probable causes of a project not working — there are many others which are more difficult to detect. Further articles in this magazine will deal with some of the techniques used in fault-finding. These are applicable both to previously built projects and to brand new circuits, hot off the breadboard. So, if all else fails — keep reading Hobby Electronics! **HE**

BUYLINES

LAST MONTH we presented several projects that were — or could be — powered from solar cells, but we found considerable difficulty in locating inexpensive sources for them.

Now we have found a reasonably inexpensive source of solar cells — somewhat after the event, but "better late than never". The company concerned is **Rheinbergs Sciences Ltd**, Sovereign Way, Tonbridge, Kent TN9 1RN. They do a bag of mixed solar cell 'chips', of varying size, producing between one and six milliamps at 0V45 under load. The bag contains 50 chips and costs £10.95, all inclusive.

Digital Millivoltmeter

The 1% resistors (vital for accuracy) are available from several of the larger suppliers, but for a good bargain, try **Ace Mailtronix Ltd.**, at 3A Commercial Street, Batley, West Yorks WF17 5HJ. **ElectroValue** are a good company to contact for the cermet presets — quite hard to find — and the 20-way ribbon or jumper cable. They can also supply the case used for our prototype. The M73 (±1) and DL707 displays come from **Watford**, along with the 7107 digital panel meter IC. The cost of components (excluding case and PCBs) will be about **£20**.

Audio Analyser

Naturally, with a project of this kind, there are quite a few components you may have problems obtaining. The 430R resistor is quite critical — 470R or 390R won't do — but they are not too hard to find; try **Ace Mailtronix**, who can also supply the LF353 dual BIFET op-amp. The only supplier we could find for the 1u0 metallised polycarbonate capacitor was **Maplin** (PO Box 3., Rayleigh, Essex SS6 8LR) and since they sell a cheap electret microphone (code YB33L) as well, it's worth contacting them.

The 220u 16V axial electrolytic capacitor is sold by **Watford**, who can also supply the TL064 as well as the CMOS ICs. For a suitable case, try writing to **Lightning Electronics** and, for the IC sockets, **Rapid** and **TK** are both very reasonable. The LEDs used on our prototype were from **Bi-Pak**, who do a bargain pack of these commonly used devices. Alternatively, and for that special touch, **Zaerix** will supply — to Hobby readers only — 100 off quantities of their high intensity cylindrical LEDs at £12.30 plus VAT and postage. Their address is Zaerix Electronics Ltd., Electron House, Cray Avenue, St. Mary Cray, Orpington, Kent BR5 3QJ.

The cost of the analyser will be between **£45** and **£65**, depending on the case and LEDs you use.

MicroTrainer

Since this project requires specially programmed EPROMs and a high-quality double-sided, through-hole-plated PCB, we do not recommend that readers attempt to build it other than from the kit supplied by **Technomatic** (£68-94 inclusive). However, the PCB and EPROMs are available separately for £17.19 and £28.75 (plus £1 postage), respectively. One final point about the kit, it does NOT include the case featured on the cover of the June 82 issue of Hobby.

SWR Meter

Since the project uses very few parts, you shouldn't have problems getting hold of them. The 100uA meter and S0239 UHF sockets are available from **Rapid Electronics**, who have recently moved to new premises in Colchester. A good source for the enamelled copper wire is the **Scientific Wire Company** (PO Box 30, London E4). Total cost to build the meter; **£10**.

Clever Dick

After a month's absence, CD returns with his usual page of wit and wisdom.

Yes, I'm back . . . but did anybody even notice that I was away?
Here we go again, another page another . . . well, let's not get into the sordid details. Ready then?

Dear CD,
I have been reading HE for a year and I enjoy it apart from two things. Why have you stopped (in April '82 issue) printing the approximate cost of projects? This was very useful information.
Also, why do you only rent binders to people like me who are kind, and who grovel, like me?
T.L Homer,
Stratford-upon-Avon,
Warwicks.

No Bard, this . . . a mere thousand monkeys could produce a better letter. As to the project costs, due to circumstances beyond my control (someone forgot) projects costs did not appear, as you say. However, He Who Decides has assured me that the matter will be attended to. 'Nuff said?.
Your idea concerning the Rental of binders has a certain appeal . . . .

Here's a slightly dated letter I found in my files (so you've been wondering what's happened to that letter you wrote six months ago, have you? Don't worry — I've still got it!)

Dear CD,
Yours Sincerely,
A. Barnes,
Brentwood,
Essex.

PS I didn't have anything to say.
PPS Are you still doing that silly short-letter stuff? I was going to send a blank sheet of paper but then you wouldn't know where to send the binder.

Since I'm still getting a selection of "that silly short-letter stuff", I thought I'd print this one to give me the opportunity of saying NO, I'M NOT.

When will you all realise that urgent, desperate pleas for help can only be answered quickly (and I don't mean instantly) if a stamped, self-addressed envelope is enclosed. I hope this gentleman had not been waiting too long . . . .

Dear Clever Dick,
I am writing to you in a state of desperation and this letter, I hope, will receive prompt attention, for which I will be very grateful.
What I would like to know is — where can I obtain a slider potentiometer of value 5MO, log scale?
M. McHugh,
Dublin.

He's probably given up by now — but the answer is, you'll have to make one up by putting a fixed resistor in series with a high value pot. Potentiometers from Electrovalue are available up to 1MO and RadioOhm of East Grinstead can supply pots up to 2M2, log.
Please remember, if you would like an early reply, to send in an SAE next time you write. I don't have an unlimited budget for postage, you know (anything extra comes out of my salary, so you can calculate your chances . . .).

Our very clever design team are always getting suggestions for new projects — and, occasionally, an idea for modification for an old project. Here's one they've taken note of.

Dear Brilliant Richard,
I have been reading Hobby Electronics for about two years now, and I think it is brilliant. I was scanning through my numerous back copies looking for something to build when I saw the 'Diana' Metal Detector.
After carefully transferring the PCB foil pattern on to copper-clad board, I realised that the design did not make provision for headphones or a loudspeaker. Could you please send me a circuit diagram for an audio output that can be added to this project?
S. Goddard,
Gwynedd,
North Wales.

PS I am still at school but I have learnt a lot about electronics from both HE and ETI. I think that your staff all deserve medals for producing such high quality magazines.

If you're a regular reader, as you claim to be, you should know quite well that I don't send off circuits in the mail. However, you're in luck. In response to earlier requests, our design team has produced an audio output for the 'Diana' and I am reliably informed (an impeccable source) that it will appear shortly.
I approached the Editor with your idea for awards but he only suggested that if I wanted a medal I should join the Navy.

Dear CD,
Would it be possible to have a project for a computer in HE, explaining it as you go along?
Yours very hopefully,
F. McDonald,
Dublin.

PS The ZX81 has only four ICs.
PPS This is my fourth letter — binder, please.
PPPS Please print this.

Short and sweet, that's the way I like them. As a matter of fact it is quite possible to have a computer project in HE; we started on in June and it continues in this issue. This month, I believe, the component overlay and assembly instructions will be given. The design is rather advanced, but most readers will be able to learn from it how the various components of a microcomputer go together. In the case of the ZX81, as you point out, there are four of them. Now tell something I didn't know.

At last an astute reader has penetrated one of Hobby Electronic's deepest, darkest secrets — but I don't mean the secret of my identity.

Dear CD,
Having loyally collected all your mags, I've noticed that your numbering system has gone somewhat hay-wire (no pun intended). I noticed that in the 80/81 volume, the numbers go up to 14. Why is this, when all the previous volumes were numbered from one to twelve?
K. Dutton,
Walsall,
West Midlands.

PS My wife said you've got to send a binder to put my HEs in, so she can tidy the place up.

The solution of the mystery is devastatingly simple. The first edition of HE was published in November 1978, and since there are twelve months in a year (just kidding), the issues were numbered from one to twelve. Last year, we decided to bring our issue numbers in line with the calendar year, so that No. 1 would be January issue, No. 2 February, and so on. To do this, though, we had to bring out 14 issues in one volume. It's that simple . . . isn't it?
Let it never be said that Clever Dick was the cause of domestic wife . . . er, strife. A binder has been dispatched with all speed. **HE**

Step-by-step fully illustrated assembly and fitting instructions are included together with circuit descriptions. Highest quality components are used throughout.

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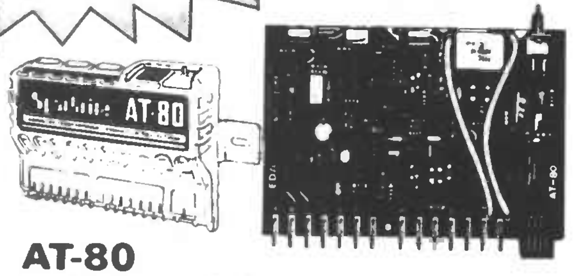

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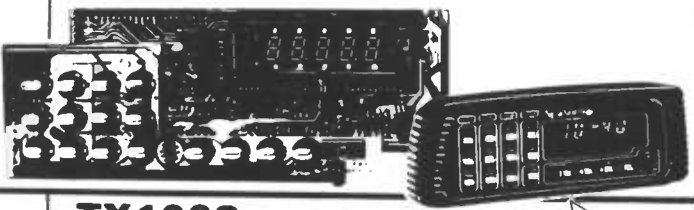
A real challenge for the electronics enthusiast!



SX1000

Electronic Ignition

- Inductive Discharge
- Extended coil energy storage circuit
- Contact breaker driven
- Three position changeover switch
- Over 65 components to assemble
- Patented clip-to-coil fitting
- Fits all 12v neg. earth vehicles

TX1002

Electronic Ignition

NEW

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- Extended coil energy storage circuit
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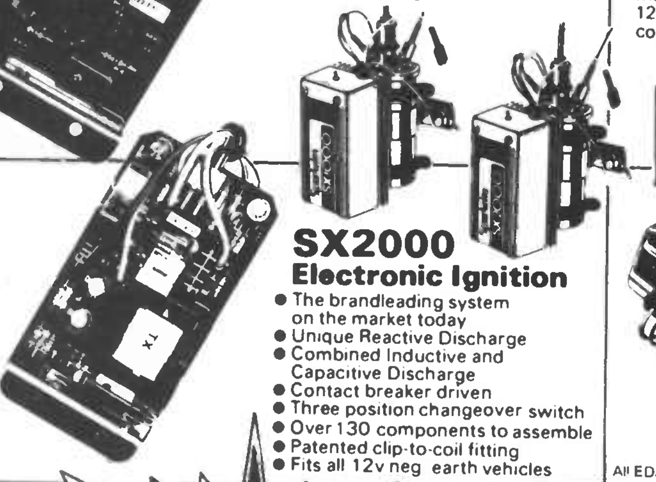

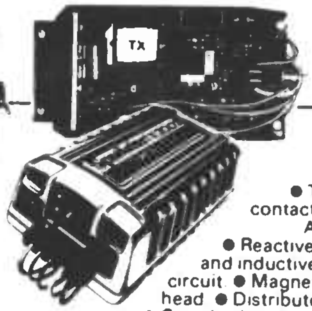

SX2000

Electronic Ignition

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- Combined Inductive and Capacitive Discharge
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- Three position changeover switch
- Over 130 components to assemble
- Patented clip-to-coil fitting
- Fits all 12v neg earth vehicles

TX2002

Electronic Ignition

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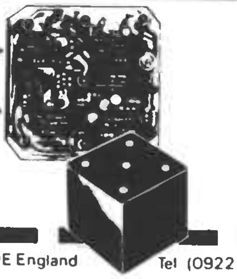

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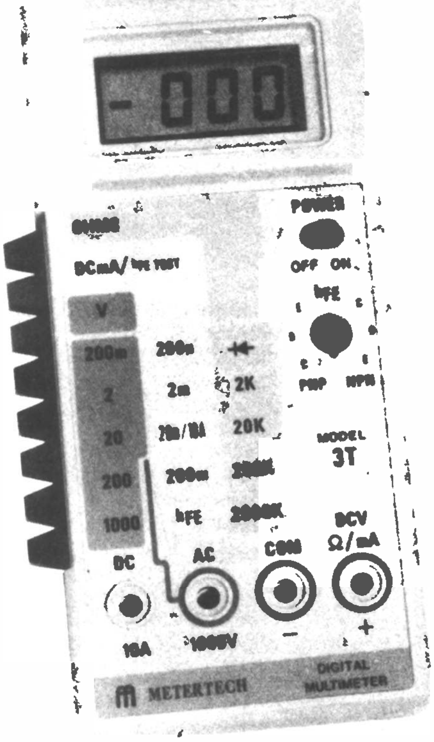

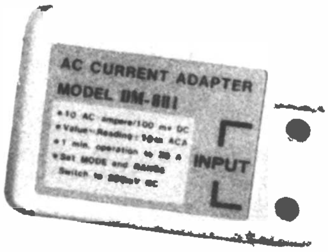

FROM TIME TO TIME the Hobby offices receive pieces of electronic equipment for review and evaluation. This month we were sent a new digital multimeter from Centemps. The Metertech model 3T is an attractive, portable multimeter with a large four digit LCD display. In addition to the usual functions the meter also has a built-in transistor tester. This makes it extremely versatile for its a small size — the case measures just 180 x 82 x 38 millimetres.

The basic measuring ranges are selected by a row of pushbutton switches along the side of the unit. Three red buttons set the requied function: Ohms, Voltage and DC current. AC current can be measured via the optional adapter; though no specification data is available at present, we were assured that technical information would be on hand soon. However the plug-in unit performed well, albeit after a slight struggle to understand it!

Each function has a number of ranges provided by the remaining five black buttons. This colour coding is quite a nice touch and makes operation just that bit easier — you've always got to ensure that one black and one red button are depressed to take a reading. Another advantage of this facility is that it permits one-handed testing, leaving the other free to position the test prods. Something I did miss though, is that the leads do not come with interchangeable tips or extras like crocodile clips — so be prepared to add your own clips or having to hold the leads in place when taking measurements.

The DC voltage scale has five steps; 200mV, 2V, 20V, 200V, and 1kV. This provides a staggering resolution of less than one millivolt on the lowest range, with a quoted accuracy of 0.5%. All five settings have an input impedance of 10M, so they will not significantly load the circuit under test. A very useful protection arrangement allows overloads up to 500V DC, so it's virtually impossible to damage the meter.

The two AC voltage ranges are equally well protected, up to 350 V RMS AC, but do not have such a high resolution. Sinusoidal voltages are measured with the red test lead plugged into a special AC socket (one of four at the bottom end of the meter). The lower two black buttons select either 200 V or 1kV and work over a frequency band from 40 Hz to 500 Hz. This stated narrow bandwidth did not prove a serious limitation, however, since readings up to about 20 kHz were founded to be possible! However, the lack of a really low AC setting was found to be a drawback when dealing with audio signals within low-level circuitry.

The DC current scale has five steps, like the voltage scale. This gives readings from 100nA (not 100uA as in the booklet) up to 200mA with a separate socket for measurements of currents up to 10A. All these ranges are protected by a 0A5 fuse and an extra fuse is supplied with the meter. With an accuracy of 1.2% (our meter was actually better than 1%), it is possible to work out exact current demands of battery powered equipment. This also allows precise setting up of regulator circuits in PSU's for minimum ripple. In fact the only slight reservation I had about the current ranges is that you have to change test sockets to move up from 200mA to 10A.

The uppermost red function button puts the meter into resistance mode. There are five steps covering the range 2k to 2M with one ohm resolution on the lower end. Accuracy is stated as 1%, but I measured several 0.1% resistors without detecting any discrepancies. The resistance ranges are protected against an overload of up to 250V AC and DC (though I didn't test this!) and test currents — the currents put through the circuit being tested — are very low (100 uA maximum).

One interesting aspect about this range is that you can check the 'resistance stability' of presets and pots by watching the final digit on the display changing, even though you're not moving the wiper on the pot. The first black selector, in conjunction with the ohms range, also allows checking of diodes by providing an output current of 2 mA. By multiplying the display value by ten, an approximate measure of forward voltage is obtained. Short or open circuits are signified by a reading of '1' or '00.0' respectively.

The model 3T has an extra facility in that it can be used to measure the DC current gain or h_{FE} (common emitter mode) of small transistors. On the right of the case below the display is a transistor socket, clearly marked to take PNP and NPN transistors. The mode is selected by the lowest black button on the DC mA/h_{FE} setting. This makes light work of matching transistors from a bargain pack, or simply selecting the best one for a specific purpose. Indeed, backed up by such an accurate voltage/current capability, the transistor testing range makes the whole unit extremely versatile.

So, here is a no-nonsense precision multimeter with all the extras you could want from such a device. The ranges are wide and accurate, and though a low AC voltage range would have been advantageous, for most applications the unit performs admirably. I found it easy to use, due to the clear markings and colour coding on the front panel, and consider it to be a valuable addition to any hobbyist's test bench. The Metertech DVM we reviewed was from Centemp, 62 Curtis Road, Whitton, Hounslow, Middx. TW4 5PT. It is available from them, priced at £49.95 (including VAT, p&p). The optional case is £6.90, as is the AC current adaptor. **HE**

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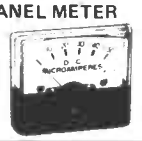
6½" 8 ohm 25 watt £4.50. 2½" 8 ohm tweeter. £2.50. No extra for postage if ordered with cabinets. Xover £1.50.

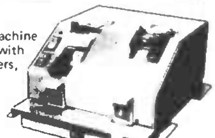
THIS MONTH'S SNIP

0 - 100 MICRO AMP PANEL METER



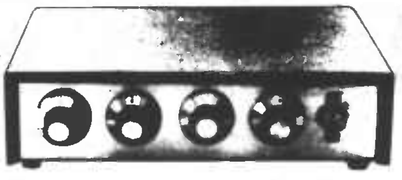
Japanese made, flush mounting, size approximately 45mm x 50mm x 30mm deep.
PRICE £2.95.

TAPE PUNCH & READER



For controlling machine tools, etc, motorised 8 bit punch with matching tape reader. Ex-computers, believed in good working order, any not so would be exchanged. £17.50 pair. Post £4.00.

3 CHANNEL SOUND TO LIGHT KIT



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.

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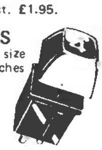

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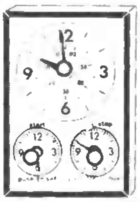

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£13.50 + £2.00 post.
This is far less than the value of the switches alone. Diagram of this keyboard is available separately for £1.

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Not much bigger than a pea, 600 ohm condenser type. Ideal for bugging and simiiar applications. 50p each or 10 for £4.50

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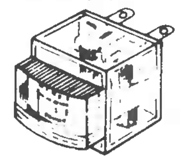

Size approximately ¾" square, scaled signal and power but cover easily removable for rescaling. Sensitivity 200uA. 75p.

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Carbon film, 1/4 or 1/3 watt, standard leads, not pre-formed, all 5% values: 1p each 100's. 2p each 10. 5p each less than 10 per value. OR – INVENTOR'S PACK Containing 10 of each of 60 different values from 1 ohm to 10 megohm, packed separately, £5.75.

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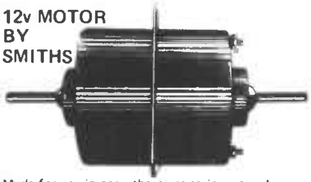

Made for use in cars, these are series wound and they become more powerful as load increases. Size 3½" long by 3" dia. These have a good length of ¼" spindle – price £3.45. Ditto, but double ended £4.25.

EXTRA POWERFUL 12v MOTOR

Made to work battery lawnmower, this probably develops up to ¼ h.p., so it could be used to power a go-kart or to drive a compressor, etc. etc. £6.90 + £1.50 post.
(This is easily reversible with our reversible switch - Price £1.15).

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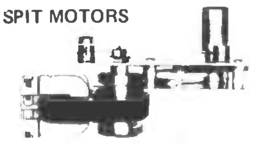

These are powerful mains operated induction motors with gear box attached. The final shaft is a ½" rod with square hole, so you have alternative coupling methods – final speed is approx. 5 revs/min, price £5.50. – Similar motors with final speeds of 80, 100, 160 & 200 r.p.m. same price.

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• 1 Framco motor with gear box. • 1 manual reversing and on/off switch. • 1 push to start switch. • 1 x 100w auto transformer. • 2 limit stop switches. • 1 circuit diag. of connections.
£19.50 plus postage £2.50.

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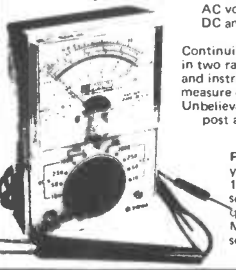
Deluxe pocket size precision moving coil instrument, Jewelled bearings - 2000 o.p.v. mirrored scale.
11 instant range measures: DC volts 10, 50, 250, 1000. AC volts 10, 50, 250, 1000. DC amps 0 – 100 mA.



Continuity and resistance 0 - 1 meg ohms in two ranges. Complete with test prods and instruction book showing how to measure capacity and inductance as well. Unbelievable value at only £6.75 + 60p post and insurance.

FREE Amps range kit to enable you to read DC current from 0 - 10 amps, directly on the 0 - 10 scale. It's free if you purchase quickly, but if you already own a Mini-Tester and would like one, send £2.50.

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3 wafer types 99p each,		
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9 pole 4 way	12p 3 way	18p 2 way

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Ideal for discos and garden parties, allows complete freedom of movement. Play through FM radio or tuner amp. £6.90 comp. kit. (not licenceable in the U.K.).

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Made up and working, complete with scale and pointer needs only headphones, ideal for use with our surveillance transmitter or radio mike. £5.85. or kit of parts £3.95.

Julius Plucker

We see one of his discoveries every night.

JULIUS PLUCKER was born in 1801 at Elberfield, Germany, of well-to-do parents. His education was conventional for the time; high school, followed by the University of Heidelberg, where he showed considerable promise in mathematics. He pursued further courses at the Universities of Berlin and of Paris and, in 1825, took a job as a lecturer at Bonn University. This post carried no salary — it was deemed such an honour that the lecturer was expected to be able to support himself either by inherited wealth or (less likely) by private teaching. Plucker did so for four years, in which time he distinguished himself suffiently to be appointed Assistant Professor of Mathematics, at Bonn, in 1829.

His achievements in Mathematics were considerable; Plucker's most notable achievements were in what is termed analytical geometry, an algebraic system for dealing with geometrical problems. His discoveries resulted in his appointment to a Professorship at Halle in 1834 then, in 1836, he returned to Bonn.

Faraday Fever

Within nine years, however, his interests totally changed. He became fascinated by the work of Faraday in England and decided to devote the rest of his life to studying this and other electrical work. The contrast between these two men, who never met, could not have been greater. Faraday was the son of a blacksmith, self-educated, with little more than simple arithmetic to his credit and a considerable aversion to mathematical ideas. Plucker, from a wealthy background and well-educated, mathematically a near-genius, was completely bowled-over by Faraday's ideas — which Faraday himself could not express mathematically! Plucker, better able to analyse the ideas but lacking the feeling for the subject that Faraday had by instinct, saw them as totally revolutionary. He was, of course, correct — they were the most revolutionary steps in Physics since Newton's Laws of Motion.

Plucker's interest in, and devotion to, Electrical Science led to his appointment, in 1847, as Professor of Physics at Bonn, a post which left him time and provided the resources to extend very greatly his research interests; at that time, these centred on magnetism. Plucker became fascinated by the behaviour of materials in strong magnetic fields. His contemporary in England, James Prescott Joule, had already demostrated one remarkable effect, that of magnetostriction. Magnetic materials change length as they are magnetised and demagnetised, and the effect is used nowadays as a way of producing ultrasonic waves with very high power. Plucker was interested from a different angle. He saw the effect, correctly, as evidence for the idea that atoms of materials, for so long regarded as single units, were made up of electrically charged smaller particles.

Plucker soon launched himself into completely original work, however and, in 1852, announced the discovery of diamagnetism. This is a little-known effect which can be observed in crystals of materials that we normally think of as non-magnetic. In fact, all materials are magnetic to some extent, in the sense that they respond to magnetic fields, but only iron and its close relatives, nickel and cobalt, are strongly magnetic. We call such substantaces ferromagnetic, meaning magnetic like iron (Ferrum in Latin).

Plucker, using very powerful electromagnets (another idea borrowed from Faraday), was able to classify two other types of magnetism; parmagnetism and diamagnetism. The differences depend, as Plucker suspected, on fundamental differences in the way the atoms of these materials are constructed but the very incomplete knowledge of atoms, at the time, did not permit him to go much further.

Like many before and since, he turned to another line of research; the conduction of electricity through gases. It had been known for some time that gases were not completely insulating. Measurements made using the very sensitive leaf electroscopes fo the 18th century, had shown that gases would start to conduct electricity when their temperature was raised. By the middle of the 19th century, the remarkable effects produced by lowering the pressure of gases had been discovered and it was to this area that Plucker directed his research. It proved to be a most rewarding study.

Gas Displays

It's not difficult to understand why gas discharges (passing electric currents through gases at low pressures) were so fascinating; they provide some of the most beautiful spactacles in Physics. When a high voltage is placed across two metal plates, at opposite ends of a tube which can be connected to a vacuum pump, nothing much happens until the pressure of the gas in the tube (air or anything else) has been considerably reduced. The first indication of activity is a series of irregular sparks which flash between the plates (or 'electrodes'). As the pressure is reduced, the sparks merge into a continuous discharge, becoming a glow which fills the tube completely, apart from a dark space near the negative electrode (the cathode dark space). The colour of the glow is vivid and bright and depends on the type of gas that filled the tube. When neon is the filling material, the effect is the familiar orange glow of the neon lamp. This much had already been noted by Geissler and several others, though they had little idea of what caused the effect.

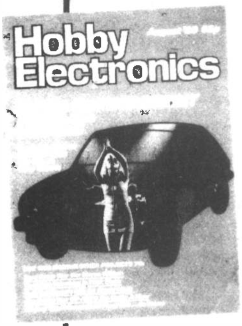
We know now that the reduced pressure causes the molecules of gas to separate, and that any one molecule which splits into atoms and then into charged particles can cause all the rest of the molecules of the gas to split in the same way. What happens is that any charged particle will be accelerated to a high speed, because of the electric field, and will crash into other molecules, splitting them into fragments; each fragment will in turn be accelerated and will split up others in a chain reaction. The cause of the glow is the energy given out when the fragments recombine and the dark space near the cathode is the region in which the fragments are accelerating rather than recombining. Most of the voltage drop is across this dark space.

Plucker, in 1859, was determined to take the process a stage further. Using an improved vaccum pump, only just invented, he reduced the pressure in such a tube very much further. As the pressure dropped, the glow in the gas broke up into bands and eventually disappeared. Examining the tube in a darkened room, however, Plucker found that there was still a glow — but it was not inside the tube. A faint glow now seemed to be on the wall of the tube, near the positive electrode (the anode), and was green in colour. Plucker found that any object placed between the anode and the cathode would cast a shadow under these conditions, so that it looked as if there were a ray emitted from the cathode and striking the glass. The phrase 'cathode rays' has been with us ever since!

Deflections

By 1860, Plucker had gathered a team of researchers around him, all of whom were to make their names in connection with cathode rays. An early result of their work was the discovery that the rays travelled in straight lines, but Plucker's interest in magnetism led him to test the effect of a magnet on the rays — and he found that they were deflected. Deflection by a voltage applied between metal plates was also demonstrated, along with the heating effect produced when the 'rays' hit any material, an effect we make use of nowadays in electron-beam welding. To crown it all, an elegant experiment proved that the rays were probably moving particles, with mass and speed, because they were capable of turning a wheel held within the evacuated tube.

Plucker's publication of the results of his work, and that of his associates, produced great excitement in scientific circles because cathode rays were the first firm evidence that atoms could be split, to produce smaller charged particles. As an academic, Plucker did not exploit the discoveries in any way, but he undoubtedly paved the way for the elegant measurement of the charge/mass ratio of the electron, by J.J. Thomson, at the end of the century, and to the invention of the first practical cathode ray tube by Braun, at about the same time. **HE**



BACKNUMBERS

February 1980
Passion Meter, Win Indicator, Short Circuit Special, Kit Review Special, Into Electronics Construction Part 1.

May 1980
MiniClocks, 5080 Preamp, Model Railway Track Cleaner, 5080 Loudspeakers, Loudspeaker Crossover Design, Radio Controlled Model Survey.

June 1980
Microbe Radio Control System, Egg Timer, Two Watt Amplifier, Fog Horn, Short Circuits, LEDs and LED Displays.

July 1980
Sound-Operated Flash Trigger, 18 + 18 Car Stereo Booster, Hazard Flasher, Electronics in Photography, Electronic Espionage, Piezo Electricity.

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EquiTone Car Equaliser, Pass-The-Loop Game, Gaztec Gas Detector, OP-Amp Checker, In-Car Entertainment Survey, Introducing Microprocessors.

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MicroMixer, Reaction Tester, Guitar Phaser, Development Timer, Teletext Explained, Into Digital Electronics Part 1.

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April 1981
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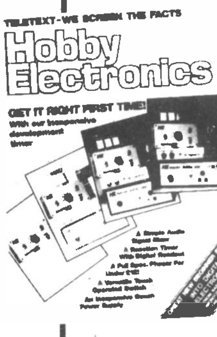
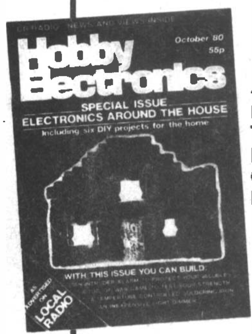
May 1981
Electronic Organ, Voice-Operated Switch, Infra-Red Controller, Pre-Amplifier Part 2, Audio Millivoltmeter.

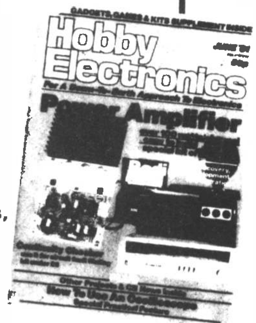
June 1981
Power Amplifier Part 1, Continuity Checker, Envelope Generator, Early Radio, Gadgets, Games and Kits Supplement.

July 1981
Burglar Alarm, Doorbuzzer, Treble Booster, Electronic Aids for the Disabled, Power Amplifier Part 2.

August 1981
Electronic Ignition, Thermometer, Electronic Organ (final part), RPM Meter, Bench Power Supply, Radio Control Survey, Into Electronic Components Part 1.







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Breadboards

This month we have two or our own circuits that may be easily modified to suit many purposes. The first is a simple two watt audio amplifier, based around the LM380 IC, which can be used as a bench amplifier, as a guitar practice amp or for any other purpose that requires an audio power output. The second features a TL082 BIFET op-amp (with two FET amplifiers in the package) wired as a 50 Hz hum filter; it is also adaptable to notch out and other desired — or undesirable — frequency.

Gaining Power

The most impressive fact about the LM380 is that it can be turned into a practical amplifier with the addition of only a few extra components. With a quiescent current (ie, no signal input) around 7 mA, battery operation is not a problem, and it will drive almost any load with an impedance greater than four ohms.

The circuit we have here couldn't be much simpler. The input signal is fed to the non-inverting input (the LM380 is essentially an op-amp with power gain) via coupling capacitor C1 and potentiometer RV1, which functions as a simple volume control. Although the gain of the IC may be increased to as much as 300, by the application of positive feedback, the pre-set gain of 50 — 34 dB — is enough for this application.

The network R2,C3, connected across the output, is to aid the stability of the amplifier (preventing feedback), however it can be ommitted if the load is high impedance (more than 16R). High impedance loads mean less current drain, therefore the battery life will be extended — but at the cost of reduced power output. Low impedance loads — a four ohm speaker, for example — will generate greater power but with the risk that the IC will 'shut down' because its maximum current rating (1A3, peak) is being exceeded.

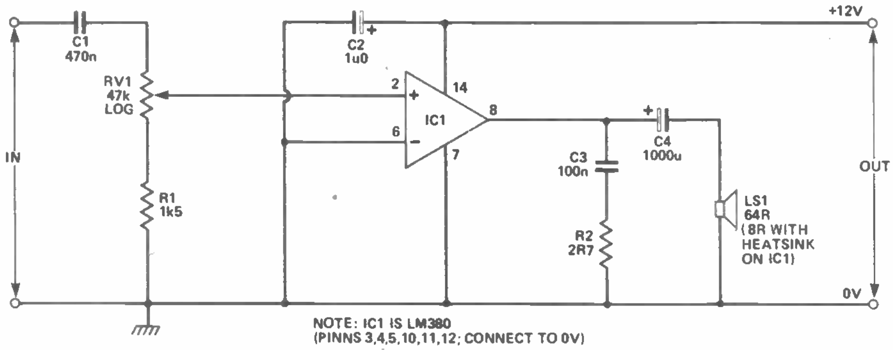


Figure 1. Circuit diagram of the LM380 2-watt amplifier.

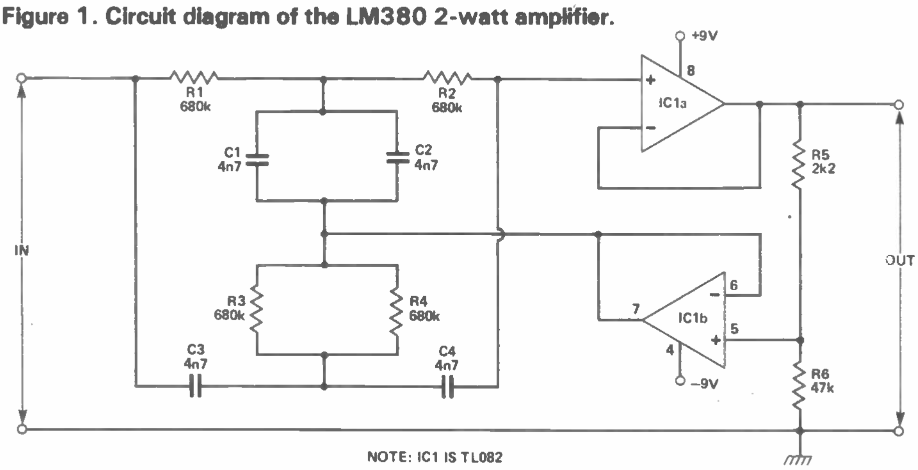


Figure 2. The 50 Hz hum rejection filter circuit.

Down and Out

The circuit shown in **Figure 2** is a 50 Hz hum rejection filter; it 'notches out' a narrow band of frequencies centred around 50 Hz, but allows all other frequencies to pass. There are quite a few circuit configurations for notch filters, most of them based around an RC filter network. This one uses the Twin-T configuration (R1-4 and C1-4) and the active elements, IC1a and b, to obtain a sharp notch at 50 Hz (this particular configuration is called a Sallen and Key Filter).

The Q of the circuit — the quality factor, equal to the centre frequency divided by the '3 dB down' bandwidth — is set by R5 and R6; replacing these resistors with a potentiometer (with the wiper connected to IC1b, pin 5) allows the Q to be made variable, however the penalty is that the notch depth becomes less deep. The values chosen here for R5/R6 give a notch of 40 dB.

The centre frequency is set by the components in the Twin-T filter and it can easily be changed to make, say, a 100 Hz notch filter. The centre frequency is Fc = 1/(6.28 x R x C), where R = R1, R2 and C = C3, C4. Notice that the parallel combination of C1, C2 make up 2C and the combination R3, R4 make R/2. These relationships must be maintained when the centre frequency is changed.

The IC is a TL082, which contains two FET op-amps in an eight-pin DIL package. The circuit is powered from two 9 V batteries wired in series, with the 0 V rail taken from the junction of the batteries, and current consumption is less than 6 mA into a high impedance load. If the filter is to be 'boxed', it's a good idea to add capacitors (100u 10 V electrolytics) from each voltage rail to 0 V.

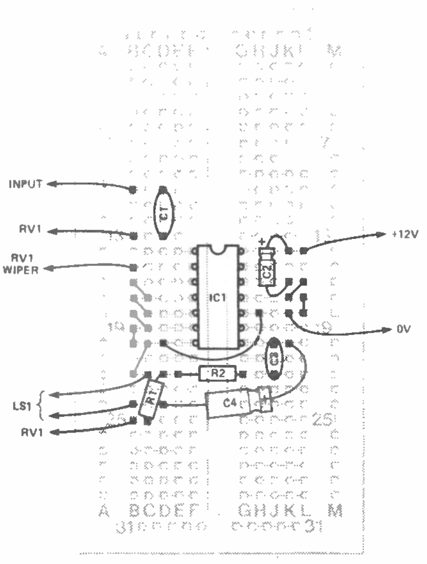


Figure 3. Component layout for breadboarding the amplifier.

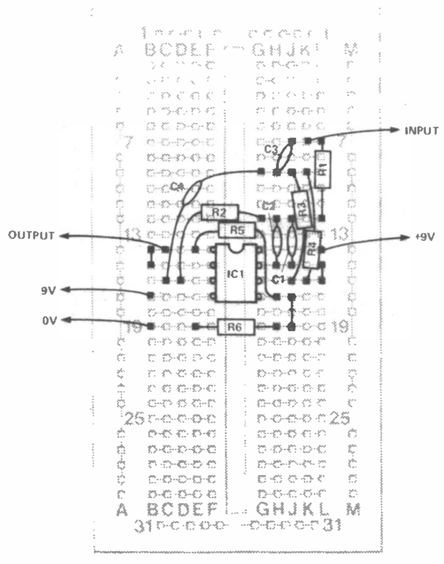
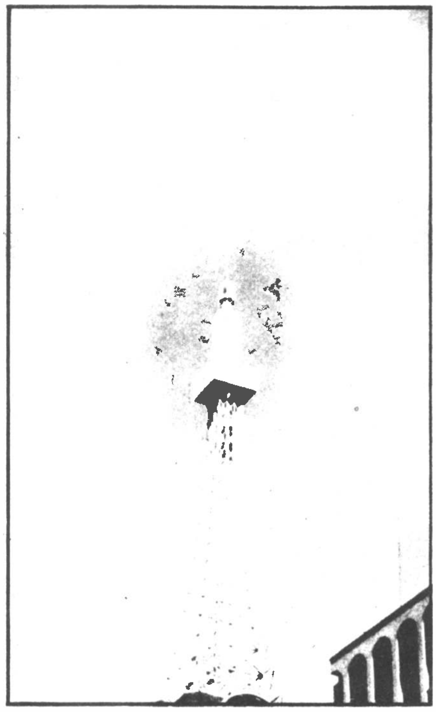


Figure 4. Breadboarding layout of the notch filter.

HE

RADIO RULES



Carrying on from last month, we now look at the behaviour of capacitance, inductance and resistance in series and parallel circuits.

A circuit that contains inductance and capacitance behaves in a very interesting way when the reactance of the capacitor equals the reactance of the inductor. If the capacitor and the inductor are connected in series (**Figure 1**) then the AC voltage across them will be equal and opposite and they will cancel, leaving only the voltage across the resistor. This is in phase with the current, as the phase diagram of **Figure 1** shows. For any combination of inductance and capacitance, then, there will be a frequency, called the resonant frequency or frequency of resonance, at which this happens and we can use the equations for reactance to calculate what the resonant frequency will be. This is shown, with examples, in **Figure 2.**

The algebraic formula for impedance also shows that when a capacitor and an inductor are connected in series and are in resonance, all that is left is resistance. At the frequency of resonance, therefore, the impedance of a series resonant circuit reaches its minimum possible value, equal to the amount of resistance, and the phase angle is 0° **Figure 3** shows the variations of impendance and of phase in a series resonant circuit. It is also possible to have parallel resonant circuit, in which a capacitor and an inductor are connected in parallel. In this circuit, the impedance becomes a *maximum* at the frequency of resonance; this maximum impedance is called the 'dynamic resistance'. The voltage across a parallel resonant circuit is also in phase with its current, but its value does NOT correspond to the value of any resistance in the circuit. The value of dynamic resistance, R_D, when the circuit is at resonance, is given by the formula of **Figure 4**. The size and phase of the voltage across a parallel circuit is plotted, assuming a constant current, in **Figure 5.**

At resonance, very large currents can flow in resonant circuits and these can cause large voltages to be generated — in some cases, larger than the input voltage! For example suppose that, in a series circuit, we have reactances of $X_L = X_C = 1000$ ohms, a resistance of 10 ohms and there is a constant AC voltage of 10 V across the circuit. Now if we vary the frequency of the AC until it equals the resonant frequency, the current will increase until it reaches a maximum of 1A, assuming that the source of the AC can

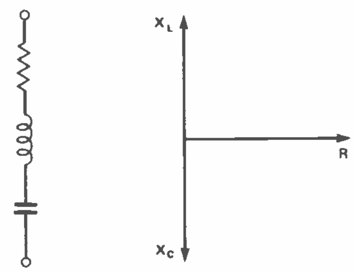


Figure 1. A simple series RLC circuit and the phasor diagram representing the voltages across each component.

SINCE $X_L = X_C$

THEN $2\pi \times f L = \frac{1}{2\pi \times f C}$

SO THAT $(2\pi \times f)^2 = \frac{1}{LC}$

AND $2\pi \times f = \frac{1}{\sqrt{LC}}$

THEREFORE $f = \frac{1}{2\pi\sqrt{LC}}$

eg. L = 15 mH, C = 10 nF

RESONANT FREQUENCY, $f = \frac{1}{2\pi\sqrt{15 \times 10^{-3} \times 10 \times 10^{-9}}}$

$= 12995\text{Hz OR } 12.995\text{kHz}$

Figure 2. Deriving the formula for the resonant frequency of a series-resonant circuit, together with a practical example.

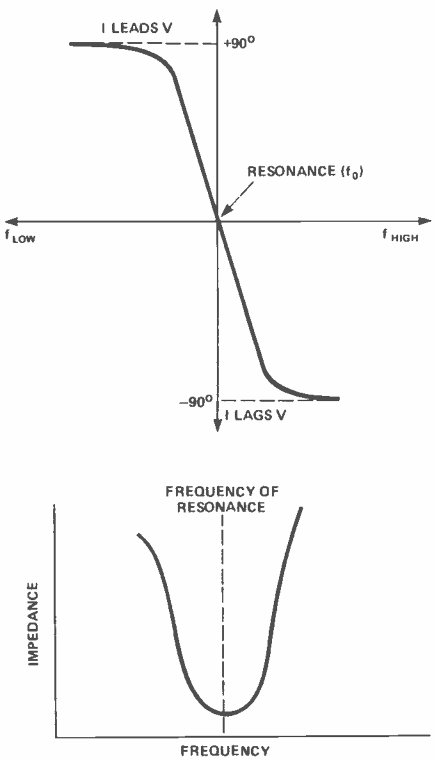
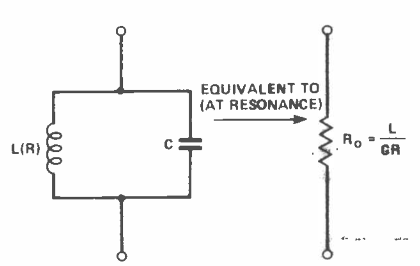


Figure 3, top. At resonance, the phase shift through a series resonant circuit is zero; bottom, the impedance plotted against frequency — it reaches a minimum at resonance.



eg. L = 22 mH, C = 5 nF, R = 1.2 OHMS

$R_D = \frac{22 \times 10^{-3}}{5 \times 10^{-9} \times 1.2}$

= 3.7 MEGOHMS

Figure 4. A parallel resonant circuit and its equivalent 'dynamic resistance' at resonance. In contrast to the series circuit, this reaches a maximum.

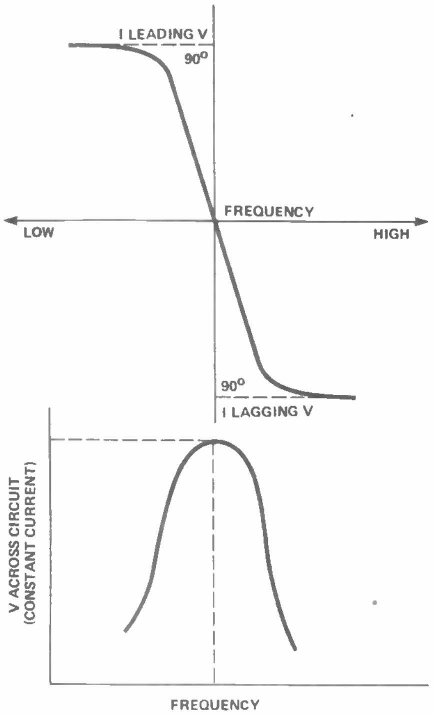


Figure 5, top. The phase shift through a parallel resonant circuit; bottom, the voltage across the circuit plotted against frequency — compare this with the series resonant circuit.

AT RESONANCE, $Z = R$

THEREFORE $I = \frac{V_I}{R}$

THE VOLTAGE ACROSS THE CAPACITOR IS

$$V_X = I \times X_C = \frac{V_I}{R} \times \frac{1}{2\pi \times f C} = \frac{V_T}{2\pi \times fCR}$$

AND

$$Q = \frac{V_X}{V_T} = \frac{V_T}{2\pi \times fCR} \times \frac{1}{V_T} = \frac{1}{2\pi \times fCR} = \frac{1}{\omega CR}$$

WHERE $\omega = 2\pi \times f$

THE VOLTAGE ACROSS THE INDUCTOR IS

$$V_X = I \times X_L = \frac{V_T}{R} \times 2\pi \times fL$$

AND

$$Q = \frac{2\pi \times fLV_T}{R} \times \frac{1}{V_T} = \frac{2\pi \times fL}{R} = \frac{\omega L}{R}$$

eg, C = 4.7 nf, R = 1.5 OHMS, f = 400 kHz

$$Q = \frac{1}{2\pi \times fCR} = \frac{1}{2\pi \times 400 \times 10^3 \times 4.7 \times 10^{-9} \times 1.5}$$

Figure 6. The phase differences between current and voltage in reactive circuits; (top) current leads voltage in a capacitive circuit; (bottom) voltage leads current in inductive circuits.

$$f = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{22 \times 10^{-3} \times 5 \times 10^{-9}}} = 15.175\text{ kHz}$$

IF $V_T = 1.5\text{V}$ THEN

$$I_T = \frac{V_T}{R_D} = \frac{1.5}{3.6 \times 10^6} = 0.417\ \text{uA}$$

AT RESONANCE, $X_L = X_C = 2\pi \times fL$

$$= 2\pi \times 15175 \times 22 \times 10^{-3} = 2.1\ \text{KILOHMS}$$

THEREFORE,

$$I_L = \frac{V_T}{X_L} = \frac{1.5}{2.1 \times 10^{-3}} = 715\ \text{uA}$$

AND THE CURRENT MULTIPLICATION

$$= \frac{I_L}{I_T} = \frac{715}{0.417} \times 10^{-6} = 1715$$

COMPARE THIS WITH THE VALUE OF Q:

$$Q = \frac{2\pi \times fL}{R} = \frac{2\pi \times 15 \times 10^3 \times 22 \times 10^{-3}}{1.2} = 1728$$

Figure 7. Current multiplication in a parallel resonant circuit. Notice that the value compares closely with the Q of the circuit.

supply this much. With 1A flowing in the circuit, though, we have to remember that it flows through *all* of the components and that there will be a voltage developed across each component. Across the capacitor, for example, there will be a voltage equal to the current times the reactance which in this example, will be 1000 V! There will also be equal voltage across the inductor, though its phase will be opposite. Remember also that the phase of both of these voltages will be 90° to the phase of the voltage across the resistor — which is also the phase of the supply voltage.

This effect is called 'voltage magnification' and the voltage magnification factor is defined as V_X/V_T, where V_X is the voltage across a reactive component (either C or L) and V_T is the total applied voltage. The voltage magnification factor is given the symbol 'Q' and its size can be calculated, as illustrated in **Figure 6**. A parallel resonant circuit also causes magnification but it's *current* magnification, with large currents flowing in each leg of the resonant circuit but only a small current actually flowing *though* it (**Figure 7**). The same formula can be used for Q, providing the value of R is not too high.

Bandwidth and Damping

If a tuned circuit had no resistance it would be in resonance at one frequency and only one frequency but every inductor, being made from wire, must have some amount of resistance so that, in practice, the resonance will extend to a range of frequencies that we call the 'bandwidth'. If we imagine a parallel-resonant circuit used as the load of a transistor (as it usually is), then a graph of signal output plotted against frequency, assuming a constant amplitude input to the transistor, would look as shown in **Figure 8**. We take the frequency of resonance as being that frequency represented by the top of the curve, but the frequencies around this one are also *selectively amplified* and we have to decide what amplitude will be large enough to count as part of this bandwidth. As with so many other examples, the amplitude limit is taken to be 70% of the peak (or peak x 1.4, if you prefer), so that the two frequencies, one on each side of the resonant peak, whose amplitudes are equal to 70% of the peak are the limits of bandwidth.

As you might suspect, there is a relationship between bandwidth and the magnification factor Q, as shown in **Figure 9**. There are two important points about this; one is the effect of frequency. Suppose you have a resonant circuit which has a Q-factor of 100 (determined mainly by the inductor, which has all the resistance) and it operates at 1 MHz. Your bandwidth, then, is 1/100 of a MHz, which is 10 kHz. If your resonant circuit with a Q of 100 were to operate at 100 MHz, though, then the bandwidth would be 1 MHz. This illustrates the difficulties of working with high frequencies; it also illustrates why we use very wide bandwidths — we can't help it! Unless very high-Q circuits can be used, high resonant frequencies automatically mean large bandwidths.

We can increase the bandwidth of any parallel-resonant circuit, at the expense of voltage magnification, by adding some resistance across the tuned circuit. The smaller this resistance is, the wider the bandwidth (**Figure 10**) and the lower the peak, because the Q of the circuit has been reduced. This called 'damping' and a

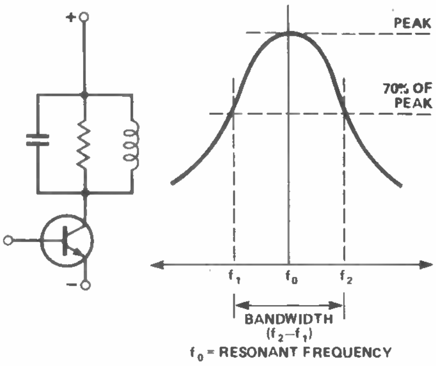


Figure 8. The bandwidth of a tuned circuit is taken from the frequencies at which the amplitude is 70% of the peak value.

resistor used in this way is called logically, a damping resistor.

Coupled Circuits and Filters

We can achieve interesting effects by placing the inductors of two resonant circuits, tuned to the same frequency, close enough together to cause some mutual inductance. If the mutual inductance is small, the circuit is said to be loosely coupled and only a fraction of the signal in one circuit will be transferred to the other, the bandwidth of the induced signal will be smaller — narrower than we could achieve with either tuned circuit alone. As the coils are brought closer together, the coupling increases until a point, known as the 'critical' coupling point, is reached (**Figure 11**) where the amplitude of the signal in the secondary coil is at a maximum at the frequency of resonance. If

$$Q = \frac{f_0}{f_2 - f_1}$$

AND THE BANDWIDTH $= f_2 - f_1 = \frac{f_0}{Q}$

IF Q = 100 AT 1 MHz THEN:

$$f_2 - f_1 = \frac{f_0}{Q} = \frac{10^6}{10^2} = 10^4 = 10\text{kHz}$$

HOWEVER, AT 100 MHz,

$$f_2 - f_1 = \frac{10^8}{10^2} = 10^6 = 1 \text{ MHz}$$

Figure 9. For a circuit with a Q of 100 operating at 1 MHz, the bandwidth is 10 kHz. To achieve the same bandwidth at 100 MHz we would need a Q of 10000!

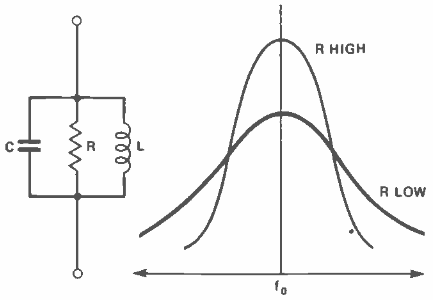


Figure 10. Using a damping resistor to obtain greater bandwidth, at the expense of Q. Note that the bandwidth is narrowest (and Q highest) when R is an open circuit (high resistance).

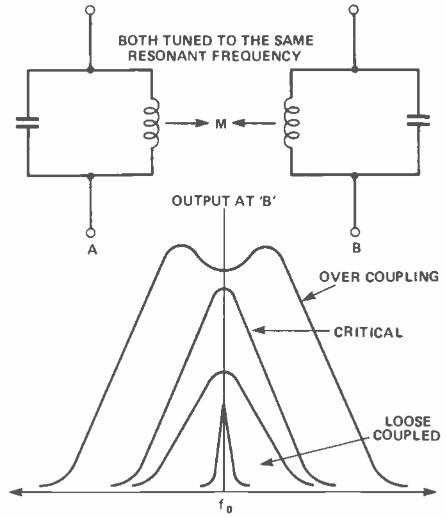


Figure 11. Mutally coupled tuned circuits; the Q reaches a maximum at the critical coupling point. Increasing the coupling further results in a dip in the response at the resonant frequency.

the coupling is increased beyond this point by bringing the coils closer still, then the shape of the curve changes to a double-hump with the amplitude at the resonant frequency *less* than the amplitude of the frequencies on each side of it. Overcoupling, as this is called, can be combined with the use of dampling resistors to give a shape which is almost flat-topped and is ideal wideband amplifiers.

The double-tuned circuit is a type of filter circuit which selects one range of frequencies. This particular one is called a band-pass filter, because it selects and passes (from one circuit to another) a

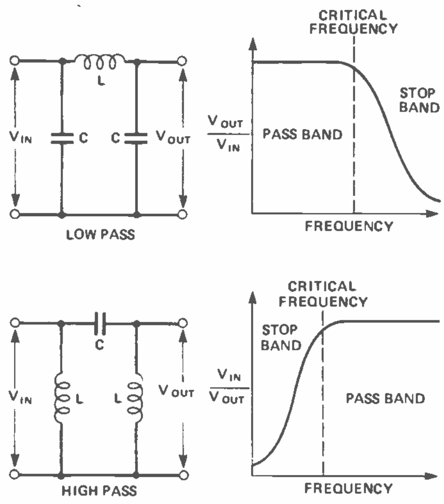
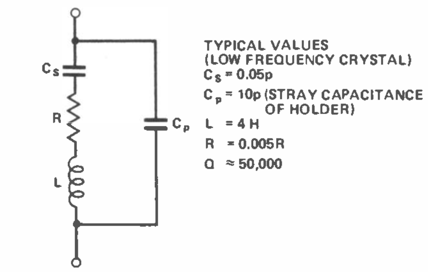


Figure 12. Pi-section LC filters can be made to give either low-pass or high-pass response. Bandpass response is produced by a resonant circuit.



NOTE: Cs, R AND L ARE NOT 'REAL' COMPONENTS, THEY ARE THE EQUIVALENT ELECTRICAL COMPONENTS WHICH WOULD GIVE THE SAME EFFECT AS THE MECHANICAL RESONANCE OF THE CRYSTAL. Cp IS REAL, HOWEVER; IT IS THE STRAY CAPACITANCE ACROSS THE TERMINALS.

Figure 13. The equivalent circuit of a quartz crystal. Note the extremely high value of Q!

range (band) of frequencies. We can also use inductors and capacitors to form other useful filter circuits, such as the low-pass and high-pass circuits of **Figure 12**. Any filter will have a pass-band, the range of frequencies which it will allow to pass with no attenuation (reduction in amplitude) and a stop-band, which is the range of frequencies that will be greatly attenuated. A low-pass filter has its pass band at low frequencies, a high-pass filter at high frequencies.

Mixing

Mixing (also called Heterodyning) is the name given to the process of frequency changing or conversion. The idea is that we can mix together two sinewave signals to produce a signal whose frequency is equal to the *difference* between the frequencies of the original signals. For example, we could mix 1.2 MHz with 1.15 MHz to give 0.05 MHz, which is 50 kHz. The mixing process, which is carried out in a diode or a transistor, will also produce a frequency which is equal to the *sum* of the frequencies of the mixed signals but, since all of the signals are at high frequencies except for the difference signal (50 kHz) we can pick it out using a low-pass filter. If one of the signals that we mixed happened to be modulated and the other was just a sinewave, then the differnece frequency will carry the modulation of the original modulated signal. This is the principle which makes the superhet receiver possible.

Piezoelectricity and Quartz Crystals

A crystal is an arrangement of atoms and, since the forces which help to hold the atoms in place are electrical, it's not surprising that certain types of crystals will generate a voltage across opposite faces when they are compressed or expanded. The process will also work in the opposite direction, so that applying voltage across the faces of a crystal can cause it to change size and if the voltage is alternating then the crystal will vibrate at the frequency of the AC. The effect is called the 'piezoelectric effect'.

Quartz crystals, which occur naturally, are piezoelectric and natural quartz crystals can be cut, like diamonds, in certain preferred directions. Crystal cutters refer to certain standard directions in a crystal as AT, BT, DT and so on. When a thin plate or bar of quartz crystal is supported between metal plates, or has metal deposited on its opposite faces, it can be used to form a resonant circuit, with very high values of Q. The electrical equivalent of a vibrating crystal is shown in **Figure 13** — the values of Q range from 25000 to over 50000; these are values which could not possibly be obtained by using coils and capacitors in resonant circuits! Crystals are therefore used: (a) in oscillators, to generate a good pure sinewave at a precise frequency, and (b) in filters, to achieve very narrow bandwidths.

Because the resonance of the crystal is mechanical (it's vibrating), the dimensions of the crystal and the way it is cut greatly affect the resonance. The maximum natural frequence of resonance is around 15-20 MHz and crystals which can operate at higher frequencies do so by vibrating when the frequency applied to them (the 'exciting' frequency) is a harmonic of the natural frequency — some crystal cuts do this very readily, (others don't) and a crystal that is designed to operate in this way is called an 'overtone' crystal. Alternatively, the crystal can be used at its natural frequency and the waveform squared to generate harmonics, which can be filtered to select a wanted harmonic, usually the second or third.

The resonant frequency of a crystal varies as you change the temperature of the crystal. The variations are small, never more than 50 Hz per MHz per degree Celsius change, but the AT cut crystal has a much lower change with temperature (almost zero). So for the best possible frequency stability, an AT cut crystal would be used inside a thermostatically-controlled oven.

So much for the hard facts. Next month we return to more practical matters — using these basic elements in radio frequency circuits. **HE**

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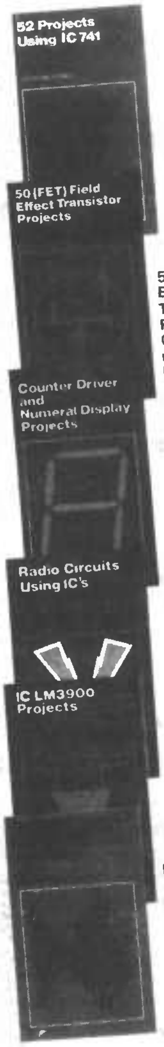

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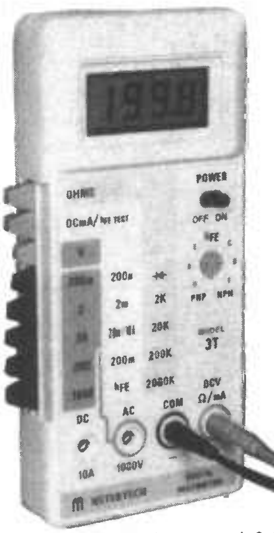

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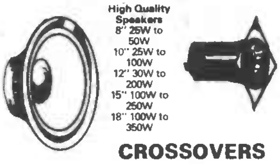

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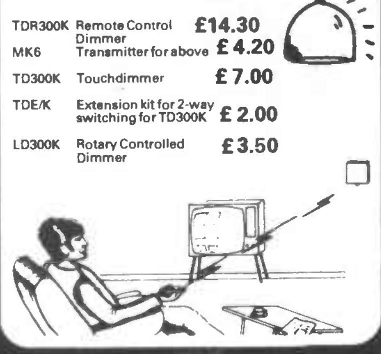

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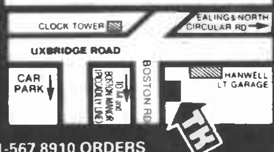

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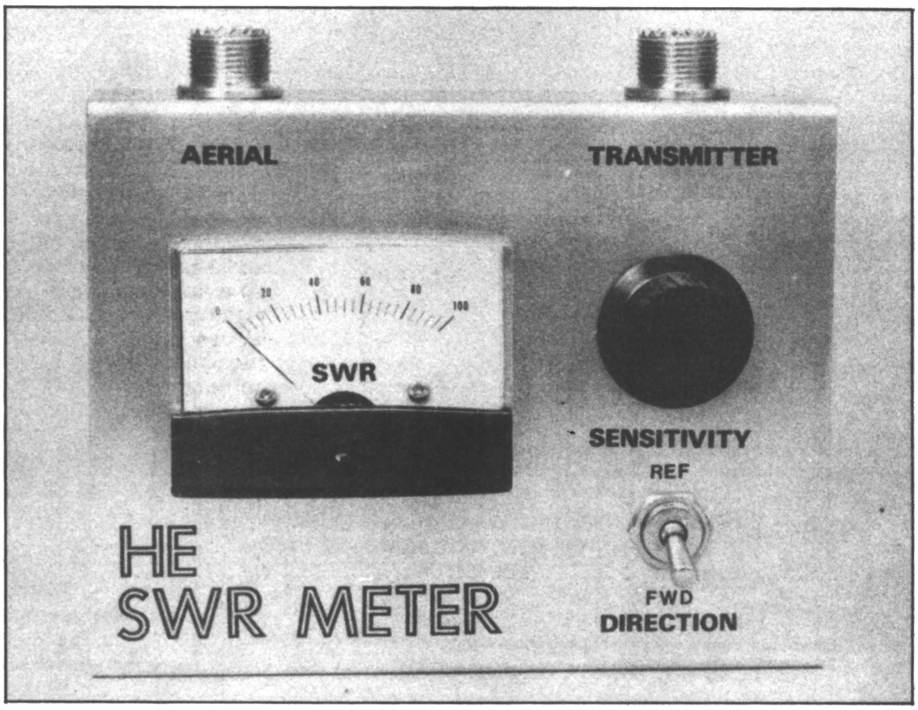
SWR Meter

Designed for 27 MHz CB rigs.

R. A. Penfold



ALTHOUGH a random length of wire may give acceptable — or even excellent — results for reception purposes, for transmission it is important that the transmitter, aerial feeder, and antenna are all properly matched. An SWR (standing wave ratio) meter enables the feeder to be trimmed or adjusted to match the antenna and transmitter properly, so that maximum signal is transferred and a minimum of power is wasted. In CB radio, however, it is more usual to trim the antenna, for example by adjusting the length of a telescopic whip-antenna, to obtain the correct SWR.

This simple and inexpensive SWR Meter is primarily intended for use with 27 MHz FM Citizens Band rigs, but should also work properly with similar (50R output impedance) high frequency transceivers.

Matching

There is not usually any problem in matching the output impedance of a transmitter to a feeder (coaxial cable) since transmitter output impedances and co-ax impedances are limited to a few standard values. Most CB rigs and other high frequency communications equipment have an output impedance of 50R and so they should be used with a 50R coaxial cable, such as RG58C or an equivalent cable.

While it might at first seem strange to refer to the impedance of a cable, it should be borne in mind that there is inductance in the two conductors of the cable and capacitance between them. This is analogous to the circuit shown in **Figure 1** where the longer the cable, the more inductors and capacitors are added into the system. The impedance, or 'characteristic impedance' of a cable, as it is more correctly known, always varies somewhat with changes in frequency. However, both coaxial and ribbon cables are designed to have inductance and capacitance values that give a virtually constant characteristic impedance over a wide frequency range.

If the feeder is terminated in a resistor, or other load having an impedance which is identical to that of the cable, the load effectively acts as a continuation of the cable and there is a perfect transfer of power from the cable and to the load. In practice, there is always a small loss through the cable, which is primarily caused by its series resistance, and should not be significant unless an unusu cable is used.

If the load has the wrong impedance this results in some of the signal being reflected from the load back down the cable to the signal source and the greater the impedance mismatch, the greater the reflected power. With a matched system, the voltage at any point along the feeder varies from zero to some peak level as the wave travels down the feeder. With any degree of mismatch this does not occur, as the forward and reflected waveforms add together to produce a waveform that is static and does not move along the cable; this is known as a 'standing wave'.

In an exteme case, all the power fed into the cable is reflected, so that the voltage in the standing wave varies from zero to a high peak level, and the standing wave ratio (the ratio of the maximum to the minimum voltage in the standing wave) is infinite. With a perfect match there is no standing wave, so with both the maximum and minimum standing wave voltages at zero, the SWR is 1 to 1. Thus one should aim for the lowest possible SWR, as this gives the maximum signal transfer to the aerial.

The Circuit

BASICALLY, the unit first measures the power fed down the feeder to the aerial, and then the power level reflected back down the cable, so that the efficiency of the aerial matching can be assessed.

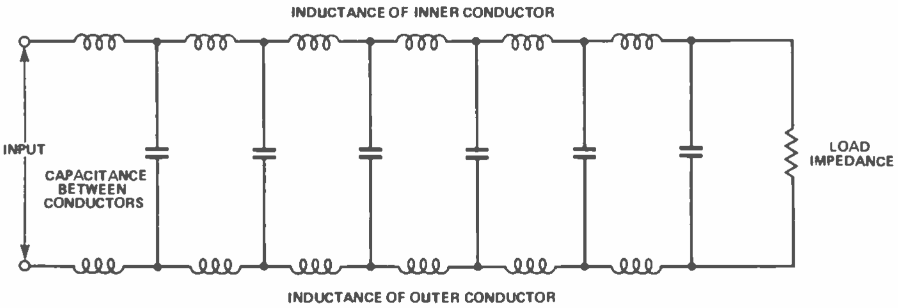
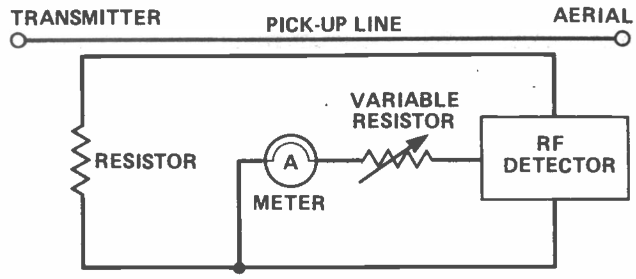
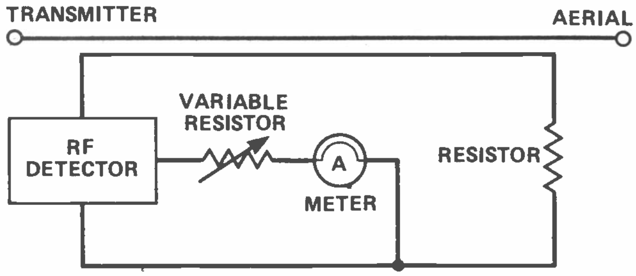


Figure 1. The equivalent circuit of a length of coaxial cable.



(a)

Figure 2(a). Forward power is measured by detecting the voltage induced at the aerial end of the pick-up wire. A simple meter is adequate for this.



(b)

Figure 2(b). Reference power, from the transmitter, is measured by the reverse procedure; the aerial end of the pick-up is earthed via a resistor and the voltage induced at the transmitter end is detected and measured.

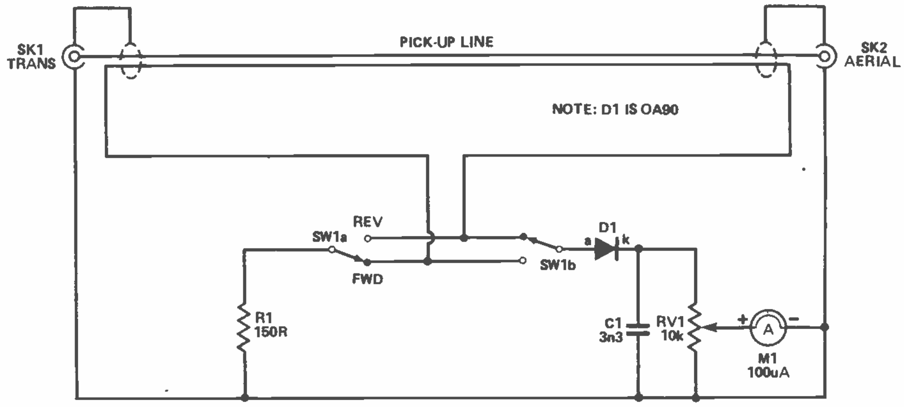


Figure 3. The complete circuit is simply a combination of the two circuits of Figure 2.

To measure forward power, the input end of the pick-up line is connected to earth via a resistor and the signal from the other end of the line is fed to an RF detector circuit which produces a DC output signal proportional to the RF signal level. This voltage is fed to a meter via a potentiometer, and the latter is adjusted to give a full scale reading on the meter. This arrangement is illustrated in **Figure 2(a)**.

Basically the same set-up is used to measure the reverse power, as can be seen from **Figure 2(b)**. The only change here is that the aerial end of the pick-up line now connects to the resistor and the input end connects to the RF detector. So, by simply transposing the connections to the pick-up line, the circuit indicates the power reflected down the feeder from the antenna. Thus a reading of 100 (full scale), at this stage, would mean that all the transmitter power was being reflected and the SWR would be infinite. The ideal case would be a reading of '0' — no reflected power — indicating an SWR of 1:1.

The SWR meter uses a conventional bridge circuit; the full circuit diagram appears in **Figure 3**. The pick-up line is simply a piece of 50R coaxial cable, to which an extra wire is added between the inner conducor and the outer braiding. The detector circuit is a straight-forward half wave type, which uses D1, C1 and RV1, with the latter enabling a proportion of the resultant DC voltage to be fed to meter M1. S1 is used to switch the pick-up line to give 'forward' or 'reverse' power reading, as desired. R1 is part of the bridge circuit and it is important to use the specified value here, if accurate results are to be obtained.

Strickly speaking, the circuit is measuring forward and reverse voltages, rather than power, so it is really a VSWR (voltage standing wave ratio) meter. However, units of this type are usually — and more accurately — just referred to as SWR meters because the ratio of forward to reverse power, current or voltage, will be the same in each case.

Construction

There are few components in the circuit and the most practical method of construction is to hard-wire the unit. Use a metal case for this project — one having dimensions of about 133 x 102 x 38 mm is ample to accommodate all the components.

The two sockets, the two controls and the meter are fitted as shown in the photograph. It is strongly recommended that the general layout used on the prototype should be copied fairly closely, as it might otherwise be awkward to wire up the unit.

If the meter is a standard 60 x 45 mm plastic front type, it will require a main 38 mm diameter cutout and four 3.2 mm diameter mounting holes. The 38 mm hole can be cut using a fretsaw or a miniature round file; a third alternative is to drill a ring of small, closely spaced holes, and then punch out the metal within the ring. With the last method it will be necessary to use a large half-round file to suitably enlarge the cutout and to produce a neat finish.

It is not necessary to use an expensive meter in the circuit; there are inexpensive types of around 100 uA sensitivity which will work perfectly well! Most ready-built SWR meters seem to use inexpensive meter movements, incidentally. It may be necessary to vary the mounting of the meter to suit the particular component employed; many inexpensive meters do not have provision for screw fixing and it will then be necessary to glue the component in position.

All the wiring of the unit is shown in **Figure 4** and this is mostly straight-forward. D1 is a germanium device and care should be taken not to overheat this component when wiring up the unit.

The pick-up line is make from a piece of RG58C or similar 50R coaxial cable, about 300 mm long. This is the type of cable that is usually used as the aerial feeder for CB rigs and it will probably be possible to trim a suitable piece from the aerial lead. Do not use a heavy-duty 50R coaxial cable, such as UR67, as this would probably be too thick and inflexible, and consequently unusable.

Step one in the construction of the pick-up line is to remove the plastic sheath from the cable; this is done by using a modelling knife to cut through the sheath along the full length of the cable. However, do be careful not to damage the copper braiding beneath the plastic sheath.

Next the braiding is bunched up slightly by pushing both ends of it towards the middle. The point of this is that it makes the outer braiding rather

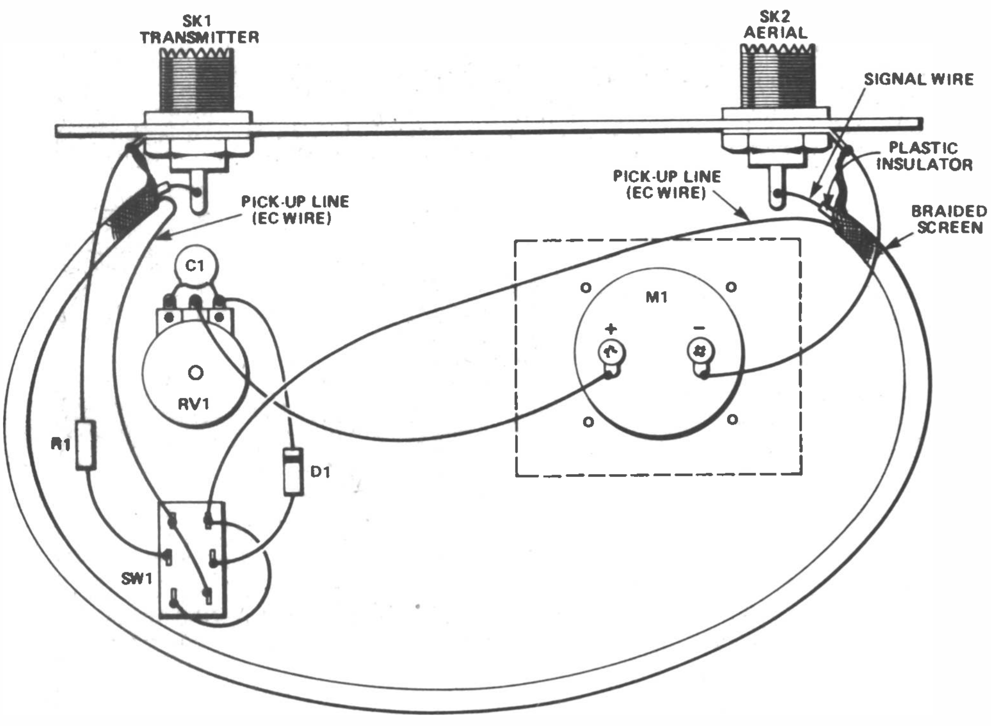


Figure 4. The component layout.

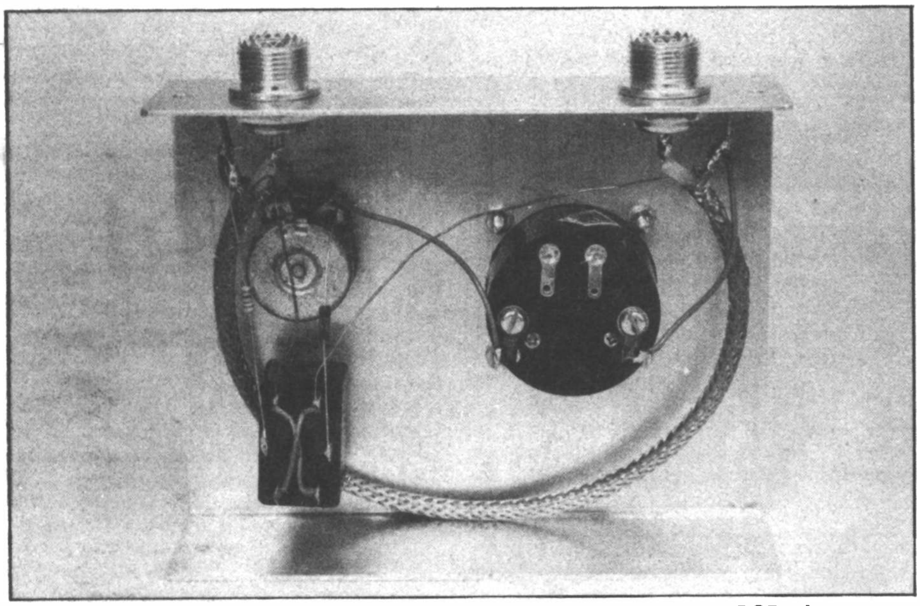


Figure 5. The internal view of the completed unit. Since there is no PCB, the construction is identical to the component layout.

Parts List

RESISTORS (All ¼ Watt 5% carbon)
R1 . . . . 150R

CAPACITORS
C1 . . . . 3n3 ceramic

POTENTIOMETERS
RV1 . . . . 10k linear carbon

SEMICONDUCTORS
D1 . . . . OA90 signal diode

MISCELLANEOUS
M1 . . . . 100uA FSD moving coil panel meter (see text)
SW1 . . . . DPDT toggle switch
SK1,2 . . . . S0239 50R UHF socket
Aluminium case (133 x 102 x 38); knob; coaxial cable (50R); enamelled copper wire (24 SWG); connecting wire, solder etc.

Buylines . . . . page 34

loose, so that the additional wire can easily be slipped under. The additional wire is a piece of 24 SWG (or any thin gauge) enamelled copper wire about 450 mm long, so that a leadout wire about 75 mm is left at each end of the pick-up line.

After stretching the braiding, so that it is as close to its original condition as possible, the pick-up line is complete and ready for connection.

Setting Up

The input socket (SK1) is fed from the transceiver via a short 50R coaxial cable fitted with PL259 plugs. Many CB shops can supply ready-made leads of this type, or you can easily put one together yourself. The aerial plug connects to SK2 of the SWR Meter instead of the output socket of the rig.

Start with RV1 adjusted almost fully anticlockwise and SW1 set to the 'forward' position. With the rig set to 'transmit', there should be a small forward reading on the meter and it should be possible to adjust RV1 for full scale deflection. Now with SW1 set to 'reverse', a much lower reading should be obtained. It is this second reading that indicates the SWR.

The SWR is 3 to 1 at half full-scale, 5 to1 at two thirds of full-scale, 7 to 1 at three quarters of full-scale, 9 to 1 at 80% of full-scale, and infinite at full-scale. A reading anywhere in this part of the scale indicates poor efficiency and a possibility of the reflected power damaging the rig.

Readings of 5,10,20 and 33% of full scale correspond to SWR values of 1.1 to 1, 1.2 to 1, 1.5 to 1, and 2 to 1 respectively. As an SWR of 2 to 1 represents 88% of the output power being transferred to the aerial, and a lower SWR will not give a significant improvement, results are satisfactory provided a reverse reading of no more than one third full scale is obtained in any channel. Note that in order to ensure good accuracy, the unit should be switched to the 'forward' mode and RV1 should be re-adjusted for full scale deflection of the meter after adjustments to the aerial have been made.

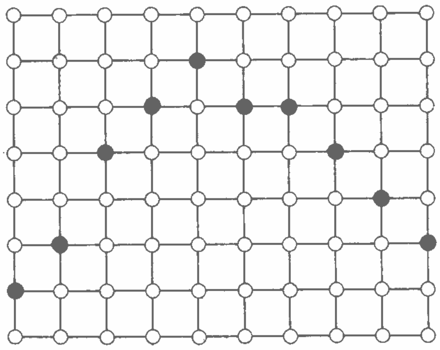
A new scale, calibrated in SWR values can be added to the meter but, as the precise SWR is not of great importance and the purpose of the unit is simply to ensure that a reasonably low SWR is being obtained, it is obviouly far from essential to recalibrate the meter.

It is perfectly acceptable to leave the meter permanently connected in the aerial lead and set to the 'reverse' mode and the unit will then give warning if a fault develops in the aerial or feeder.

An important point to bear in mind is that a low SWR does not mean that a strong signal is being radiated; it simply shows that the output of the transmitter is being effectively transferred to the aerial. How effectively the aerial radiates the signal is another matter!

HE

Audio Analyser



For creative audio applications.

AUDIO spectrum analysers can be used for a variety of tasks. Their most valuable use is to set up a room acoustically, for live music or in conjunction with a graphic equaliser connected to your hi-fi — something you'll be keen to do if you've caught the hi-fi bug after reading our 'Scaling the Hi-Fi Heights' series. This will allow you to compensate for deficiencies in either your speaker system alone, or the system/living room combination. The procedure used involves feeding pink noise (more on this later) into the room via your hi-fi system and monitoring the sound with the Analyser. The Analyser points out the peaks and troughs in the audio so that you can get rid of them by adjusting the graphic equaliser controls — hopefully this will produce a flat response.

Other uses for a spectrum analyser include monitoring live programme material or (let's be honest!) as a great little gadget to impress your friends.

To Sweep Or Not To Sweep

There are two main methods of performing spectrum analysis. The first uses a single tuneable filter which can have its centre frequency swept across the band of interest. When the filter output is displayed on an oscilloscope screen it constitutes a graph of amplitude against frequency for the input signal. This gives a well-formatted and accurate display but unfortunately it has the disadvantage of not being 'real time'; if something happens at one frequency while the filter is sweeping somewhere else, it will not be recorded. Consequently, this method is normally only used where the spectral content is constant and the sweep is to be made over a small percentage of the total frequency. A typical example of this would be checking that the emissions of a CB rig were within legal limits; the rig is turned on, with no audio input, so that only the carrier wave is being transmitted; a sweep is then made either side of 27 MHz to check that there are no spurious emissions.

When the spectrum of the input is rapidly changing, as is the case with an audio signal, then we must choose a different method. For real time analysis we use several bandpass filters, with fixed centre frequencies, to chop up the frequency spectrum into several bands. The content of each band is rectified, averaged and displayed on an oscilloscope or, as in this project, on columns of LEDs. Commercial spectrum analysers are available with anything from 10 one-octave steps to 30 third-octave steps, but the cost and complexity of the filters increases dramatically as you make the bands narrower. Consequently, we have opted for a 10 channel version, the filters' outputs being 12 dB down one octave from the centre frequency. The centre frequencies of the filters follow the standard scale; measured in Hertz they are 32, 63, 125, 250, 500, 1k, 2k, 4k, 8k, and 16k. The amplitude scale has 3 dB steps.

Admittedly, the fact that this type of analyser breaks up the frequency spectrum into octave chunks means that it isn't capable of picking out individual harmonics in the way that the sweep analyser can. Nevertheless, it does allow you to instantaneously

Parts List

RESISTORS (All ¼ watt 5% carbon)

R1,2	220k
R3	2k2
R4,5	15k
R6-10,31-35,72	10k
R11-15,21-25, 36-40,46-50,78	1M
R16-20,41-45	220R
R26-30,51-55,76	100k
R56	680k
R57	6k8
R58-67	27k
R70	430R
R71	27k
R73	4k7
R74	180k
R75	18k
R77	390k

POTENTIOMETERS

RV1	47k log carbon
PR1-10	220k min horiz preset

CAPACITORS (All metallised Polycarbonate unless noted

C1,13,43,49,50	100n
C2,3,41	10u 16V tantalum bead
C4,5,7	1u0
C6	56n
C8,10	27n
C9,11	270n
C16-20,35-39	2u2 35V tantalum bead
C12	6n8
C14	18n
C15	3n9
C21,22	39n
C23	1n5
C24	33n
C25,32,33	2n2
C26,44	820p ceramic disc
C27	12n
C28	3n3
C29	470p ceramic disc
C30	10n
C31	180p ceramic disc
C34	100p ceramic disc
C40	22n
C42	1n
C45	2n7
C46	5n6
C47,48	220u 16V axial electrolytic

SEMICONDUCTORS

IC1	LF353 dual BIFET op-amp
IC2-6	TL064 quad lo-power op-amp
IC7	4011 CMOS quad 2-input NAND
IC8,9,10	4016 CMOS quad analogue switch
IC11	LM3915 bargraph driver
IC12	4017 CMOS decade counter/divider CMOS quad exclusive-OR
IC14	4006 CMOS 18-stage shift register
Q1-11	BC184L silicon NPN transistor
D1-22	1N4148 signal diode
LED1-100	high efficiency red LED (see Buylines)

MISCELLANEOUS

SK1	¼" jack socket with break contacts
MIC1	electret microphone

PP3 battery clips (2 off); IC sockets (13 off); case; wire; solder; PCBs, etc.

Buylines . . . . page 34

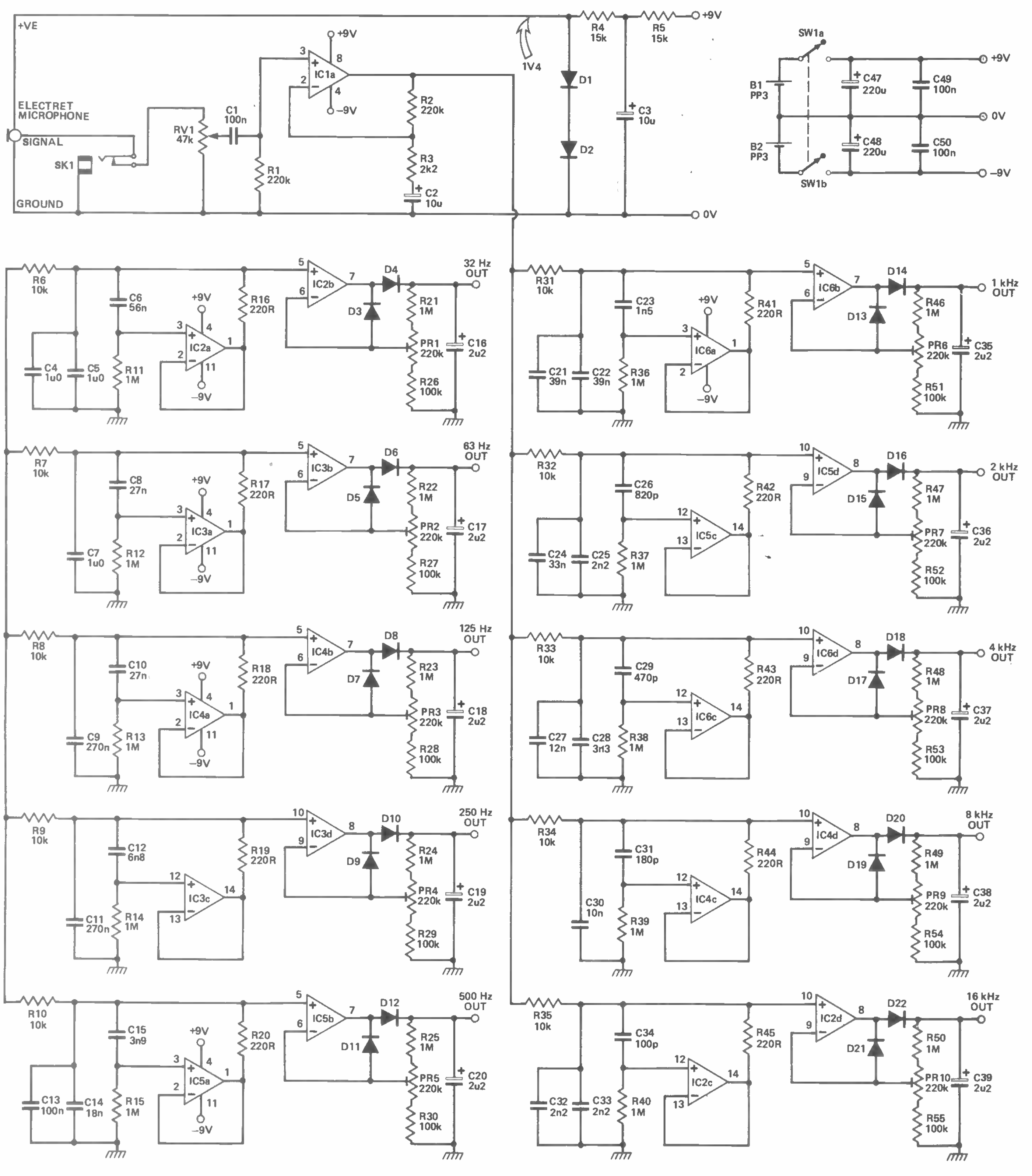


Figure 1. The input and filter stages of the circuit.

determine the average spectrum of a sound, which is all we require.

The Circuit

The input to the circuit (**Figure 1**) is either from the built-in microphone or via the external input socket. The jack socket automatically disconnects the mic if a plug is inserted. The microphone requires a reasonably flat frequency response but must be relatively inexpensive, so we chose an electret condenser type which meets these requirements. However, electret mics require a 1V5 power supply, normally provided by an AA cell. Ours has a built-in regulated supply built around D1-D2-R4-R5-C5. Zener diodes with a value of 1V5 aren't available but, by using two ordinary diodes in series, we can get an output voltage of about 1V2-1V4 (each diode has a forward voltage drop of about 0V6-0V7).

The input sensitivity can be adjusted with level control RV1, while IC1a boosts the signal to a suitable level to drive the filter bank. The gain of IC1a is set at 101, ie, (R2 + R3)/R3. Each of the ten filter-rectifier blocks is identical in structure. To obtain a bandpass response with the required roll-off, the simplest solution is to use a parallel LC

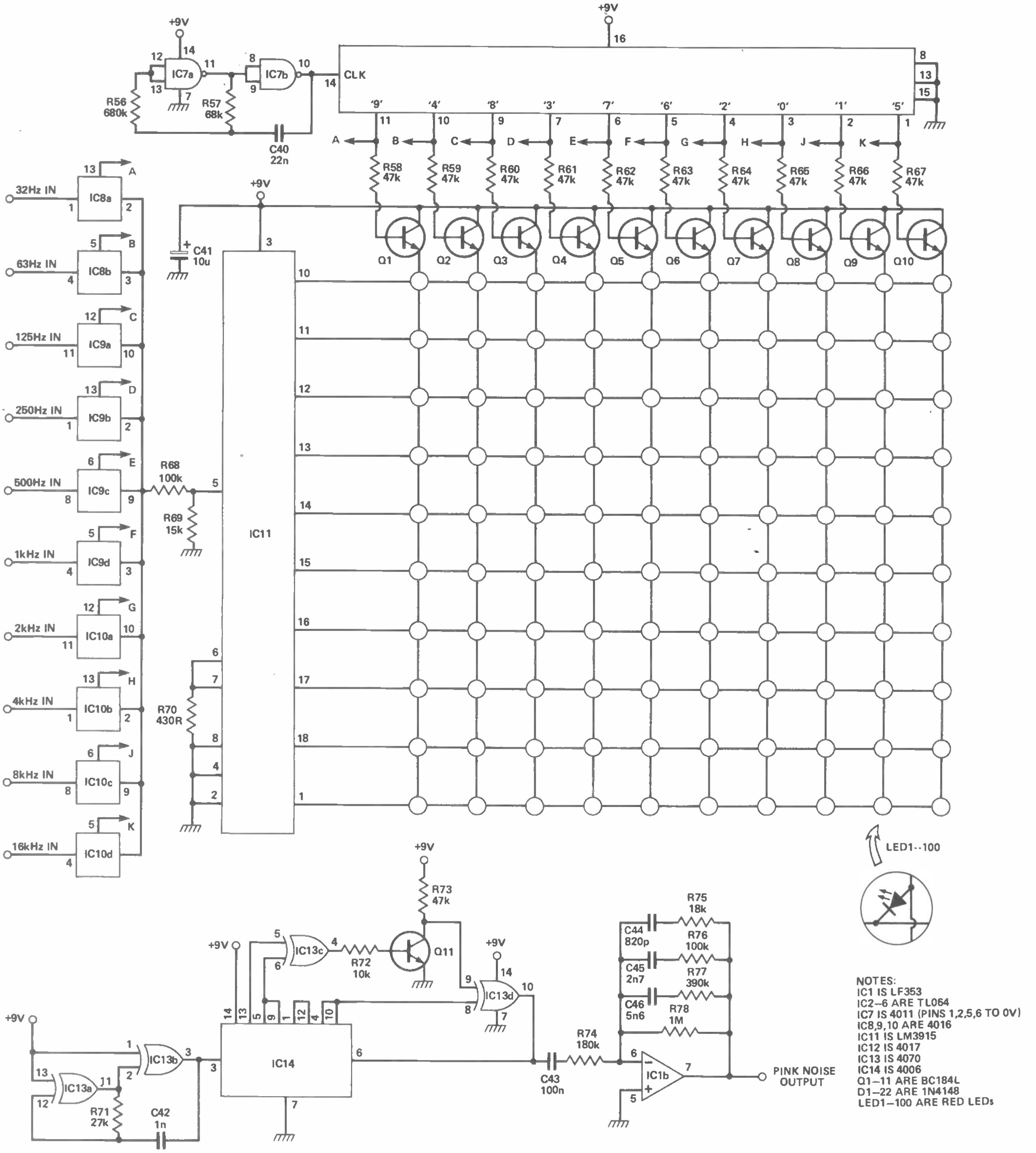


Figure 2. The display generation circuitry.

network with a series resistor. Unfortunately, large value inductors are both bulky and expensive, which rules out their use. We can overcome this easily, however, since the only *electrical* difference betwen an inductor and a capacitor is the phase relationship between the current and the voltage. By using an op-amp to reverse the phase relationship of a capacitor we can make it look like an inductor — this type of circuit (**Figure 3**) is known as a gyrator. The value of the equivalent inductance is given by:

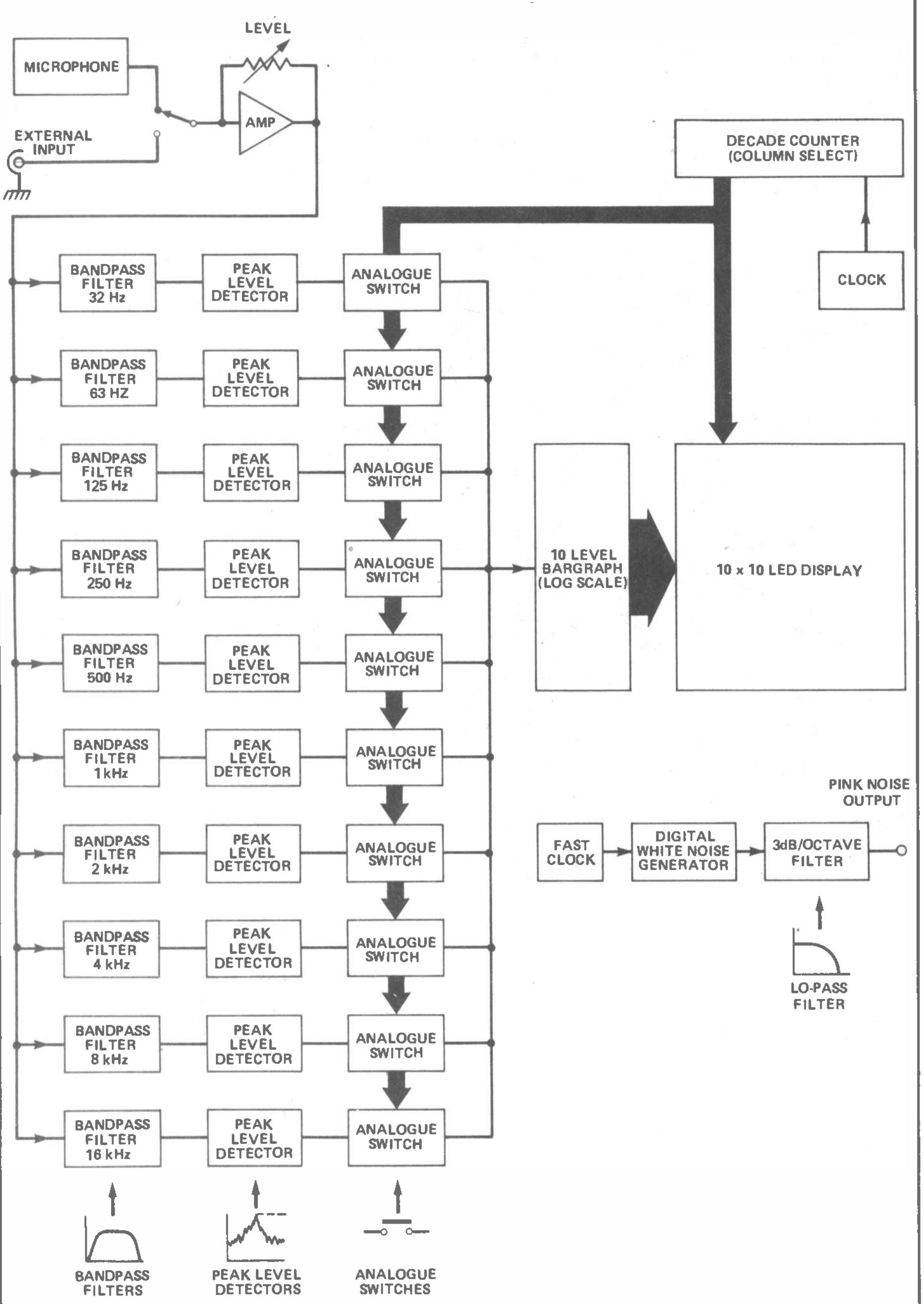
$$L1 = C1 \times R1 \times R2 \text{ Henries}$$

where C is in Farads, R in ohms. Just like a real inductor, we also have a series resistance (winding resistance) which is R2, and a parallel resistance, R1 (in a real coil this is due to winding capacitance). Hence we can tune our filters to the required frequencies by altering the capacitor values in each one, using parallel pairs in some cases, to get the correct values.

The rectifier section is a half-wave type, with a gain variable from about four to 12, using the presets. When the output of the op-amp swings positive, capacitor C1 charges rapidly via the diode; D1; when the output falls, the capacitor can only discharge slowly via the resistor chain. The second diode D2, from the op-amp output back to the inverting input, keeps the op-amp in the linear region on the negative half-cycle.

The outputs of the ten rectifiers are multiplexed to reduce the component count and cost; if we drove each column of LEDs separately we'd need

How It Works



The audio signal to be analysed is taken from the microphone or external input socket to the level control/preamplifier section. This amplifies the signal to a suitable level to drive the circuitry that follows. The signal is fed to 10 bandpass filters spaced one octave apart, each of which will only allow through a small section of the signal around the centre frequency. Each filter is followed by a peak level detector which averages out the signal, responding quickly to peaks but decaying slowly so that the display is easy to read. The outputs of the 10 peak detectors are connected one at time (by the CMOS analogue switches) to the input of a 10-level LED bargraph driver. A logarithmic driver is used to give 3 dB steps. To reduce current consumption the baragraph operates in dot mode, so that the height of the illuminated LED up the column represents the peak level. The decade counter which controls the analogue switches also switches on the correct column of LEDs for each passband. All the columns are blanked for a short period, as the switches changed over, to prevent garbage being displayed.

The white noise is generated digitally by cyclingg a scrambled sequence of 1s and 0s through a shift register. The white noise is passed through a filter with a slope of 3 dB/octave to produce pink noise.

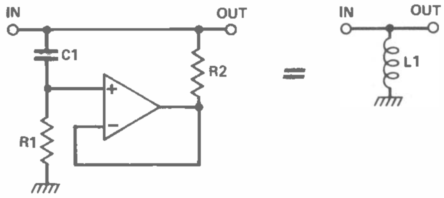


Figure 3. A gyrator circuit 'looks like' an inductor.

ten LM3915s, which is a bit expensive! Multiplexing means that each rectifier output is switched to the input of the LM3915 (IC11) one after another, by the analogue switches IC8, 9 and 10. The switches are controlled by a 4017 decade counter (IC12) with ten decoded outputs, each of which is high for one clock period only. These outputs also switch on one of the transistors Q1-10, connecting the required column of LEDs to the positive supply rail. Meanwhile the LM3915 has turned on one of its outputs corresponding to the voltage on its input (remember, it's wired in dot mode). Hence a current path between the supply rails exists for only one LED of the 100 in the display, so at any moment only one LED is turned on. By clocking the 4017 at a fairly slow speed (about 500 Hz) the display cycles through all ten columns 50 times a second and the eye sees ten LEDs 'continuously' lit.

To generate an adequate light level, a red LED requires at least 4 or 5 mA continuous current. Since each LED is only on for one-tenth of the total time, it requires ten times the current to give the same apparent brightness. The maximum current capability of the LM3915 is only 30 mA, so high efficiency LEDs must be used (see Buylines). The 4017 is even worse at supplying current, hence the use of the drive transistors.

The clock generator for IC12 is a standard configuration built round IC7a,b.

White noise is an audio signal which contains all frequencies and has equal energy per unit bandwidth. However, what we require here is equal energy per *percentage* bandwidth (ie, equal energy per octave). This is known as pink noise and it is obtained by passing white noise through a filter (IC1b) with a slope of 3 dB/octave. The white noise is generated digitally rather than by a Zener noise diode, which can be temperamental. IC14 is an 18-stage shift register clocked by the 30 kHz oscillator IC13a,b. Two EX-OR gates and an inverter (IC13c,d and Q11) are used to feed various outputs of IC14 back to the input (pin 6) so that a complex sequence of 1s and 0s flows through the register, repeating once every few seconds. This produces an apparently random jumble of fundamental frequencies with a vast number of harmonics — ie, noise.

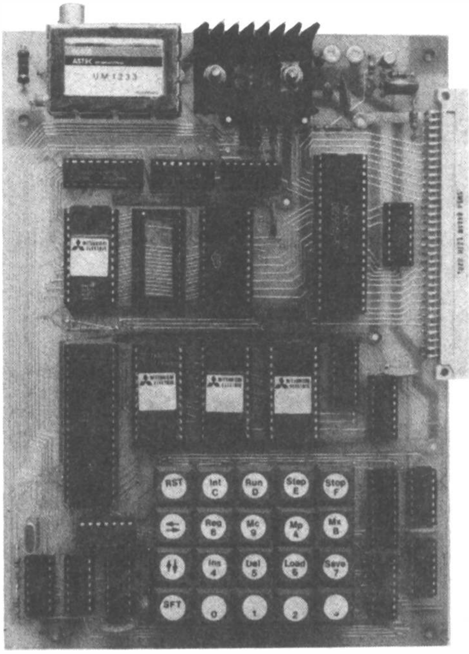
And that's about enough to digest for one month! Next issue, we'll present the PCB foil patterns and all the information needed to complete the Audio Analyser. **HE**

HE MicroTrainer

For ease of construction, the MicroTrainer is built on a double-sided, through-hole-plated printed circuit board.

THE HE MicroTrainer is a fairly complex piece of computer hardware, and for this reason, its construction must be carried out very carefully, with close attention to detail. All of the parts and components of the MicroTrainer (with certain exceptions — see the Parts List) are available from Technomatic Ltd. These include a high quality double-sided, through-hole plated PCB (this keeps the size of the board to practical dimensions and simplifies construction by eliminating the need for large numbers of wire links) and the specially programmed EPROM ICs, which are used to implement many of the logic functions, eg in generating the video display.

The box shown on the cover of the HE June issue, in which the MicroTrainer was introduced, is NOT part of the kit!



Construction

Assembling the kit should be easy provided that your soldering is neat and that you are careful to check the placement of components. You will need to refer to the component overlay diagram and the Parts List.

First, fit and solder in position all the IC sockets. You may find it easier to do this one socket at a time, ensuring that the pins are pushed right through the holes and that the socket is flush with the board. Do not use excess solder, or short circuits will be formed on the component side of the board; ⅛" of 22 SWG solder should be sufficient for each joint and the sign of a well formed joint is a cone of solder, surrounding the pin, which is neither sunken nor bulbous. Next, fit and solder all the passive components, with the capacitors and the crystal standing upright, close to the board. Bend the leads of the resistors so that they lie horizontally on the board. After soldering each of these components, cut away the excess leads. Finally, fit and solder the modulator, the regulator, with its heatsink, and the 20 keyswitches. A thin smear of silicone grease should be applied to the metal tab of the regulator which, together with the heatsink, should then be bolted tightly to the PCB as shown in the component overlay diagram. Take care that each keyswitch is pushed firmly onto the board before soldering, to produce a neat and level keypad.

Testing

Do not, at this stage, attempt to fit the IC's to their sockets. It is worthwhile carefully checking over the board looking for solder 'bridges' or otherwise badly made joints. Now connect a DC power supply (8-12 volts @ 800 mA or more) again using the overlay to provide the connection details. Check the sockets from the top side of the PCB with a voltmeter, to ensure that the supply voltage (5 V) is correct for each IC, using the circuit diagram (published last month) to determine the correct pins. Now, having switched off the power supply, fit each IC into its (correct) socket and check that no pins are folded under, or folded outside the socket.

Connect a coaxial lead from the modulator to a TV set and tune it to channel 36, UHF. Switch on the power supply and press reset (RST). By fine tuning the TV set and adjusting the brightness and contrast controls, it should be possible to produce a sharp display that looks something like **Figure 1**.

If there is no display, or the display is distorted in some way, it is likely that there is a fault in the construction, therefore once again check the board against **Figure 2** and check for solder splashes or bent IC pins. If, despite all checks and precautions, your MicroTrainer still does not produce the above display, it is probable that something more serious has gone wrong. Unless you are very experienced with microcomputers — and have to hand all the necessary test equipment — it is better not to attempt further fault-finding. Technomatic Ltd will repair any unsuccessful efforts at constructing their MicroTrainer kit, so contact them immediately. Their service charge is £10, including return postage, plus any component replacement costs, of course.

MicroTraining

After power-up, or pressing reset, the machine generates a display of the contents of the first 32 bytes of RAM, in Hexadecimal. Immediately below this is a four digit, Hexadecimal 'cursor' address, initially 0000H, which gives the memory address of the data byte indicated by the flashing cursor. Programs, in the form of Hexadecimal data, can be stored in memory, at the address of the cursor, by typing on the

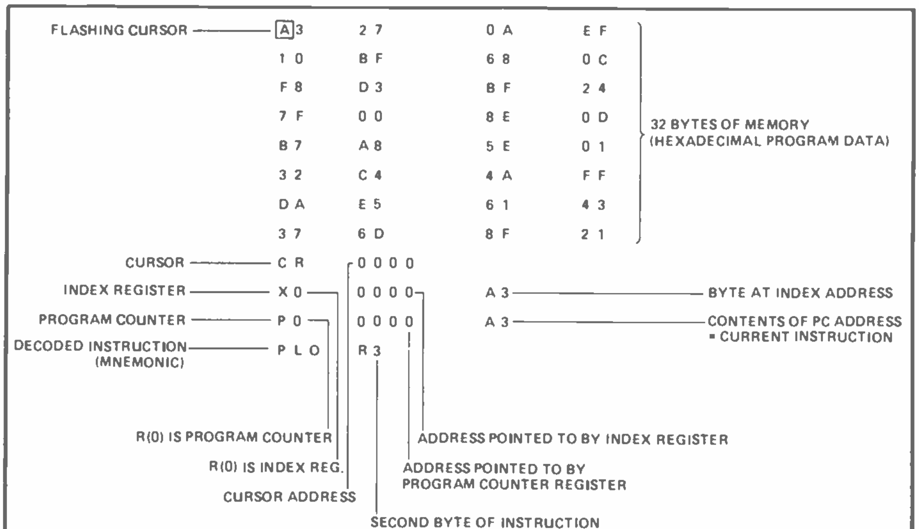


Figure 1. The screen in Memory Display Mode, with the meaning of the various symbols indicated.

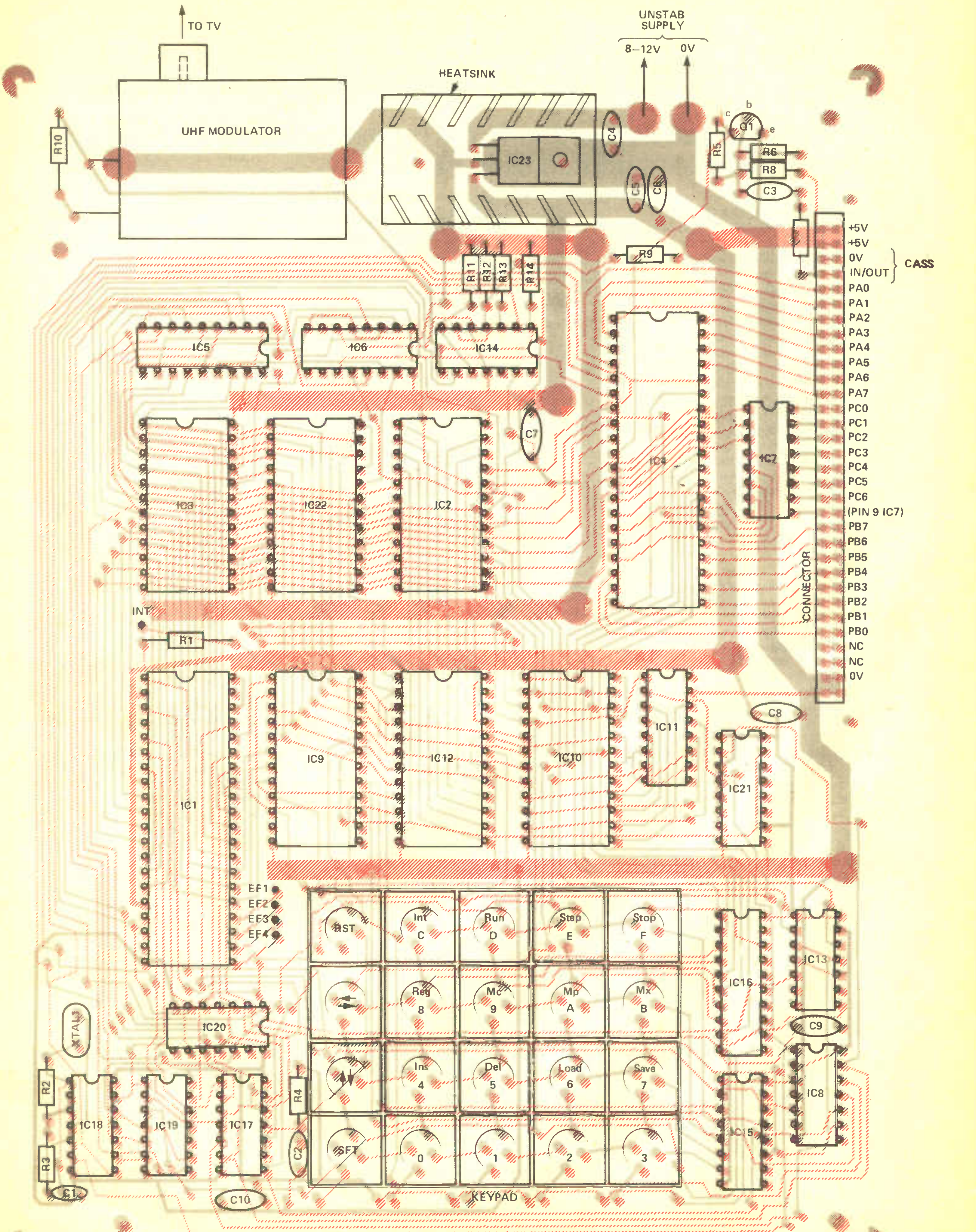


Figure 2. The component layout diagram. The tracks printed in colour are those on the TOP (component side) of the PCB.

keypad. For example, try typing in the following data:
F8 20 B1 F8 00 A1
51 11 81 3A 06 00

Notice that, as you type, the data appears at the cursor position and the flashing cursor advances; the cursor address increments each time. In the event of typing mistakes, the key labelled with a left-right arrow, in conjunction with the shift key (SFT), can be used to step the cursor backwards.

The above data is, in fact, a simple program, as shown in **Figure 3.** This program will write the character codes 00H to FFH in memory locations 2000H to 20FFH respecticely, ie display the complete character set over the entire screen. We can now use the MicroTrainer itself to illustrate the working of this program — and introduce some of the machine's more important features at the same time.

Having entered the program into memory, put the machine in register display mode (**Figure 4**) by holding down 'SFT' and pressing 'REG'. You will see displayed on the screen the contents of the 1802's internal register set: the 16-bit address registers R(0) through R(F), and the minor registers CF (carry flag), AC (accumulator), IE (interrupt enable flag) and T (temporary register). R(0) is, for the moment of particular concern because it is the register used by the 1802, after reset, as the program counter and it has the initial value of 0000H. This is indicated by the 4 bit register P, displayed near the bottom of the screen together with the contents of the program counter register and the memory byte to which it points (you should see: P0 0000 F8). This latter byte is, in fact, the current instruction code, which has been 'decoded' or disassembled into its mnemonic representation on the bottom line. Thus, the mnemonic of F8 is LDI, which means Load Immediate (data into the accumulator); this is much easier to remember and understand than simply 'F8'. The full instruction is, in fact, 'LDI $20', meaning that the data byte immediately following the instruction ($20) is to be loaded into the accumulator (AC). Now, hold down the shift key and press 'STEP'. Observe the effect this has on the accumulator; notice also that the program counter, R(0), has automatically incremented by two so as to point to the next instruction. Now, the bottom two lines of the display show the next instruction, B1, mnemonic PHI R1. Execute this next instruction by using the STEP function again, and observe the effect on R(1) and on the program counter; the accumulator is copied into the high order byte of R(1) and the program counter is incremented by one.

After the execution of the first four instructions, the address 2000H will have been copied into R(1); this now points to the first byte of the display RAM. The following instruction, STR(R1) causes the accumulator contents (which in this case are the same as the contents of the *low byte* of R(1)) to be stored at the memory address pointed to by R(1). During single step operation, the characters will not be displayed, as the screen is over-written by the display of the register data and this prevents the effect of this last instruction from being seen. Briefly, what is happening is: INC R1 increments R(1); GLO R1 copies the low order byte of R(1) into the accumulator; BNZ $06 (Branch if Not Zero) causes the byte immediately following the instruction ($06) to be copied into the low byte of the program counter if the accumulator is non-zero, else the program counter is increment-

```
0000 F8  20  LDI  $20   ; Load high byte of register 'I' with
0002 B1      PHI  R1    ; hex '20'
0003 F8  00  LDI  $00   ; Load low byte of register 'I' with
0005 A1      PLO  R1    ; hex '00'
0006 51      STR  (R1)  ; register 'I' points to display address
                        ; range
0007 11      INC  R1    ; advance to next display position
0008 81      GLO  R1    ; get next character code
0009 3A  06  BNZ  $06   ; loop until 256 characters displayed
000B 00      DLE        ; stop
```

Figure 3. A simple program to inspect the character set.

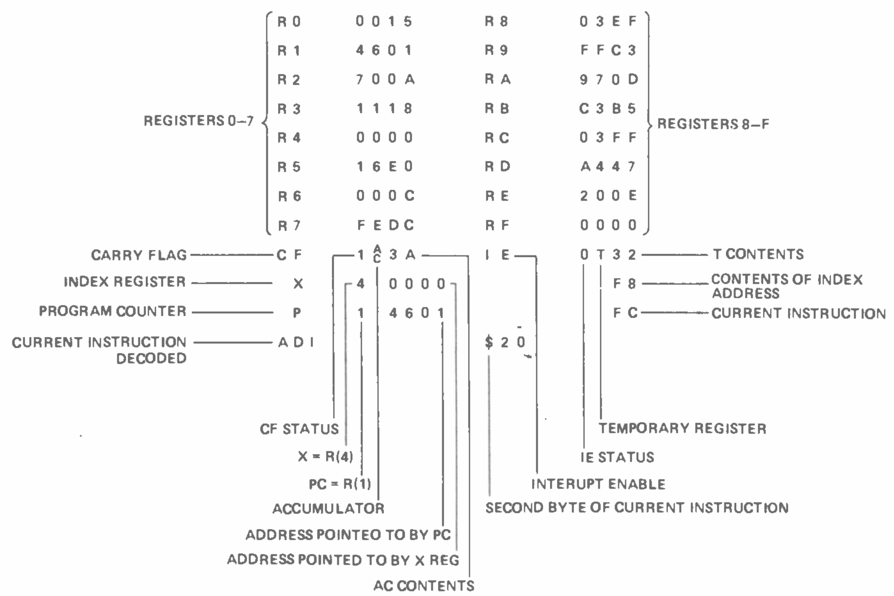


Figure 4. The screen in Register Display Mode.

RST	**Reset:**	**the machine assumes its initial power-up state; P = 0, X = 0, R(0) = 0000H, CR = 0000H; the display is of 32 bytes of memory with independent cursor.**
INT	**Interrupt:**	**executes the current instruction and then simulates the normal interrupt action of the 1802.**
RUN		**Perform simulated execution of the 1802 code, commencing from the present program counter address.**
STEP		**Perform one instruction at the preset program counter address and update display.**
STOP		**Stop program simulation and await display command.**
REG		**Display registers.**
MX		**Display memory using index register as cursor address.**
MP		**Display memory using program counter as cursor address.**
MC		**Display memory using indepentent cursor.**
INS	**Insert:**	**move all data, at and forward of the cursor, forward one byte in RAM.**
DEL	**Delete:**	**eliminate the byte under the cursor, thus moving back, by one byte, all data previously forward of the cursor.**
→		**Move cursor forward one byte.**
←		**Move cursor back one byte.**
↓		**Move cursor forward one page (32 bytes).**
↑		**Move cursor back one page.**
SAVE		**Save the contents of the entire 1K5 of RAM on cassette tape.**
LOAD		**Load into ram any program previously stored on cassette.**

Figure 5. The Command Table. All except Reset and two of the Cursor Control Commands are entered using the Shift (SFT) key.

Parts List

RESISTORS (All ¼ watt 5% carbon)

R1,4,8*,15,16,17,18,19	4k7
R2,3,7*,9,14	470R
R5*	5k6
R6*,13	680R
R10,11,12	220R

CAPACITORS

C1	33p disc ceramic
C2	47u 6V3 tantalum bead
C3*,6,7,8,9,10	100n disc ceramic
C4,5	2u2 16V tantalum bead

SEMICONDUCTORS

Q1*	BC108 silicon NPN transistor
IC1	1802 microprocessor
IC2	6116 8-bit RAM
IC3,22*	2532 EPROM
IC4*	8255 programmable peripheral interface
IC5,16	74LS374 TTL octal D-type flip-flop
IC6	74LS138 TTL 3-8 line decoder/multiplexer
IC7*	ULN2003 darlington array
IC8	74LS113 TTL dual J-K flip-flop
IC9,10,12	2716 EPROM
IC11	74LS165 TTL 8-bit parallel-to-serial converter
IC13	74LS74 TTL dual D-type flip-flop
IC14	CA3086 transistor array
IC15	74LS156 TTL dual 1-of-4 decoder/demultiplexer
IC17	74LS14 TTL hex Schmitt trigger
IC18	74LS04 TTL hex inverter
IC19	74LS00 TTL quad 2-input NAND
IC20	74LS08 TTL quad 2-input AND
IC21	74LS163 TTL binary counter
IC23	7805 voltage regulator
UHF MOD	UM1233 UHF TV modulator

MISCELLANEOUS

Heatsink (TV-21, for regulator); switch-caps (20, for keypad); IC sockets (optional); power supply (800mA 8-12V unregulated); double-sided, through-hole-plated PCB.

NOTE: The 2716 and 2532 EPROM's (IC's 3,9,10,12) are only available from Technomatic — they have to be specially programmed.

* These components are NOT included in the kit supplied by Technomatic.

Buylines .... Page 34

ed by two. With these limited explanations, you should be able to arrive at an understanding of the program, aided by stepping through the instructions and carefully observing what has happened. A much more detailed description of the 1802's instruction set will be given next month, together with further program examples. However, for the time being, the real point of exercise is to familiarise yourself with the operation of the MicroTrainer; the more you can work out for yourself the better.

To round off the example in hand we should now attempt to Run this program. First, type 'SFT MP' ; this enables the program to be displayed as before, however the program counter itself now becomes the cursor address counter. You can now step the cursor back using the 'left-arrow' so that the program counter points to the first byte of the program; then type 'RUN'. The TV screen will fill up with a set of characters and then stop, leaving a steady display. With a program this simple, some of the characters are placed outside the main display area and, by their proximity to the SYNC pulses, there may be some slight distortion. How this can be avoided will be explained in a later issue.

In addition to details of the instruction set, next month, we shall be describing how to interface the MicroTrainer to external devices, with the addition of the I/O port.

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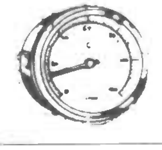

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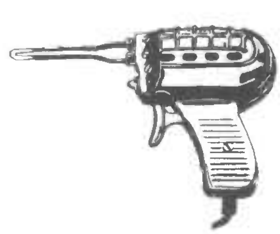

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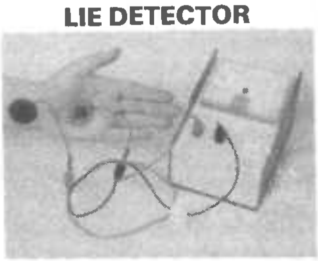

This beautifully made precision instrument is not a toy or gimmick, it was originally used on an Open University course to measure changes in emotional balance by detecting small changes in skin resistance. Full details of how to use it are provided, together with a circuit diagram. Supplied complete with probes, leads and conductive jelly. Needs 2 × 4½V batteries. Overall size 155 × 100 × 100mm. The 100-0-100uA 4" panel meter is worth more than we're asking for the whole unit!! £7.95

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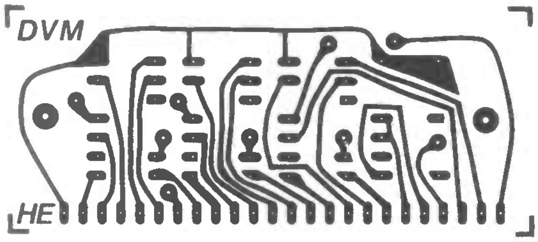

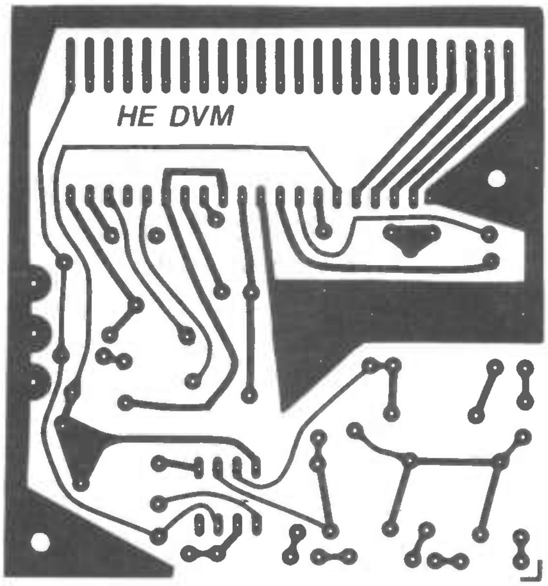

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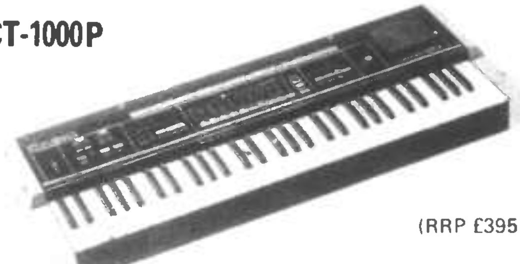

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