Australia $1.60 New Zealand $1.75 Malaysia $4.95

PRACTICAL

NOVEMBER 1984 · 90p

ELECTRONICS

ROBOTICS · MICROS · ELECTRONICS · INTERFACING

16 Page SPECIAL Pullout!

robotics SUPPLEMENT

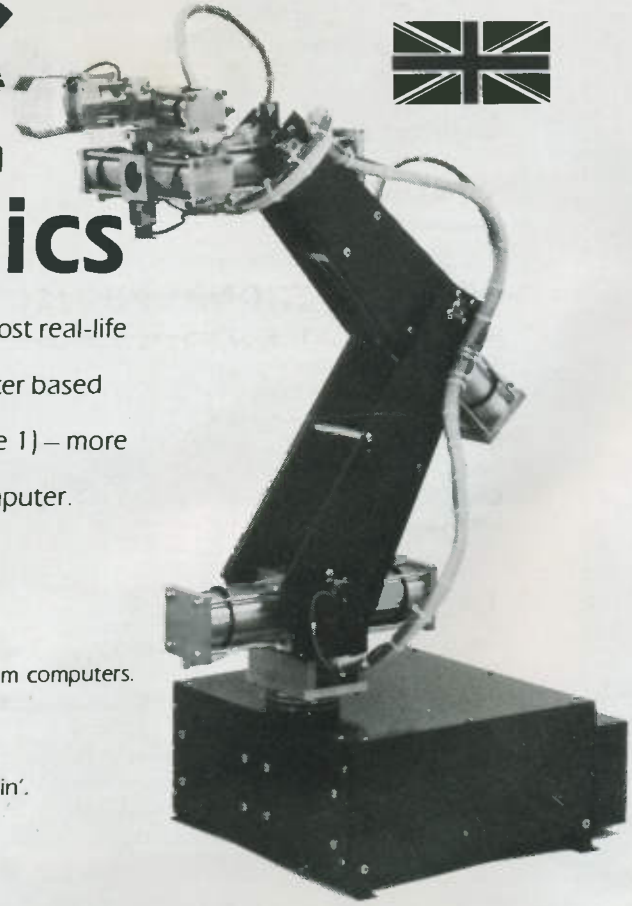
NICKEL CADMIUM BATTERIES

RING MODULATOR

neptune

for low-cost training in

real-life robotics



The advanced design of the Neptune 2 makes it the lowest cost real-life industrial robot.
It is electro-hydraulically powered, using a revolutionary water based system (no messy hydraulic oil!)
It performs 7 servo-controlled axis movements (6 on Neptune 1) – more than any other robot under £10,000.
Its program length is limited only by the memory of your computer.
Think what that can do for your BASIC programming skills!

And it's British designed, British made.

Other features include:

- Leakproof, frictionless rolling diaphragm seals.
- Buffered and latched versatile interface for BBC VIC 20 and Spectrum computers.
- 12 bit control system (8 on Neptune 1).
- Special circuitry for initial compensation.
- Rack and pinion cylinder couplings for wide angular movements.
- Automatic triple speed control on Neptune 2 for accurate 'homing in'.
- Easy access for servicing and viewing of working parts.
- Powerful – lifts 2.5 kg. with ease.
- Hand held simulator for processing (requires ADC option).

Neptune robots are sold in kit form as follows:

Neptune 1 robot kit (inc, power supply)	£1250.00
Neptune 1 control electronics (ready built)	£295.00
Neptune 1 simulator	£45.00
Neptune 2 robot kit (inc. power supply)	£1725.00
Neptune 2 control electronics (ready built)	£475.00
Neptune 2 simulator	£52.00
ADC option (components fit to main control board)	£95.00
Hydraulic power pack (ready assembled)	£435.00
Gripper sensor	£37.50
Optional extra three fingered gripper	£75.00
BBC connector lead	£12.50
Commodore VIC 20 connector lead and plug-in board	£14.50
Sinclair ZX Spectrum connector lead	£15.00

All prices exclusive of VAT and valid until the end of 1984.

mentor

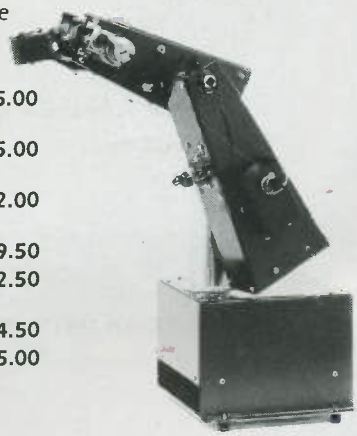
desk-top robot

This compact, electrically powered training robot has 6 axes of movement, simultaneously servo-controlled. It gives smooth operation, and its rugged construction makes it ideal for use in educational establishments. Other features include long-life bronze and nylon bearings, integral control electronics and power supply, special circuitry for inertial compensation, optional on-board ADC, and hand-held simulator as the teaching pendant. Like Neptune, Mentor's program length is limited only by your computer's memory. Programming is in BASIC.

Mentor is all-British in design and manufacture and comes in kit form at an astonishingly low price:

Mentor robot kit (inc. power supply)	£345.00
Mentor Control electronics (ready built)	£135.00
Mentor Simulator (requires ADC option)	£42.00
ADC option (Components fit to control electronics board)	£19.50
BBC connector lead	£12.50
Commodore VIC 20 connector lead and plug-in board	£14.50
Sinclar ZX Spectrum connector lead	£15.00

All prices exclusive of VAT and valid until the end of 1984.



Cybernetic Applications

CYBERNETIC APPLICATIONS LIMITED

PORTWAY TRADING ESTATE, ANDOVER, HANTS SP10 3PR
TEL: (0264) 50093 Telex: 477019

PRACTICAL
ELECTRONICS

VOLUME 20 **No. 11** **NOVEMBER 1984**

CONSTRUCTIONAL PROJECTS

GENERAL FEATURES

NEWS AND COMMENT

SPECIAL SUPPLEMENT

Unfortunately we are unable to publish the
Radar Security Alarm ***Part 2 in this issue.***

OUR DECEMBER ISSUE WILL BE ON SALE FRIDAY, NOVEMBER 2nd, 1984
(for details of contents see page 36)

WATFORD ELECTRONICS

33, CARDIFF ROAD, WATFORD, HERTS WD1 8ED, ENGLAND

Tel. Watford (0923) 40588. Telex: 8956095 WAELEC

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ALL DEVICES BRAND NEW. FULL SPEC. AND FULLY GUARANTEED. SEND CASH, P.O.'s OR CHEQUE WITH ORDER. GOVERNMENT AND EDUCATIONAL INSTITUTIONS OFFICIAL ORDERS ACCEPTED (ACCESS ORDERS BY TELEPHONE 0923-50234). TRADE AND EXPORT INQUIRY WELCOME. P & P ADD 70p TO ALL CASH ORDERS. OVERSEAS POSTAGE AT COST. PRICES SUBJECT TO CHANGE.

VAT Export orders no VAT. U.K. customers please add 15% VAT to total cost incl. p&p. We stock thousands more items. It pays to visit us. We are situated behind Watford Football Ground. Open Monday to Saturday, 9.00am to 6.00pm. Ample FREE Car parking.

POLYESTER RADIAL LEAD CAPACITORS: 250V; 10n, 20n, 15n, 22n, 27n **6p**; 33n, 47n, 68n, 100n **8p**; 150n, 220n **10p**; 330n, 470n **15p**; 680n **19p**; 1µ **23p**; 1µ5 **40p**; 2µ2 **46p**.

ELECTROLYTIC CAPACITORS (Values in µF). 500V: 10µF **52p**; 47 **78p**; 63V: 0·47, 1·0, 1·5, 2·2, 3·3, **8p**; 4·7 **9p**; 10 **10p**; 15, 22 **12p**; 33 **15p**; 47 **12p**; 68 **18p**; 100 **19p**; 220 **26p**; 1000 **70p**; 2200 **99p**; 50V: 68 **20p**; 100 **17p**; 220 **24p**; 40V: 6·8 **15p**; 22 **9p**; 33 **12p**, 330, 470 **32p**; 1000 **46p**; 2200 **90p**; 25V: 4·7, 10, 22, 47 **8p**; 100 **11p**; 150 **12p**; 220 **15p**; 330 **22p**; 470 **25p**; 680, 1000 **34p**; 1500 **42p**; 2200 **50p**; 3300 **76p**; 4700 **92p**; 16V: 2·5, 40 **8p**; 47, 68, 100 **9p**; 125 **12p**; 220 **13p**; 330 **16p**; 470 **20p**; 680 **34p**; 1000 **27p**; 1500 **31p**; 2200 **36p**; 4700 **79p**.

TAG-END TYPE: 64V: 4700 **245p**; 3300 **198p**; 2200 **139p**; 50V: 3300 **154p**; 2200 **110p**; 40V: 4700 **160p**; 25V: 4700 **98p**; 10,000 **320p**; 15,000 **345p**.

TANTALUM BEAD CAPACITORS: 35V: 0·1µ, 0.22, 0·33 **15p** 0.47, 0·68, 1·0, 1·5 **16p** 2·2, 3·3 **18p** 4·7, 6·8 **22p** 10 **28p** 16V: 2·2, 3·3, **16p** 4·7, 6·8, 10 **18p** 15 **36p** 22 36p 33, 47 **50p** 100 **95p** 220 **100p** 10V: 15, 22 **26p** 33, 47 **50p** 100 **75p**.

SILVER MICA (pf)
2, 3·3, 4·7, 6·8, 8·2, 10, 12, 18, 22, 27, 33, 39, 47, 50, 56, 68, 75, 82, 85, 100, 120, 150, 180 **15p**. 220, 250, 270, 330, 360, 390, 470, 600, 800 & 820pF **21p**.
1000, 1200, 1800 **30p each**
3300, 4700 **60p each**

SIEMENS mulitlayer miniature capacitors.
250V: 1nF, 1n5, 2n2, 3n3, 4n7, 6n8, 8n2, 10n, 15n, 22n **7p**; 18n, 27n, 33n, 47n **8p**; 39n, 56n, 68n **9p**, 100nF **11p**.
100V: 100n, 120n, **10p**; 150n **11p**; 220n **13p**; 330n **18p**; 470n **23p**; 680n **30p**; 1µF **34p**; 2µ **50p**.

CERAMIC Capacitors: 50V
Range 1pF to 6800pF **4p**; 10nF, 15n, 33n, 47nF **5p**; 100nF/30V **7p**.

POLYSTYRENE Caps:
10pF to 1nF **8p**
1n5 to 12nF **10p**

POTENTIOMETERS: Carbon Track, 0·25W Log & Linear Values.

500Ω, 1K & 2K (LIN ONLY) Single	**35p**
5KΩ-2MΩ single gang	**35p**
5KΩ-2MΩ single gang D/P switch	**95p**
5KΩ-2MΩ dual gang stereo	**99p**

SLIDER POTENTIOMETERS
0·25W log and linear values 60mm track
5KΩ-500KΩ Single gang **80p**

PRESET POTENTIOMETERS

0·1W 50Ω-2·2M Mini Vert. & Horiz.	**8p**
0·25W 220Ω-4M7 Vert. & Horiz.	**12p**

RESISTORS Hi-stab, Miniature. 5% Carbon.

	RANGE	Val.	1-99	100+
0·25W	2Ω2 - 4M7	E24	3p	1p
0·5W	2Ω2 - 4M7	E12	3p	1p
1W	2Ω2 - 10M	E12	6p	4p
1% Metal Film	51Ω-1M	E24	8p	6p

RESISTORS S.I.L. Package: 7 Commoned, 100Ω, 680Ω, 1K, 2K2, 4K7, 10K, 47K, 100K **24p**.
8 Commoned: (9 pins) 150Ω, 180Ω, 270Ω, 330Ω, 1K, 2K2, 4K7, 6K8, 10K, 22K, 47K, 100K **26p**.

TRANSISTORS

AC127/8	35
AC141/2	35
AC176	35
AC187/8	35
AC188	35
AD142	120
AD149	79
AD161/2	42
AF118	95
AF139	40
AF239	55
BC107/8	12
BC107B	14
BC108B	14
BC108C	14
BC109	12
BC109B	14
BC109C	14
BC114/5	30
BC117/8	25
BC140	38
BC142/3	38
BC147/8	12
BC147B	15
BC148C	10
BC149	12
BC149C	15
BC153/4	30
BC157/8	14
BC159	11
BC167A	14
BC168C	12
BC169C	12
BC171/2	12
BC173	15
BC177/8	16
BC179/B1	20
BC181	30
BC182/3	10
BC184	10
BC182L	10
BC184L	10
BC186/7	28
BC212/3	12
BC212L	10
BC213L	12
BC214	10
BC214L	12
BC237/8	15
BC307B	15
BC308B	16
BC327/8	15
BC337/8	15
BC441	34
BC461	34
BC477/8	40
BC516/7	40
BC547/8	12
BC549C	15
BC556/7	15
BC558/9	15
BCY41/42	30
BCY70	18
BCY71/2	20
BCY72	25
BCY78	30
BD131/2	85
BD133	60
BD135	45
BD136/7	40
BD138/9	40
BD140	40
BD158	68
BD245	65
BD434	70
BD695A	150
BD696A	150
BF115	45
BF154/8	30
BF167	35
BF173	35
BF177	35
BF178	35
BF179	40
BF194/5	12
BF198/9	18
BF200	30
BF224	40
BF244A	28
BF244B	29
BF245	50
BF256B	50
BF257/8	32
BF259	40
BF394	40
BF451	40
BF494/5	40
BF594/5	30
BFR39/40	25
BFR41/79	25
BFR80/81	25
BFR98	105
BFX29/84	35
BFX84	35
BFX85/86	35
BFX87/88	28
BFY50/51	30
BFY52	30
BFY53	35
BFY55	35
BFY56	35
BFY64	40
BFY90	80
BRY39	50
BSX20	30
BSX29	45
BSY26	35
BSY95	35
BU105	180
BU205	190
BU206	200
BU208	200
MJ2955	90
MJE340	54
MJE371	100
MJE2955	99
MJE3055	70
MPF102	45
MPF103/4	30
MPF105	30
MPSA05	30
MPSA06	25
MPSA08	30
MPSA12	32
MPSA55	30
MPSA56	30
MPSA70	40
MPSU05	58
MPSU05	60
MPSU06	60
MPSU52	65
MPSU55	60
MPSU56	60
OC23	170
OC28/36	220
OC41/42	75
OC70	40
OC72	50
OC75/76	55
OC76	50
OC81/82	50
OC83/84	70
TIP29A	32
TIP29C	38
TIP30A	35
TIP30C	37
TIP31A	38
TIP31C	45
TIP32A	43
TIP32C	45
TIP33A	70
TIP33C	75
TIP34A	B5
TIP34C	105
TIP35A	120
TIP35C	130
TIP36A	130
TIP36C	140
TIP41A	50
TIP41B	52
TIP42A	55
TIP42B	5B
TIP120	70
TIP121	73
TIP141	120
TIP142	120
TIP147	120
TIP2955	70
TIP3055	70
TIS43	50
TIS44	45
TIS88A	50
TIS90	30
TIS91/93	32
VK1010	99
VN10KM	70
VN46AF	95
VN66AF	110
VN88AF	120
VN89AF	120
ZTX107/8	12
ZTX109	12
ZTX212	28
ZTX214	30
ZTX301/2	16
ZTX303	25
ZTX304	17
ZTX320/26	30
ZTX500/1	14
ZTX502/3	18
ZTX504	25
ZTX531	25
ZTX550	25
2N696	30
2N697	23
2N698	40
2N699	4B
2N706A	25
2N708	25
2N914/5	32
2N918	40
2N930	20
2N1131/2	40
2N1303/4/5	
2N1307	70
2N1613	30
2N1671B	160
2N2160	325
2N2219A/20A/	
21A/22A	25
2N2369A	18
2N2646	45
2N2846	80
2N2904A/05A/	
06A/07A	28
2N2926G	10
2N3053	25
2N3054	55
2N3055	50
2N3442	140
2N3615	199
2N3663	20
2N3702/3	10
2N3704/5	10
2N3706/7	10
2N3708/9	10
2N3710	10
2N3771	179
2N3772	195
2N3773	210
2N3819	35
2N3820	80
2N3822/3	60
2N3866	90
2N3903/4	15
2N3906/5	15
2N4037	60
2N4058	15
2N4061/2	15
2N4264	30
2N4286	25
2N4289	25
2N4400	25
2N4427	80
2N4859	78
2N5135	30
2N5138	25
2N5172	25
2N5180	45
2N5191	75
2N5194	80
2N5305	24
2N5457	30
2N5458/9	30
2N5485	36
2N5777	45
2N6027	32
2N6109	60
2N6290	70
2SA636	250
2SA671	250
2SA715	75
2SC495/6	85
2SC1061	250
2SC1096	85
2SC1162	45
2SC1172/3	125
2SC1306	100
2SC1307	150
2SC1449	95
2SC1679	190
2SC1678	140
2SC1923	65
2SC1945	225
2SC1953	90
2SC1957	90
2SC1969	165
2SC2028	85
2SC2029	200
2SC2078	170
2SC2091	85
2SC2166	165
2SC2314	85
2SC2335	200
2SC2465	125
2SC2547	40
2SC2612	200
2SD234	75
2SK45	90
2SK288	225
2SJ83	225
2SJ85	225
3N128	115
3N140	115
40251	150
40311	60
40313	130
40361/62	70
40408	76
40412	90
40467	130
40468	85
40594	105
40595	110
40603	110
40673	70
40871/2	90

LINEAR IC's

555 CMOS	105
702	75
709C 8 pin	35
710	48
741	16
747C 14 pin	70
748C 8 pin	30
753 8 pin	165
810	159
9400CJ	375
ADC0808	885
AY-1-1320	225
AY-1-5050	99
AY-1-5051	160
AY-1-6720	210
AY-3-1270	730
AY-3-8910	400
AY-3-8912	500
AY-5-1317A	630
CA3011	130
CA3012	175
CA3014	275
CA3018	86
CA3019	90
CA3020	210
CA3023	210
CA3028A	130
CA3035	255
CA3036	270
CA3043	275
CA3045	365
CA3046	70
CA3048	220
CA3059	325
CA3075	213
CA3080E	75
CA3081	190
CA3085	160
CA3086	60
CA3089E	200
CA3090AQ	375
CA3123	165
CA3130	90
CA3140	55
CA3160	95
CA3161E	160
CA3162	450
CA3189	275
CA3240	110
HA1366	175
HA1388	235
ICL7106	690
ICL7107	975
ICL7611	99
ICL7660	248
ICL8038CC	360
ICL8211	350
ICM7205	1150
ICM7207	475
ICM7215	1050
ICM7216A	£22
ICM7217A	750
ICM7224	785
ICM7240	300
ICM7555	105
ICM7556	150
LA3350	250
LA4031P	340
LA4032	295
LA4400	350
LA4422	320
LC7120	300
LC7130	320
LC7137	350
LF347	150
LF351	70
LF353	90
LF355	95
LF356	99
LF357	110
LF398	495
LM10	325
LM301A	30
LM307	45
LM308	95
LM311	65
LM318	175
LM319	195
LM324	60
LM334Z	115
LM335	135
LM337	275
LM339	40
LM348	60
LM349	125
LM358	60
LM377	215
LM379	495
LM380	120
LM381N	175
LM382	200
LM384	225
LM386	90
LM387	135
LM389	145
LM393	85
LM394CH	385
LM558	170
LM725CN	300
LM733	70
LM1871	300
LM1889	350
LM2907	395
LM2917	325
LM3900	70
LM3909	85
LM3911	185
LM3914	445
LM3915	350
LM3916	350
LM13600	150
LS7220	280
M51513L	230
M51515L	320
M51516L	475
M706B1	150
MB3712	200
MB3756	440
MC1204	250
MC1301	90
MC1303	9B
MC1304P	260
MC1310P	150
MC1445	250
MC1455	50
MC1458	35
MC1469	300
MC1494	894
MC1495	350
MC1496L	70
MC1596	225
MC1648	290
MC3302	75
MC3401	50
MC3403	95
MC3404	85
MC3405	150
MC3442	00
MC3423P	80
MC3487	00
MC4016	00
MF10	350
MFC6040	75
ML924	275
NE515	275
NE529	225
NE531	140
NE543	225
NE544	200
NE555	25
NE556DB	65
NE558	170
NE560	350
NE562B	410
NE564	420
NE565A	120
NE566	155
NE567	140
NE570	410
NE571	400
NE5532	175
NE5534	160
OM335	750
RC4136D	60
RC4558	80
S566B	225
SAB3209	425
SAB3210	325
SAB3271	485
SAB4209	595
SG3402	295
SL490	350
SL924	00
SL6270	150
SN76013N	350
SN76033	350
SN76488	525
SP0256AL	799
TA7120	140
TA7130	125
TA7204	150
TA7205	90
TA7222	150
TA7310	00
TAA900	395
TAA621	296
TAA661	190
TAA700	275
TAD100	159
TBA120S	70
TBA540	275
TBA550Q	330
TBA641	290
TBA651	190
TBA800	80
TBA810S	95
TBA820	80
TBA920Q	200
TBA990	350
TCA270	350
TCA280A	220
TCA940	175
TCA950	00
TCA965	180
TDA1008	310
TDA1010	235
TDA1022	499
TDA1024	115
TDA1034	350
TDA1054	00
TDA1490	350
TDA2002	325
TDA2003	250
TDA2004	300
TDA2006	330
TDA2020	320
TDA2030	190
TDB0791	420
TL061CP	40
TL062CP	65
TL064CN	98
TL071CP	40
TL072CP	76
TL074CN	150
TL081CP	3S
TL082CP	60
TL083CP	75
TL084CP	120
TL091CP	60
TL170	50
TL430C	90
TL507	110
TL509	110
UA2240	120
UA78540	230
UAA170	180
UAA180	180
ULN2003	90
ULN2004	90
ULN2283	100
ULN2803	190
UPC556	00
UPC575	275
UPC1025H	375
UPC1156H	295
UPC1181	00
UPC1182	425
UPC1366	195
XR2206	375
XR2207	400
XR2211	575
XR2216	675
XR2266	360
ZN414	80
ZN419CE	180
ZN423E	130
ZN424E	130
ZN425E-8	345
ZN426E-8	300
ZN427E-8	590
ZN428E	450
ZN429E-8	245
ZN459	290
ZN1034E	200
ZN1040E	665
ZNA234E	925

COMPUTER IC's

2102L	160
2114	200
2147-3	425
2516	350
2532-4	400
25L32	450
2564	700
27L08	450
2716-5V	350
2732	450
2764-250	525
27C64	1095
26501	75
27128/250n	£19
3242	675
4027	95
4164-150	450
4416-2	475
4532-3	250
4816-100ns	300
5514	250
6116-150	525
6116L-120ns	575
6117-100n	525
6167-6	795
6264L-15	£28
6402	350
6502 CPU	355
6502A	545
6503	650
6504	600
6505	650
6520	175
6522 VIA	340
6530 RRIOT	£11
6532 RIOT	650
6545 CRTC	899
6551 ACIA	650
6592	00
6800	220
6802	275
6803	850
6805	670
6808	520
6809	650
6810	175
68B21	220
6821	175
6840	375
6843	00
6845	850
6845SP	750
6846	625
6847	650
6850	175
6852	250
6854	750
68B54	800
6875	500
68000	£50
8035	800
8080A	425
8085A	£15
8088	1750
81LS95/96	140
81LS97/98	140
B123	160
8131	475
8154	£9
8155	1050
8156	650
8202	£25
8212	495
8214	495
8216	200
8224	350
8226	350
8228	270
8243	550
8250	£11
8253	750
8255	1750
8256A	£35
8257A	700
8259	£7
8271	POA
8272	£25
8279	750
8282	450
8283	450
8284	550
8288	£11
8748	£55
8T26A	99
8T27	150
8T31	350
8T95N	90
8T97N	90
9364AP	550
9602	220
AM26LS31C	125
AM26LS32A	125
AM26LS33	150
AM7910	£32
AY-3-1015	300
AY-5-1013	300
AY-5-1350	388
AY-5-3600	750
COM8017	275
COM8116	700
DM8131	275
DP8303	450
DP8304BN	350
DS3647	00
DS3691N	595
DS8820	110
DS8830	198
DS8831	125
DS8832	250
DS88LS120	495
E9364	800
E9365	£36
FD1691	£15
FD1771	£15
FD1791	£22
FD1793	£23
FD1795	£28
FD1797	£28
HD26501	75
HM6845	755
IM6402	350
INS8060N	1250
MC1488	100
MC1489	100
MC14411	675
MC14412	725
MC3242	590
MC3446	250
MC3447P	315
MC3486	175
MC3487	175
MK3886-2M	£7
MM5280D	695
MM5303	635
MM5307	1275
MM5387A	475
MM58174	875
RO-3-2513L	700
RO-3-2513U	650
SAA5050	875
SFF96364E	800
SP0256AL2	750
TCM3101J	£13
TMS2716-3	725
TMS4047	100
TMS4164-15	395
TMS4416-2	595
TMS4500	£14
TMS4532-3	350
TMS5100	600
TMS6011	500
TMS9914	895
TMS9927	£14
TMS9928	£20
TMS9929	£16
TMS9980	£20
TMS9995	£12
ULN2003	75
UPD7002	725
UPD7007	725
WD1691	£14
WD2143	850
Z80CPU 2·5	325
Z80ACPU4M	375
Z80ACTC	335
Z80B	£11
Z80DART	495
Z80ADART	820
Z80ADMA	925
Z80DMA	795
Z80P10	325
Z80AP10	350
Z80S10-1	850
Z80AS10	900
Z80AS10-2	£9
Z8002CPU	00

74S

74S00	70
74S02	60
74S03	60
74S04	60
74S05	60
74S08	60
74S09	60
74S10	40
74S11	50
74S15	60
74S20	40
74S22	50
74S30	40
74S32	70
74S37	70
74S38	90
74S40	45
74S51	45
74S64	45
74S65	45
74S74	85
74S85	295
74S86	115
74S112	90
74S113	90
74S114	80
74S124	300
74S132	110
74S133	80
74S134	60
74S135	110
74S138	195
74S139	195
74S140	60
74S151	180
74S153	182
74S157	250
74S158	195
74S162	00
74S163	300
74S168	00
74S169	00
74S174	250
74S175	320
74S181	00
74S182	00
74S188	320
74S189	320
74S194	320
74S195	275
74S196	00
74S197	400
74S201	350
74S225	525
74S226	00
74S240	430
74S241	430
74S244	520
74S251	270
74S257	250
74S258	250
74S260	70
74S262	£12
74S274	00
74S275	00
74S280	00
74S281	00
74S283	00
74S287	225
74S288	210
74S289	200
74S299	540
74S301	350
74S365	250
74S373	400
74S374	490
74S412	380
74S470	325
74S471	620
74S472	1150
74S473	00
74S474	400
74S475	800
74S571	620
74S573	950

75

75107/8/9	95
75110	90
75121	00
75150	125
75154	195
75158	150
75159	140
75160	420
75162	650
75182/3	99
75188/9	100
75322	140
75353	00
75361	00
75365	00
75376	00
75450	86
75451/2	52
75454	70
75491/2	65

TTL 74

7400	40
7401	30
7402	30
7403	30
7404	65
7405	40
7406	70
7407	70
7408	30
7409	30
7410	40
7411	30
7412	30
7413	50
7414	70
7416	50
7417	50
7420	30
7421	30
7422	40
7423	40
7425	40
7426	60
7427	40
7428	55
7430	45
7432	50
7433	40
7437	40
7438	95
7440	45
7441	150
7442	80
7443	110
7444	110
7445	110
7446	110
7447	115
7448	110
7450	40
7451	40
7453	40
7454	40
7460	60
7470	60
7472	50
7473	50
7474	55
7475	70
7476	48
7480	70
7481	200
7482	100
7483	120
7484	140
7485	120
7486	50
7489	225
7490	75
7491	70
7492	75
7493	75
7494	120
7495	70
7496	90
7497	230
74100	200
74104	70
74105	70
74107	50
74109	75
74110	80
74111	80
74112	170
74116	175
74118	110
74119	180
74120	100
74121	65
74122	70
74123	90
74125	65
74126	60
74128	60
74132	80
74136	75
74141	100
74142	260
74143	280
74144	280
74145	125
74147	180
74148	145
74150	190
74151	90
74153	90
74154	190
74155	90
74156	95
74157	90
74159	195
74160	120
74161	120
74162	120
74163	120
74164	125
74165	120
74166	150
74167	250
74170	200
74172	430
74173	150
74174	120
74175	110
74176	110
74177	110
74178	150
74179	150
74180	110
74181	350
74182	150
74184	190
74185	190
74186	70
74188	75
74190	145
74191	140
74192	140
74193	140
74194	110
74195	90
74196	140
74197	120
74198	245
74199	250
74221	120
74246	130
74247	135
74248	175
74249	175
74251	100
74259	100
74265	80
74273	210
74276	150
74278	180
74279	100
74283	120
74284	350
74285	350
74290	120
74293	100
74297	175
74298	200
74351	210
74365	90
74366	90
74367	90
74368	90
74376	175
74390	120
74393	145
74490	150

74C

C244	195
C245	195
C373	240
C374	245
C922	750
C923	645
C925	775

74S

LS00	30
LS01	30
LS02	30
LS03	30
LS04	35
LS05	35
LS08	30
LS09	30
LS10	30
LS11	30
LS12	30
LS13	35
LS14	60
LS15	30
LS19	45
LS20	30
LS21	30
LS22	30
LS24	80
LS26	30
LS27	30
LS28	30
LS30	35
LS32	95
LS33	25
LS37	25
LS38	45
LS40	30
LS42	85
LS47	100
LS48	100
LS49	80
LS51	25
LS52	25
LS54	25
LS55	25
LS63	00
LS73	35
LS74	40
LS75	50
LS76	40
LS78	40
LS83	75
LS85	100
LS86	40
LS90	55
LS91	100
LS92	65
LS93	60
LS95	60
LS96	100
LS107	50
LS109	55
LS112	55
LS113	45
LS114	45
LS122	75
LS123	120
LS124	100
LS125	55
LS126	55
LS132	75
LS133	50
LS135	2B
LS136	45
LS138	70
LS139	70
LS145	120
LS147	195
LS148	150
LS151	75
LS153	75
LS154	200
LS155	75
LS156	75
LS157	70
LS158	60
LS160	75
LS161	75
LS162	75
LS163	85
LS164	95
LS165	130
LS166	195
LS168	140
LS169	90
LS170	175
LS173	110
LS174	100
LS175	80
LS181	210
LS183	200
LS190	100
LS191	75
LS192	100
LS193	100
LS194	80
LS195	80
LS196	100
LS197	100
LS221	100
LS240	100
LS241	100
LS242	100
LS243	100
LS244	100
LS245	200
LS247	115
LS248	115
LS249	115
LS251	80
LS253	80
LS256	175
LS257	75
LS258	80
LS259	130
LS260	80
LS261	190
LS266	60
LS273	140
LS275	380
LS279	75
LS280	195
LS283	95
LS290	85
LS292	850
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LS294	990
LS295	140
LS298	110
LS299	240
LS320	230
LS322	360
LS323	360
LS324	150
LS325	150
LS326	290
LS327	290
LS347	130
LS348	200
LS352	125
LS353	125
LS355	220
LS356	220
LS363	180
LS365	60
LS366	50
LS367	60
LS368	60
LS373	110
LS374	140
LS375	80
LS377	145
LS378	120
LS379	150
LS380	310
LS382	310
LS384	457
LS385	330
LS386	50
LS390	90
LS393	120
LS395	13S
LS396	300
LS398	195
LS399	150
LS445	12S
LS447	80
LS465	150
LS467	120
LS490	160
LS540	145
LS541	145
LS624	150
LS629	150
LS640	200
LS641	200
LS645	200
LS668	90
LS669	90
LS670	190
LS673	890
LS674	00
LS682	250

CMOS

4000	20
4001	25
4002	25
4006	75
4007	25
4008	60
4009	45
4010	60
4011	25
4012	25
4013	60
4014	60
4015	60
4016	40
4017	60
4018	60
4019	58
4020	90
4021	58
4022	87
4023	30
4024	50
4025	22
4026	90
4027	48
4028	45
4029	75
4030	35
4031	130
4032	70
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4034	140
4035	70
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4037	115
4038	75
4039	280
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4042	50
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4047	60
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4056	85
4057	£10
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4068	25
4069	25
4070	25
4071	25
4072	25
4073	26
4075	25
4076	68
4077	25
4078	25
4081	25
4082	25
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4086	60
4089	125
4093	37
4094	70
4095	95
4096	100
4097	275
4098	80
4099	75
4160	95
4161	99
4162	99
4163	99
4174	99
4175	105
4194	105
4408	850
4409	850
4410	725
4411	750
4412	805
4415	590
4419	280
4422	770
4433	770
4435	850
4440	999
4450	350
4490	450
4500	395
4501	38
4502	60
4503	40
4504	99
4505	385
4506	100
4507	45
4508	130
4510	55
4511	55
4512	55
4513	150
4514	115
4515	125
4516	65
4517	275
4518	48
4519	32
4520	53
4521	115
4522	125
4526	60
4527	65
4528	70
4529	150
4530	90
4531	130
4532	65
4534	400
4536	275
4538	80
4539	90
4541	95
4543	70
4544	150
4549	400
4553	245
4554	180
4555	35
4556	55
4557	250
4558	120
4559	395
4560	160
4561	104
4562	350
4566	165
4568	250
4569	175
4572	45
4580	255
4581	125
4582	99
4583	100
4584	60
4585	70
4599	155
40097	45
40098	42
40100	215
40101	130
40102	140
40103	412
40104	120
40105	220
40106	60
40107	55
40108	325
40109	100
40110	235
40114	240
40161	194
40163	75
40174	75
40175	75
40181	220
40192	75
40193	95
40194	90
40195	80
40244	195
40245	195
40257	198
40373	220
40374	220

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Nicad Batteries & Chargers

High quality nickel cadmium rechargeable batteries. Equivalent in size with popular Dry Cell sizes e.g. HP7 (AA), HP11 (C), and HP2 (D). Minimum life 600 (300 PP3 size) full charge/discharge cycles. Batteries must be charged from a constant current source only. All batteries are supplied only with a residual charge and should be charged before used.

DATA & PRICES

Type	V(nom)	Capacity	Stock No.	1-9	10-49
AA	1.2V	500mAH	01-12004	0.80	0.74
C	1.2V	1.2AH	01-12024	2.35	1.99
D	1.2V	1.2AH	01-12044	2.00	2.00
PP3	8.4V	110mAH	01-84054	3.70	3.50

CH/4/50
To recharge up to 4 AA size NiCads.
Size; 112 x 71 x 37mm 01-00409 4.95

CH1/22
To charge PP3 type NiCads.
Size; 70 x 50 x 32mm 01-00159 4.30

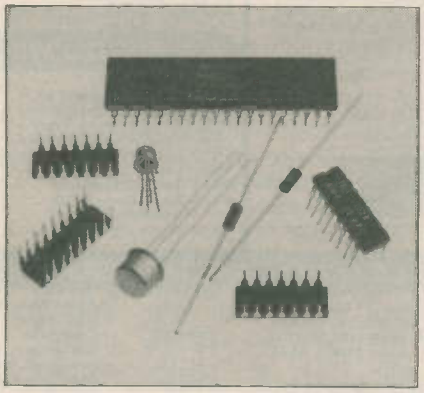
CH8/RX
Will recharge AA, C, D and PP3 size cells with automatic voltage selection. Will recharge following combinations: 4xD, 4xAA, 4xC, 2xPP3, 2xD + 2xC, 2xD + 2xAA. 2xD + 1xPP3, 2xC + 2xAA, 2xC + 1xPP3, 2xAA + 1xPP3. Charge rate: 11mA for PP3, 45mA for AA size, 120mA for C and D size, for 16 hrs. Power: 240V 50Hz. Output Voltage: 2.9V for AA, C and D size, 11.0V for PP3 size. Weight: 0.475kg. Size: 199 x 109 x 55mm. 01-02204 9.45

HT320

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

RF Generator LSG17

A stable wide-range generator for the hobbyist, service technician, schools, colleges, etc. Frequency range: A/100kHz-300kHz, B/300kHz to 1MHz (Harmonics 96-450MHz) C/1MHz-3.5MHz, D/3.0MHz-11MHz, E/10MHz-35MHz, F/32MHz-150MHz. Accuracy: k1.5%. Output greater than 100mV (no load). Ext. xtal osc for 1 to 15MHz crytal. Power required: AC100, 115 or 230V 3VA. Size & Weight: 150(H) x 238(W) x 130(D)mm, 2.5Kg approx. 56-90017 115.00



Linear ICs

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

Selected Lines

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

Books

Beginners Guide to Amateur Radio	02-11262	4.50
Beginners Guide to Electronics	02-04134	4.50
Active Filter Cookbook	02-21168	12.70
CMOS Cookbook	02-21398	11.85
TTL Cookbook	02-10358	11.00
Design of Active Filters	02-21539	10.15
Design of Op-amp Circuits with experiments	02-21537	9.30
Effectively Using the Oscilloscope	02-21794	9.30
The ZX Spectrum	02-00100	5.95
Practical Design of Digital Circuits	02-11831	10.45
Electronic Projects for Home Security	02-05351	3.80
Electronic Telephone Projects	02-21618	7.60
55 Timer Applications Sourcebook	02-21538	6.40
Television Engineers Pocket Book 7th Ed	02-21313	8.50
Electronics Pocket Book	02-21309	7.50
99 Practical Electronic Projects	02-21635	5.90
More Electronic Projects in the Home	02-21307	3.80
The Radio Amateurs Question and Answer Reference Manual	02-02157	5.95
Basic Programming on the BBC Microcomputer	02-06640	5.95
Using Microprocessors and Microcomputers: The 6800 Family	02-98728	11.05
Z-80 Microcomputer Design Projects	02-21682	12.70
Z8000 Microprocessor: A Design Handbook	02-37345	16.10

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

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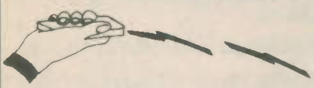
INFRA-RED REMOTE CONTROL KITS



These kits are designed to enable infra-red remote control to be incorporated into virtually any application from switching car locks or alarms to controlling Hi-Fi or TV. The application will determine the interface circuitry between the receiver and the controlled device. General instructions and applications are supplied. The kits are coded and provide a high degree of security and noise immunity.

MK 18 Transmitter Kit — for use with MK11/MK12 receivers. Requires PP3 battery. Size: 8 x 2 x 13cms. Range approx. 60 ft. £6.80

Keyboards for MK18

MK9	4-way for use with MK12	£1.90
MK10	16-way for use with MK12	£5.40
MK13	11-way for use with MK11	£4.35

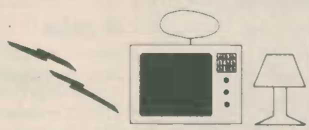
MK11 Receiver Kit — mains powered. Provides 10 latched plus 3 analogue outputs ideal for controlling audio amplifiers, TV or lighting where control of light brightness is required. £13.50

MK14 AC Power Controller Kit — for (phase) controlling AC loads from MK11 analogue outputs, eg lamp dimming. £5.20

MK19 Stereo Amplifier Controller Kit — for remote control of bass, treble and volume (or balance) by MKII. Includes a one of 10 decoder remote channel or input selection. May be connected between the pre-amp and power amp of almost any audio system. £10.70

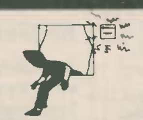
MK12 Receiver Kit — mains powered with 16 latched or momentary outputs. Latched version is for applications requiring one output on at a time, eg TV channel selection. Momentary type gives an output only during transmission. Lines may be latched as required. Size: 9 x 4 x 2cms. £13.50

MK15 Dual Latched Solid State Relay — for switching mains loads such as lamps, TVs, etc, from the outputs of the MK12 (momentary). 15 items may be switched independently using 8 MK15s. Triacs (not supplied) switch at mains zero to reduce interference. £4.50



SECURITY PRODUCTS

Protect your home and property and save by building your own burglar alarm system.



Stair Mat 23 x 7 in (950 120)	£1.70
Floor Mat 29 x 16 in (950 125)	£2.60
Tamper-proof connecting block (950 110)	£0.30
Door/Window Contacts. Flush mounting, 4 wire, Magnet/switch Per Pair. (950 140)	£0.95
Window Tape 0.5" wide. 50m. (950 145)	£2.50
Window Tape Terminations Per pair. (950 150)	£0.36
Key-operated Switch. 1.5A/250V SPST Heavy chrome metal. (350 120)	£4.50

Passive Infra-Red Detector
Detects intruder's body heat. Range 10 metres. 12V DC, n/o & n/c contact. Size: 4 x 2 x 2 ins. (950 135) £45.00

Alarm Control Unit. 4 input circuits, 2-instant and 2-delayed. Adjustable entry, exit and alarm times. Built and tested. Full instructions supplied. Size: 180 x 130 x 30mm. Supply: 12V DC. (950 160) £26.00

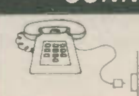
Smoke Detector. Easily installed. No adjustment. 1 year operation from PP3 alkaline battery. Consumption 25uA. Size: 175mm dia. x 45mm. White plastic case. (950 165) £8.50

8W Horn Speaker. 5.5 ins. 8 ohm. Ideal for sirens, etc. 2.5m lead and 3.5mm jack plug. (403 148) £6.15

PANTEC KITS

PN2	FM Micro Transmitter	£6.95
PN3	Stabilised Power Supply	£12.60
PN5	2 x 10w Stereo Amplifier	£13.00
PN6	2 x 40w Stereo Amplifier	£23.00
PN7	Pushbutton Stereo Preamp	£11.80
PN8	Tone & Volume Control	£12.80
PN11	3w FM Transmitter	£10.90
PN13	Single Channel FM Transmitter	£8.95
PN14	Receiver for above	£14.50

BT STYLE PHONE CONNECTORS



Line Jack Units— Master Unit (first line unit) has bell capacitor and surge arrester. Flush or surface mounting. Screw connectors.

Master (flush)	(960 110)	£3.00
Master (surface)	(960 112)	£3.00
Master (mini surface)	(960 113)	£3.00
Secondary (flush)	(960 114)	£2.65
Secondary (surface)	(960 116)	£2.65
Secondary (mini surf)	(960 117)	£3.00
Dual outlet adaptor	(960 118)	£4.20
4-way line cord — with plug to spade terminals	(960 120)	£2.00
4-way line cord	(960 130)	£0.20 per m

OTHER KITS

CT1000K	Clock/Timer	£14.90
CT1000K8*	Clock/Timer + 8ox	£17.40
XK101	Electronic Lock	£11.50
XK102*	3-Note Door Chime	£5.50
XK113	MW Radio	£5.50
XK126	DVM/Thermometer	£15.50
DL1000K	4-Channel Light Chaser with Dimmer	£15.95
DLZ1000K	4-Channel Chaser	£8.95
DL3000K	3-Channel Sound-to-Light	£12.95
TD300K +	300W Touchdimmer	£7.75
TS300K +	300W Touchswitch	£7.75
LD300K +	300W Lightdimmer	£3.95
TDR300K +	IR Remote Controlled Lightdimmer	£14.95
MK6*	IR Transmitter for TDR300K	£4.50
TDE/K +	Touchdimmer extension	£2.50
TSA300K +	Time Delay Touch Switch (300W)	£5.00
MK1	Thermostat	£4.60
MK2	Solid State Relay	£2.60
MK4	Proportional Temperature Controller	£6.50
MK5	Mains Timer (1KW)	£4.50

* includes box. + includes front panel
All kits include PCBs, components and assembly instructions.
For further details send S.A.E.

REMOTE CONTROL ICs

ML922	10-Channel Decoder	£4.10
ML924	Programmable Decoder	£2.10
ML926/7/8/9	16-Channel Decoders	£1.70
SL486	Infra-Red Preamp	£2.20
SL490	32 Command Transmitter	£2.80

TRIACS

400V Plastic

Q4006LT	6A with Trigger	£0.85
TXAL2288	8A isolated Tab	£0.65
TIC206D	3A	£0.49
TIC226D	8A	£0.58
TIC246D	16A	£0.95
TIC263D	25A	£2.10

LCD DIGITAL MULTIMETERS

LOW COST! 10M ohm. 3½ digit 0.4 in display. Auto zero and polarity, low batt. indication, overload protection. Includes test leads, battery, spare fuse, manual, carrying case.
AC Volts: 0—200—500.
DC Volts: 0-2-20-200-1000.
DC Current: 0-20m-200mA.
Resistance: 0-2k-20k-200k-2M.
Size: 138 x 86 x 36mm.
(405 202) £23.95

Professional — 10M, 0.5 in, 3½ digit. Overrange and low battery indication. Overload protection. Includes leads, spare fuse, battery, manual and case. Transistor Checker. Size: 175 x 93 x 42mm.
AC Volts: 0-200-750.
DC Volts: 0-200m-2-20-200-1000.
DC Current: 0-20u-2m-20m-200mA. 0-10A.
Ohms: 0-200-2k-20k-200k-2M. 0-20M.
(405 204) £32.00

Auto Ranging. 3½ digit 10mm display. Continuity buzzer, low battery, overload and range indication. 10A internal shunt for AC/DC current measurement. Carrying case supplied.
AC Volts: 0-2-20-200-600.
DC Volts: 0-0.2-2-20-200-1000.
AC Current: 0-200mA. 0-10A.
DC Current: 0-200mA/0-10A.
Resistance: 0-200-2k-20k-200k. 0-2M.
Size: 160 x 85 x 29mm.
(405 206) £44.85

High Sensitivity Temperature Probe. For use with a multimeter to measure temperatures from −50°C to +250°C. Accuracy: 1.5°C@25°C, 2°C@100°C. Response time (in water), 5 seconds. Includes case, calibrated scale and instructions. (405 220) £7.95

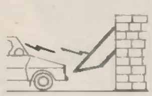
MICROPROCESSOR TIMER KIT

Designed to control 4 outputs independently switching on and off at preset times over a 7-day cycle. LED display of time and day, easily programmed via 20-way keyboard. Ideal for central heating control (including different switching times for weekends). Battery back-up circuit. Includes box. 18 time settings.

CT6000K	£39.00
XK114. Relay Kit for CT6000 includes PCB, connectors and one relay. Will accept up to 4 relays. 3A/240V c/o contacts	£3.90
701 115 Additional Relays	£1.65

IR GARAGE DOOR CONTROLLER KIT

For controlling motorised garage doors and switching garage and drive lights on/off up to a range of 40 ft.



Lots of applications like controlling lights and TVs, etc, in the home. Ideal for aged or disabled persons, this coded kit comprises of a mains-powered infra-red receiver with a normally open relay output plus two latched transistor outputs, battery-powered transmitter and opto-isolated solid state mains switch.

XK103	£25.00
XK106 Extra transmitters	£10.00

HOME LIGHTING KITS

These kits are designed to replace a standard wall switch to control up to 300w of lighting.

TDR300K	Remote Controlled Light Dimmer	£14.95
MK6	Transmitter for above	£4.50
TD300K	Touch Dimmer	£7.75
TS300K	Touch Switch	£7.75
TDE/K	2-way extension for above kits	£2.50
LD300K	Rotary controlled Light Dimmer	£3.95

ELECTRONIC LOCK KIT

With hundreds of uses indoors, garages, car anti-theft devices, electronic equipment, etc. Only the correct easily changed four-digit code will open it! Requires a 5-15V DC supply. Output 750mA. Fits into standard electrical wall box.

Complete kit (except front panel)
XK101 £11.50

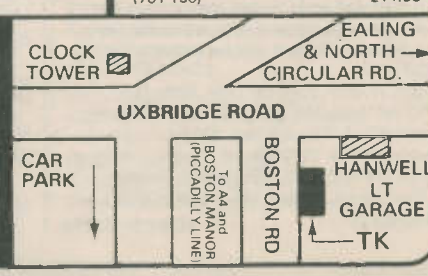
Electric Lock Mechanism for use with existing door locks and the above kit. (Requires relay.) 12V AC/DC coil. (701 150) £14.95

TK ELECTRONICS

11-13 Boston Road
London W7 3SJ

ORDERS 01-567 8910
ENQUIRIES 01-579 9794

01-579 2842 TECHNICAL AFTER 3pm



PE

VOLUME 20 No. 11 NOVEMBER 1984

UK THIRD WORLD STATUS!

AMAZING as it may seem the UK computer industry is losing ground rapidly to foreign competition in one particular area. The situation is becoming so bad that a recent report by the National Economic Development Committee commented that if we fail to exploit new technology "as urgently or effectively as other advanced nations we shall continue our decline to third world status." The report goes on to say that it may be possible to reverse the trend by taking "urgent and significant action within the next year."

Which area is it that needs such significant action so urgently? The area is one we have heard so much about over the last year, Information Technology. For a few years now various bodies have been warning that the British IT industry needs assistance in setting up a national training scheme and a policy of pro-British procurement should be introduced by the Government. These continuing warnings have now been heavily underlined by the report which also requests more money to assist medium size businesses and for development and research.

ACTION

The warnings come from an official government sponsored body which is made up of various heads of industry, trades union leaders and government officials. It does not lay blame for the situation and clearly indicates just what "urgent and significant action" needs to be taken to ensure a place for the UK in this important area of technology.

Although the report acknowledges the work of the industry in this area, it points out that overseas competitors are doing better than the UK. While the UK's share of the world IT market has fallen from 9% to 5% over the last decade our imports have risen from 29% to 54%. Significantly the USA now has 56% of the world market and Japan 23%. One other worrying aspect, and one on which we have commented in the past (June 84 Editorial), is the underlying trend of reduced employment in an expanding industry. Over the last decade nearly 30,000 jobs have been lost, a reduction of almost 20% of the total number of jobs, while the UK IT market has grown roughly 800% (yes there should be two zeros!)

FUTURE

We need to stay at the forefront of this future technology; we need to beat our European rivals and be able to challenge the USA and Japan for emerging markets. Let us hope that, as the report indicates, it is not too late to reverse the trends. Let us hope also that the action suggested by the committee is taken up at government level with sufficient urgency to ensure a bright future for UK IT, and hopefully an increase in those employed in this area of technology.

Mike Kenward

Technical *and* editorial *queries and letters (see note below) to:*
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West Quay Road, Poole,
Dorset BH15 1JG

Phone: *Editorial* Poole 671191
We regret that lengthy technical enquiries cannot be answered over the telephone

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Stamford Street, London SE1 9LS
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Components and p.c.b.s are usually available from advertisers; where we anticipate difficulties a source will be suggested.

Back Numbers and Binders

Copies of most of our recent issues are available from: Post Sales Department (Practical Electronics), IPC Magazines Ltd., Lavington House, 25 Lavington Street, London SE1 0PF, at £1 each including Inland/Overseas p&p. Please state month and year of issue required.

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PRECISION DRIVE-MOTORS

It cannot be denied that in recent years the world of the electronics hobbyist has changed quite substantially and with every innovation comes a new avenue of exploration. Robotics, in the recent past, has gathered in a large flock of interested experimenters.

The need for high precision drive-motors in this field is of course an important factor, as is their price.

Two eminently suitable motors are now available from Service Trading Co, both with high specifications and a reasonable price tag. The larger of the two motors is a 12/24Vd.c. reversible model, it will actually operate from voltages as low as 2Vd.c. A range of speeds from 2 to 36 r.p.m. is obtainable; at 6V (9 r.p.m.) the no-load current is around 6mA; at 12V (18 r.p.m.) – 10mA and at 24V (36 r.p.m.) – 18mA. The length of the motor and gearbox is 90mm, max dia 42mm; shaft length 15mm, shaft dia 6mm. The price of £19.55 is inclusive of VAT and p&p.

The smaller of the two motors is a 3/6V unit, it is an ironless rotor type geared motor with a 70 to 1 gearbox ratio. A range of speeds from 8 to 16 r.p.m. is obtainable; at 3V (8 r.p.m.) the no-load current is 5mA, and at 6V (16 r.p.m.) – 10mA. The length of this motor is 48mm, its diameter is 24mm; shaft length 5·5mm, shaft dia 3mm. These smaller motors are ex-equipment, they are in good order and are individually tested, representing great value at £5.75 including VAT and p&p. Both motors are of Swiss manufacture. From Service Trading Co., 57 Bridgman Road, Chiswick, London W4 5BB (01-995 1560).

Shock switch revelation

Detectives from Practical Electronics have uncovered the shock existence of a new type of component that can detect a whack on the back (if hard enough) and close a set of contacts in response. This "biff" switch, or shock sensor, comprises a compression spring-loaded toroidal magnet through which is positioned a reed switch. The mass of the ferrite magnet and the spring constant are selected so that the reed switch is actuated by a jerk (of the mechanical kind) exceeding a given acceleration.

Model 5818 has a threshold sensitivity of 5G, but other sensitivities are available to order. Maximum switching is 200V d.c., 5A with a total contact rating of 10W. Response time is typically 8ms from impact, and the contacts usually stay closed for around 20ms. The sensor is only 38mm long (see photo). Industrial applications are manifold, but we feel that the sensor could be a big hit in robotic mobiles. Further details are available from Hamlin Electronics Europe Ltd., Diss, Norfolk IP22 3AY.

Aces Low

Two years ago this month saw the launch of the Jupiter Ace, a micro that uses an adapted version of the compiled language FORTH.

When launched the Ace cost £89.95, since then however, the original company (Jupiter Cantab) have gone into liquidation, and now Boldfield have taken the Ace under their wing and are offering it for just £33. Although the machine has a small memory (only 3K of RAM), it is expandable and also on offer are 16K RAM Packs plus other peripheral items at greatly reduced prices.

Since February the machine's new owners have compiled a whole range of accessories,

together with eleven new software titles, all of which are in stock. Many other Ace related products are available including books, spares, components and even party built and bare circuit boards. A large database of owner/users has been compiled and those listed will be kept up to date with latest developments. The price of £33 includes VAT and p&p. For further information contact Boldfield Limited Computing, Sussex House, Hobson Street, Cambridge. (0487 840740).

ROBOT SHOP

The *Robotics Workshop* is to open as a showroom for the many emerging small robots which are primarily used in education and training. There will also be other robotic devices and some components. It is hoped that the London based forum will soon become a meeting place for those interested generally in robotics.

The Workshop is sponsored and funded by The Entryphone Company Ltd., and their Managing Director will be taking a keen interest. He is especially looking for all designers of robots and other devices be it in their factory, garage, or kitchen! For further information contact Gordon Ashbee, Robotics Workshop, 121 Ifield Road, London SW10 (01-373 8571).

MARKET PLACE

ONE FARAD CAPACITOR

Huh! Everyone knows that a *one Farad* capacitor would have to be the size of a dustbin! Everyone is wrong then, because NEC makes a 1F/5V capacitor of a diameter slightly over one inch. Its height is a fraction under one inch.

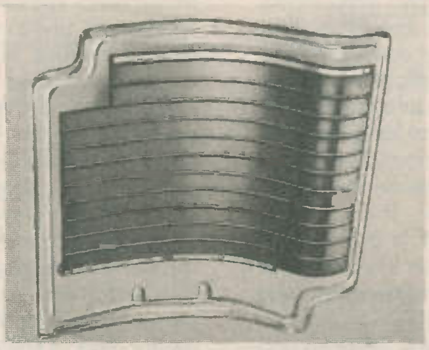
These devices are deservedly called *Supercaps*, and are intended to gradually take over from lithium and ni-cad batteries in power back-up for memories. Capacitors of such high capacity can be thought of as battery cells and will behave in a similar manner.

The extremely high volumetric efficiency derives from the double electric layer principle on which they are based. The large capacitance of such an array arises from the charge stored at the interface by the changing electric field between two available phases. In the Supercap, one phase is the activated carbon particle. The other phase is sulphuric acid solution as an ionically conducting electrolyte.

Installation is easy, they have a wide operating temperature range, are polarity free and maintenance free. Other advantages are an 'open' failure mode and long life with no dry-out problems. Supercaps, however, are *not* recommended for filtering (ripple absorption) applications, and they are not available in high voltage ratings. They are currently available, along with application notes, from: Anglia Components, Burdett Rd., Wisbech, Cambridgeshire PE13 2PS. (0945 63281).

ON THE TILES

The research people at Sanyo's Tokyo R & D centre have developed a solar rooftile which can directly substitute the traditional Japanese rooftile for size and weight, with the added advantage of around 2W of electrical power per tile. The Amorton rooftile was designed using a new technique in amorphous silicon technology. Until recently it was only possible to form amorphous silicon layers onto flat surfaces; when forming the film to a curved surface differences would arise between convex and concave sections thus preventing deposition of even layers. Now however, mainly due to improvements in the reaction chamber Sanyo can form solar cells on the most complex of curved surfaces. When you consider that a roof full of these tiles may only provide something like 2kW of power to a home, and that each tile has a conversion rate of only 6 per cent, then it's worth bearing in mind that the surface of solar/electrical conversion has still only been scratched.



Briefly...

They say that "lightning never strikes twice in the same place", well, it wouldn't matter if it did so long as your equipment was protected by a new suppressor from a British company, *Hunter Electronic Components Ltd*. Actually, the device was designed to protect military equipment from the effects of EMP (Electromagnetic pulse) radiation—a phenomenon which results after a high altitude nuclear explosion. This intense energy burst may contain 50kV/metre of electromagnetic energy and cover from 0 to 100MHz.

● ● ● ●

For the first time people in Russia will be able to buy home-built video recorders. Although production is at present very low (only 200 machines to date) interest in them is very high. Imported Western units sold in state shops cost around £2,000!

● ● ● ●

According to Electronics Weekly *British companies are at long last bringing compact disc hardware into the High Street, and if all goes to plan it will be available for Christmas. It is reported that in September, Ferguson will market a Sony manufactured machine, bearing their name, and selling for around £299. Meridian are offering a specially modified Philips CD101, it will be known as the MCD and is also due for a September launch at around £398. In November Mission are to launch a CD unit, also expected to be a 'bought-in' item; once upgraded it will sell for around £400.*

Countdown . . .

Please check dates before setting out, as we cannot *guarantee* the accuracy of the information presented below. Note: some exhibitions may be trade only. If you are organising any electrical/electronics, radio or scientific event, big or small, we shall be glad to include it here. Address details to Mike Abbott.

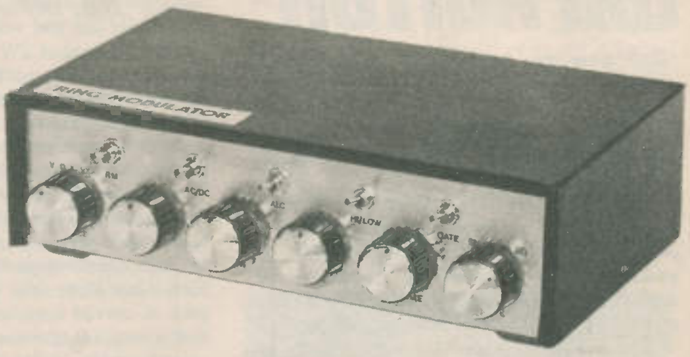
Software Expo Oct. 16–18. Wembley Conf. Cntr., London. **O**
Internepcon Oct. 16–18. Metropole, Brighton. **T1**
Scottish Energy Manager Oct. 23–24. Skean Dhu Hotel, Glasgow. **W3**
Business Equipment Show Oct. 23–26. Olympia, London. **Z**
Drives, Motors & Controls Oct. 24–26. Harrogate Exhibition Cntr. **E**
Electron & BBC Micro User Oct. 25–28. Alexandra Palace, London. **L**
Applying The 68000 (conf.) Oct. 30. City Conference Cntr., London ✆ Danny Green, 0483 31261
International Test & Measurement Oct. 30–Nov. 1. Olympia. **D4**
Test & Sensors Oct. 30–Nov 1. Wembley. **T**
Custom Electronics & Design Techniques Show Nov. 6–8. Heathrow Penta Hotel. **E**
Scottish Engineering Nov. 6–10. Kelvin Hall, Glasgow. **M**
Leisuretronics Nov. 8–11. Royal Horticultural Hall, London. **T**
Compec Nov. 13–16. Earl's Court. **K2**
P.c.b. Manufacture & UV Box Construction (meeting) Nov. 17. Electronic Organ Constructors Society. **Y4**
Systems Security Nov. 19–20. Barbican Cntr., London. **E**
Computers In The City Nov. 20–22. Barbican, London. **O**
Data Security Nov. 20–22. Barbican, London. **O**
Business & Data Processing Nov 20–24. Kelvin Hall, Glasgow. **M**
Northern Computer Fair Nov. 22–24. Belle Vue, Manchester. **K2**
Northern Energy Manager Nov. 27–28. Lancashire County Cricket Club, Old Trafford, Manchester. **W3**
Transducer Tempcon Nov. 27–29. Harrogate Exhibiton Cntr., Yorkshire. **T**
Electronic Displays Nov. 28–30. Kensington Ex. Cntr., London. **D4**
Electron & BBC Micro User Dec. 6–9. New Horticultural Hall, London. **L**

D4	Network ✆ 0280 815226
E	Evan Steadman ✆ 0799 26699
K2	Reed Exhibitions, Surrey Ho., 1 Throwley Way, Sutton, Surrey
L	Database ✆ 061-456 8383
M	Montbuild ✆ 01-486 1951
O	Online ✆ 01-868 4466
T	Trident Exhibitions ✆ 0822 4671
T1	Cahners ✆ 0483 38085
W3	MCM ✆ 01-231 1481
Y4	Percy Vickery ✆ 0202 423863
Z	Beta Exhibitions ✆ 01-405 6233

RING MODULATOR

JOHN M.H.BECKER

PART 1



OF all the circuits available to the electronic musician for sound modification, the Ring Modulator can produce some of the more dramatic changes, but the principles behind it are complex. Its function is basically very simple, to allow the combination of two frequency sources, applied to separate inputs, to interact and produce a modified pitch output. This is not the same as the function of a mixer where two or more signals are combined but retain their original frequency characteristics. In a ring modulator the two signals are combined in such a way that a composite output containing both the sum and the difference of their frequencies is produced.

CHARACTERISTICS

There are many ways in which this frequency translation can show itself, depending not only on the frequencies of the signals, but also upon their waveforms. Taking the simplest combination of all, assume two sine waves on the inputs, 264Hz on one and 396Hz on the other. The circuits within the modulator simultaneously add 264Hz to 396Hz, resulting in 660Hz, and also subtract 264Hz from 396Hz, resulting in 132Hz. Both the 132Hz and the 660Hz appear together at the output as a composite single signal. The two new frequencies cannot be separated from each other except by sophisticated filtering techniques, and in the case of closely similar resultant outputs, this filtering probably would be impossible. However, it is possible to combine the composite with both the orginals in a standard mixing procedure. The final output then consists of all four signals together.

Relating these frequencies to musical notes, 264Hz is 'C' below 'Concert A' (440Hz), 396Hz = 'G', 660Hz = 'E', 132Hz = 'C' (sub-octave), which if mixed with the original 'G' and 'C' produces a musically concordant composite. Given the correct frequencies originally presented, it will be obvious that a ring modulator can produce other chords from other two note inputs. It should also be evident that if two identical frequencies are fed in simultaneously, then their sum will be twice the original, and their difference will be zero, hence simple frequency doubling occurs, with the new note one octave higher than the original. With two or more ring modulators cascaded it is possible to build up further complex relationships, and to theoretically go on doubling the frequency again and again.

When non-sinusoidal waveforms are presented to the inputs a much more complex situation is created. A sinusoidal waveform is pure tone, but any non-sinusoidal one contains odd harmonics that become more complex the greater the shift from the pure tone. Thus triangular, ramp and squarewaves contain their own particular harmonic characteristics, and the quality of a note produced from these waveforms is heavily dependent upon the strength of the overtones. Consequently for non-sinusoidal waveforms it is no longer a matter of adding and subtracting two frequencies, even though on an oscilloscope or frequency meter the frequencies appear to be singular. It is instead a situation of combining the fundamental frequencies and also the harmonics implicit in the non-sinusoidal shape. The resultant output then takes on a highly complicated characteristic. In practical terms there is probably little difference in the composite output for the fundamentals of a sine wave and those of a triangular wave, but the overtones at the output acquire a timbre that becomes more distinctive the greater the complexity of the waveform and its harmonic structure. As the structure becomes more complicated, especially with higher frequencies, a 'ringing' quality begins to develop. Curiously this is not why such a unit is called a 'Ring' modulator, the name actually derives from the mode of circuitry used in the earlier days of electronic music modification.

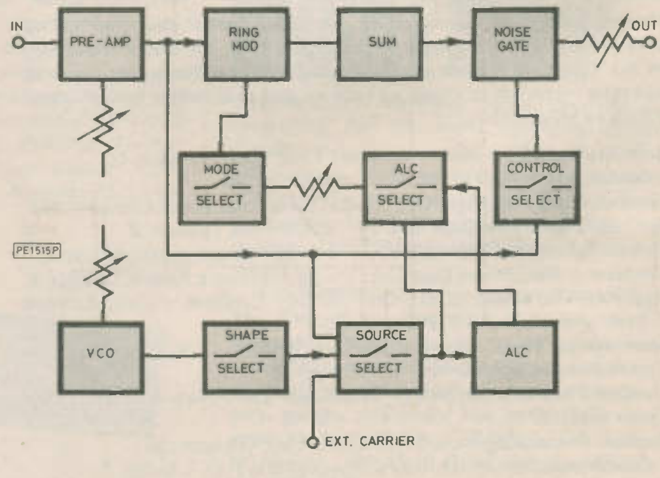
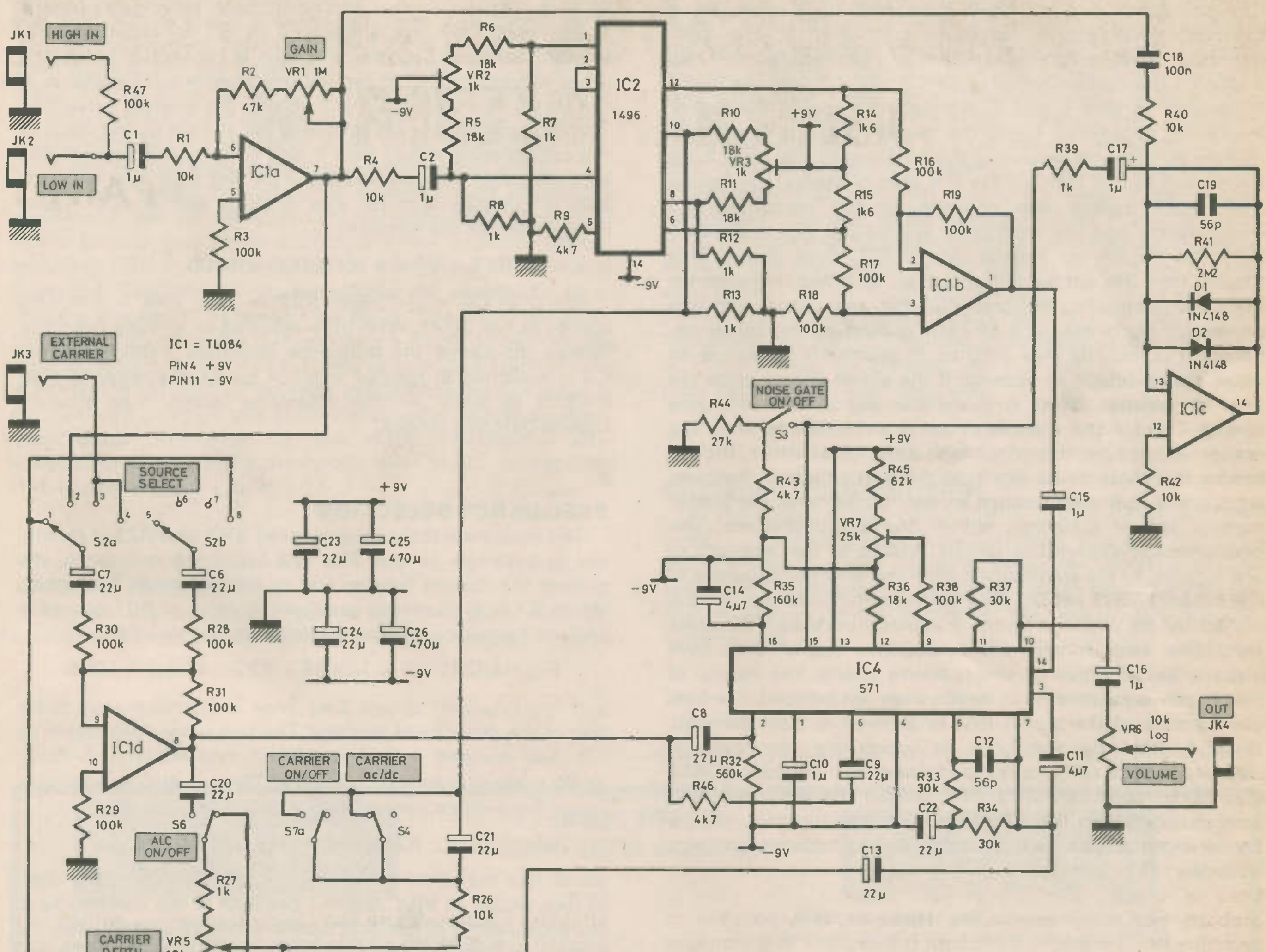


Fig. 1. Schematic diagram of the system



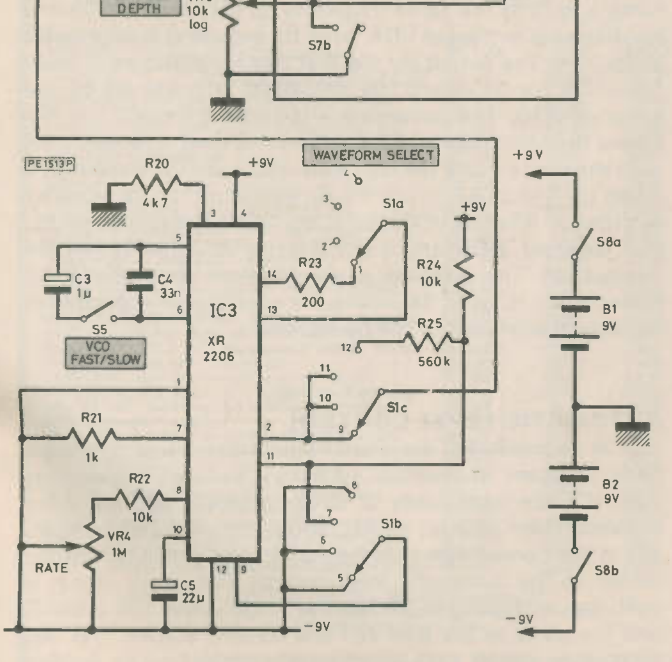


Fig. 2. Complete circuit diagram of the Ring Modulator

THE CIRCUIT

The unit has been designed to enable a wide variety of carrier and modulator combinations to be produced. In one mode speech, music or other signals can be modulated by an internal low frequency oscillator the rate of which is variable by a panel control. Normally referred to as the 'VCO' this produces four waveforms of sine, triangle, ramp and square waves, at a controllable amplitude level. Separate inputs for external carrier and modulating signals are included, enabling for example, two synthesiser VCO's to be intermodulated. Facilities for mixing the modulator and carrier signals with the processed composite have not been included as the most useful function of this facility is when both are derived from closely controlled sources, such as synthesiser VCO's, when mixing is best done back at source. An ordinary mixer unit could alternatively be used instead. An integral mixer is provided for combining the internal VCO output with an external carrier. Self modulation of an input signal can also be switched in, allowing for frequency doubling. Automatic level control of the carrier signal is included, and optimises both the internal VCO amplitude and those of external carriers. A noise gate at the final output smoothly closes down the output in the absence of a main input signal, minimising system noise both from the unit and the original source. A block diagram is given in Fig. 1, and the complete circuit diagram is shown in Fig. 2.

RING MODULATOR CHIP

Naturally the heart of the modulator is the Ring Modulator chip itself and the one chosen is the type 1496. To call it a ring modulator chip is a slight misnomer, for it is actually a balanced modulator-demodulator connected in the configuration to act as a ring modulator. The manufacturer has allocated the name Carrier to pins 8 and 10, and the name Modulator to pins 1 and 4. Normally we regard the higher frequency applied as being the carrier, and the lower frequency as the modulator, and the terms up to this point have been used in this fashion. For the sake of clarity, the names used from hereon will conform to the manufacturer's designations and the modulator will be the signal at pin 4 IC2, and the carrier that at pin 10 IC2, even though this means that the carrier will often be at a lower frequency than the modulator. Although IC2 has two carrier and two modulator ports only one of each is used as the signal application point. The bias on their counterparts though is an equally vital factor. In essence if the signal carrier ports are held in balance, then a modulator signal will not pass through, and if the modulator ports are balanced then the carrier will not get through. In the absence of either, then in theory there will be no signal at the two antiphase outputs. In practice full suppression of the carrier and modulator signals is not possible, but it can be minimised. The breakthrough strength is largely related to the strength of the signals, to the frequencies involved, and the accuracy of the balance point setting. The balance on the carrier ports is performed by VR3 and on the modulator ports by VR2. Note that they each control the throughput not of their own signals, but of those on the opposite inputs. The degree of imbalance accidentally or deliberately introduced, controls the amount of the signal that is allowed to pass through. Beyond that, the amplitude at which the composite is delivered at the outputs is determined by the values of R14 and R15, together with the current through R9. The modulator input is only controllable by an a.c. signal, but the carrier input can be variably controlled by both a.c. and d.c. voltages.

INPUT STAGE

The modulator signal is brought into the buffer and gain stage of IC1a, and can come from practically any audio source, such as most microphones, preamps, synthesisers, cassettes, and so on. Two jack sockets are provided, one for low level signals, the other for higher levels. Within reason the unit will not be damaged by applying an incorrect signal to the wrong input, but the level may not be satisfactory. The total gain given at the preamp is set by the relationship of VR1 + R2 to the total of the input resistance. For low level signals only R1 is in circuit, and the gain can be varied from X5 to X100. With signals on the high input, the gain has a range of $\frac{1}{2}$ to X10. The two sockets are not intended as mixable inputs, and priority is given to the lower level input. If a jack plug is in this socket, the other will automatically be cut out of circuit. In the absence of a plug in either, the input line will be grounded via R47. From IC1a the modulator is routed to $\bar{S}2$ for use in self modulation, to the noise gate IC4, and to the ring modulator IC2. This is sensitive to the maximum level applied to its ports, and signals are given a 1/10th reduction. The preferred maximum seen at pin 4 IC2 is about 150mV peak-to-peak, allowing a maximum output from IC1a of 1·5V p-p. At the lowest setting on VR1, the maximum signal strength on the high input jack is thus 3V p-p.

CARRIER GENERATOR

The internal oscillator is designed around the XR2206 function generator chip which has been chosen for its widely variable frequency range and selection of waveform outputs. Those used here are selectable by S1 in order of sine, triangle, ramp and square. The chip is capable of producing other waveforms but these are unconventional variations of the above four and would add little to the existing versatility. The frequency range obtainable is initially set by the value of the capacitance across pins 5 and 6. It is then controllable by the current flowing through VR4 and R22. The relationship is complex and for sine, triangle and square waves is expressed as the formula:

$$F = 1/((R22 + VR4) \times (C/1000)) \times 1000$$

For C = C4 = 0·033μF, R22 = 10k, VR4 = 1M, this comes out at 30Hz. With VR4 adjusted to nil with the other factors the same, the frequency becomes 3·03kHz. When C3 is switched in parallel with C4 by S5 the range is then 0·96Hz to 97Hz. Normal tolerance factors may produce slightly different ranges.

FREQUENCY SELECTION

The maximum resistance range of VR4 plus R22 is restricted to between 1k and 2M. The lower the resistance, the greater the current flowing and so the higher the frequency. When S1 is in the ramp position the value of R21 comes in and the frequency relationship formula changes to:-

$$F = ((2/C/1000) \times 1/(VR4 + R22 + R21)) \times 1000$$

and the resulting output frequency is approximately twice that of the other three settings. The two ranges selectable by S5 then become 1·9Hz to 176Hz, and 60Hz to 5·5kHz, again subject to tolerance factors. There is also a duty cycle factor involved expressed by:

$$R21/(R21 + R22 + VR4)$$

which has the effect of slowing the fastest edge of the ramp at low values of VR4. Clearly, because of the complexity of the formulae, it is not practical in a simple unit to keep the ramp output at the same frequency as the other waveforms for the same setting of VR4, even by switching in alternative capacitors. The output for the first three waveforms is taken from IC3 pin 2, where the amplitude is governed by the value of R20. The squarewave is taken from IC3 pin 11, where the amplitude is practically at line level, in accordance with the load current through R24. The selected waveform is taken via S1c to S2 where the carrier origin can be selected, in order of internal VCO, self modulation (frequency doubling), external modulation, and internal mixed with external modulation. The selected source is taken via the inverting buffer/mixer IC1d to S6 where the choice of unregulated or automatic level control can be selected.

AUTOMATIC LEVEL CONTROL

It is desirable for the carrier signal amplitude to remain fairly constant irrespective of origin. Each of the outputs from IC3 are intrinsically of different levels, and switching between them without an ALC varies the modulation depth. IC4 is the Compander chip type 571 used in this part of the circuit as the automatic level control. The carrier signal is split, one part going to the rectifier stage within IC4 at pin 2, and the other to the gain call and op-amp stages. The rectifier stage serves as a signal level detector and by feeding back the output, the circuit is arranged so that the gain is inversely proportional to the input level. Hence if this increases, so the output level reduces, and vice-versa, so maintaining a constant output amplitude until the input level falls below a predetermined region as set by R32. The output level is then finally allowed to reduce. The output level constant is however dependent upon the shape of the waveform applied, and the envelope timing as set by C10. If the decay of the envelope is too narrow, the response could become very edgy and uneven. If it is too slow, the response would not allow for abnormal peaks to be suppressed. The value of C10 thus represents a reasonable compromise.

The best amplitude control is achieved with sinusoidal waveforms, and square waves are not adequately controlled to the same degree, so an additional limiter has been set by including R25 as an attenuator for the square wave mode from IC3. The other three waveforms are essentially at a suitable amplitude, between 1V and 2V. The threshold level as set by R32 allows signals as low as 40mV to be applied from external sources to be brought up to within 10dB of the maximum level. R46 is partially responsible for controlling the final output level, and at its stated value allows a maximum output amplitude for sine waves of about 1·5V, suitable for presenting to the carrier input of IC2. Increasing R46 will decrease the level.

CARRIER INPUT

As with the modulator input of IC2, the carrier input is also sensitive to overloading from the carrier signal. The input level is thus attenuated by R13 and R26 to about 1/10th. The maximum signal strength applied is controlled by VR5 from nil up to the maximum limited by R27. Two modulation modes are provided and selected by S4. With S4 open the modulation is purely a.c. via C21. The controllable strength of the output from IC2 is dependent upon this level applied. With the balance preset VR2 correctly adjusted and with VR5 turned right down, there is no significant output. As VR5 is increased, so the output rises until the maximum carrier input is under d.c. and a.c. control. With VR5 up the level is reached. With S2 closed, C21 is bypassed, and the carrier level is at maximum, though its effect is slightly and deliberately reduced by its resistance now in parallel with R13, so upsetting the balance on the carrier inputs. Because of this imbalance, some of the original signal from IC1a is permitted to pass through, but partially modulated with the carrier. As VR5 is turned down now, so the carrier level decreases, but the d.c. imbalance increases as the resistance of VR5 reduces, so allowing more of the original signal to pass through with less modulation.

MIX/AMPLITUDE CONTROL

At the minimum resistance of VR5, only the original signal from IC1a is heard. Effectively VR5 thus acts as a mix control when S4 is closed, and as an amplitude control when S4 is open. S7 is an override switch that when closed, optimises the imbalance on the carrier inputs, and shunts out the carrier signal.

COMPONENTS . . .

Resistors

R1,R4,R22,R24, R26,R40,R42	10k (7 off)
R2	47k
R3,R16–R19,R28–R31,R38,R47	100k (11 off)
R5,R6,R10,R11, R36	18k (5 off)
R7,R8,R12,R13, R21,R27,R39	1k (7 off)
R9,R20,R43,R46	4k7 (4 off)
R14,R15	1k6 (2 off)
R23	200
R25,R32	560k (2 off)
R33,R34,R37	30k (3 off)
R35	160k
R41	2M2
R44	27k
R45	62k

All ¼W 5% carbon

Potentiometers

VR1,VR4	1M mono rota (2 off)
VR2,VR3	1k skeleton (2 off)
VR5,VR6	10k log mono rota (2 off)
VR7	25k skeleton (or 20k)

Capacitors

C1–C3,C10, C15–C17	1µ 63V elect (7 off)
C4	33n polyester
C5–C9,C13, C20–C24	22µ 10V elect (11 off)
C11,C14	4µ7 63V elect (2 off)
C12,C19	56p polystyrene (2 off)
C18	100n polyester
C25,C26	470µ 10V elect (2 off)

Semiconductors

D1,D2	1N4148
IC1	TL084
IC2	1496
IC3	XR2206
IC4	571

Switches

S1,S2	3 pole 4 way (2 off)
S3–S6	s.p.d.t. (4 off)
S7,S8	d.p.d.t. (2 off)

Miscellaneous

Battery clips (2 off)
P.c.b. clips (4 off)
Knobs (6 off)
14 pin d.i.l. sockets (2 off)
16 pin d.i.l. sockets (2 off)
Mono jack sockets (4 off)
Printed circuit board—231A; case type BK3; four stick-on rubber feet; wire and solder.

Constructors' Note

Complete kit of parts available from: **Phonosonics,** 8 Finucane Drive, Orpington, Kent BR5 4ED. Price £46.00 inclusive of UK VAT and p&p.

DIFFERENTIAL AMPLIFIER

IC2 has two outputs in antiphase and which are presented to the differential amplifier IC1b. It is d.c. coupled and gives equal weight to each phase. The resultant output with S7 in the override mode is twice that at the output of IC1a and is suitable for presenting to an amplifier. However, as previously stated, the complete suppression of the modulation and carrier thoughputs is not possible, and a small residual breakthrough is to be expected.

Quite distinctive waveform shapes appear, all of which have their own unique effect upon the final output quality. When bypassing the ALC control a 180° phase change occurs and the ramp waveform changes to the opposite slope introducing a fifth set of variations. Full modulation in the d.c. mode is intentionally inhibited as the increased level required would inherently raise the carrier breakthrough level. Full carrier modulation is of course provided when S4 is in the a.c. mode. When switching between both modes, the nature of the circuitry produces a cross-fade effect between them. This is due to the relative d.c. levels applied to C21 changing at a rate determined by the biasing resistors and provides a smooth changeover. A similar effect is produced when S7 is switched in and out.

NOISE GATE

Under normal conditions when signals are being processed, this residual is of no consequence. Indeed the maximum breakthrough is normally at least 50dB down, less of course if VR5 is down. In the absence of a modulator from IC1a though, it is usually undesirable to hear the breakthrough, and a modulator-sensitive noise gate is thus included and formed around IC4b. By connecting the output of IC1a to the gate, this will turn on and off in response to the presence of modulating signals. The output of IC1a is taken first to the level detector IC1c. This amplifies the modulator by an amount set by R41, but restricted to no more than 1·2V by D1 and D2. Signals from IC1a above about 100mV will produce sufficient output from IC1c to provide control of the rectifier stage of IC4b. At this level the rectifier stage allows the gate to be fully open to signals on its other input. As the control voltage drops, so the gate commences an expansion, progressively reducing lower level signals at a faster rate than the higher levels. This continues until a threshold point set by R35 is approached, whereupon the gate closes.

The attack and decay envelope is set at a reasonable shape by C14, allowing all but the harshest opening transients to come through unattenuated, and for the level to die away naturally without suddenly cutting out. Thus the gate opens for modulator signals, but in their absence it closes to low level residual carrier breakthrough. The 60dB crosstalk within IC4 is insignificant. Waveform distortion through the gate is trimmed out by the bias applied by VR7. At full signal strengths, the gain is set by R37, and the final output presented to the volume control VR6 from whence it can be sent to a normal amplifier system. The gate can be overriden by applying a fixed voltage to the control input by S3. The override bias is set bv R43 and R44, and at average signal strengths the level change is barely perceptible, though it will be at lower levels since the basic control voltage from IC1c will naturally be lower. The maximum output level available at VR6 is about 3V p-p.

POWER SUPPLY

The unit is designed to run from two 9V batteries. There is no reason why a stabilised power supply should not be used instead, though the maximum voltage should not exceed ±9V as this is the limit imposed by IC4. The current consumption is around 30mA, up to 20mA of which is taken by IC2. Whilst PP3 batteries could be used, longer battery life will come from the larger PP6s, which use the same PP3 clips. The larger still PP9s fit into the box, but require PP9 clips. Due to the current drawn by IC3, large smoothing capacitors are mounted off the board at the power switch, this minimises interference from the internal carrier clock frequency. With a stabilised power supply they can probably be eliminated, but batteries do not deliver their current so readily and smoothly.

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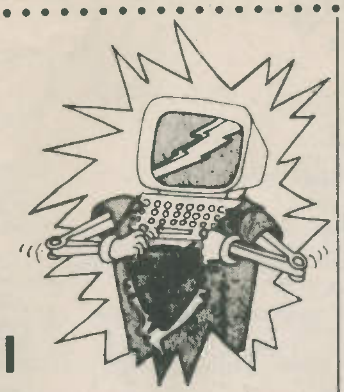

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THIS two-part article sets out to explain both the advantages and disadvantages of nickel cadmium cells. The characteristics of some common types of nickel cadmium battery are described and a typical application is discussed. Finally, we shall conclude with the description and constructional details of an automatic charger suitable for use with most commonly available nickel cadmium cells.

An appropriate choice of power source is crucial to the design and use of portable electronic equipment. The traditional solution to the problem of providing an energy supply for small items of electronic equipment has usually involved the use of one, or more, dry cell batteries of the zinc carbon (Leclanché) variety. These consumable items are readily available throughout the country.

Unfortunately, the prices of dry cells have followed the general rate of inflation in recent years, whilst the cost of electronic components, and integrated circuits in particular, has fallen in real terms. As an example of this, a dry cell battery which ten years ago cost 8p now costs 36p whereas, by contrast, an industry standard operational amplifier has fallen in price from 60p to 15p in the same period. It now becomes increasingly apparent that the life-cycle cost of replacement zinc carbon batteries can easily far outweigh the initial cost of the equipment to which they are fitted. This is true of both home-built and commercial equipment such as personal cassette players and the like.

A more cost effective energy source is thus highly desirable, and ideally this should retain some degree of compatibility with conventional zinc carbon batteries so that these cheaper alternatives may be substituted in emergency.

Nickel cadmium batteries, whilst not in any way a new development (they were first patented in 1901!), have achieved some measure of popularity in recent years. Whilst this has largely been in the industrial sector, an attempt to launch these cells on the consumer market has met with moderate success. These cells are now readily available in most high street stores in a range of popular physical sizes compatible with their zinc carbon counterparts.

Nickel cadmium cells offer significant advantages over zinc carbon types, not the least of which is that they may be charged and discharged many hundreds of times. The electrical characteristics of nickel cadmium cells are very different from zinc carbon types. As an example, provided it is treated in accordance with the manufacturer's recommendations, a single 'AA' type nickel cadmium cell is capable of the following performance:

—delivering a current of half an amp for an hour, or more
—supplying a load current of several amps for a short period
—operating over a wide range of temperatures (from minus 40°C to +50°C with reduced capacity at the extremes)
—surviving for a minimum of 600 charge/discharge cycles
—accepting prolonged overcharging
—requiring no maintenance other than periodic charging.

CONSTRUCTION

Nickel cadmium cells, or 'Nicads', are available in two types of construction, cylindrical (sintered) and button (mass plate). These cells have quite different characteristics, as summarised in Table 1.

Button cells invariably consist of either one or two pairs of circular plates separated by a porous insulating material, as shown in Fig. 1. Types with multiple plates generally exhibit a lower internal resistance than their two-plate counterparts of nominally similar capacity. The plates themselves are formed by compressing the active constituents into a metal mesh and hence they are often referred to as mass plate cells.

Cylindrical cells, on the other hand, employ a form of rolled construction using flexible plates which have been

NICKEL CADMIUM BATTERIES

MICHAEL TOOLEY BA
DAVID WHITFIELD MA MSc CEng

PART ONE

	Cylindrical	Button
Charge retention	Moderate	Good
Packing density	Fair	Good
Energy density	80 to 100Wh/litre	60 to 80Wh/litre
Ratio of max. to nom. discharge rate	50 to 100	20 to 40
Internal resistance for typical 1Ah cell	25mohm	50 to 100mohm
Recommended temp.	−20 to +45°C	0 to +45°C
Relative cost	Medium/high	Low/medium

Table 1. Comparison of cylindrical and button cells

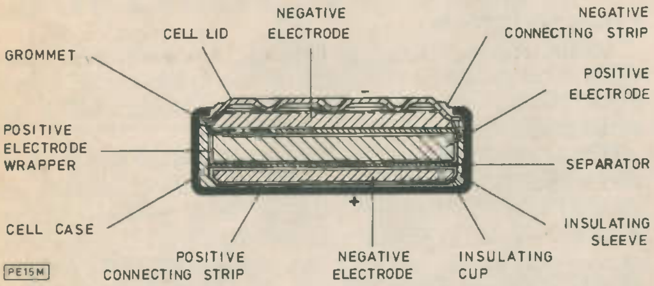


Fig. 1. Typical construction of a nickel cadmium button cell

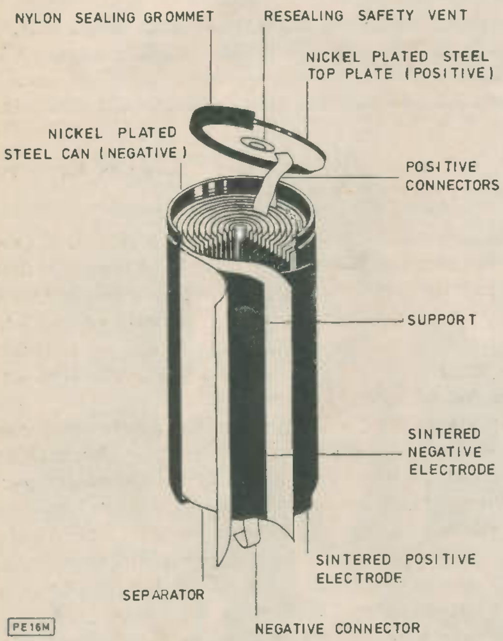


Fig. 2. Typical construction of a nickel cadmium tubular cell

produced by sintering nickel powder onto a nickel substrate. The plates are separated by a thin porous material as shown in Fig. 2.

In either case, the battery is totally sealed by means of a nylon or rubber grommet. Cylindrical cells are, however, normally fitted with a pressure relief vent which prevents the internal pressure from reaching a dangerous level during excessive charge or discharge. This safety device operates at pressures of about 14atm and closes at about 11atm.

GENERAL CONCEPTS

Cells fall into one of two principal categories, primary cells which end their useful life when their chemical constituents are exhausted, and secondary cells in which the chemical reaction may be reversed thus permitting re-charging. Leclanché cells are perhaps the most common example of the former type whilst Nicads are an example of the latter type.

Groups of individual cells may be connected in series (parallel connection of cells is not usually recommended) according to the desired terminal voltage. The resulting arrangement is referred to as a battery, and the terminal voltage is the sum of the individual cells' terminal voltages.

A number of terms are used to describe the electrical characteristics and performance of batteries and, since these may be bewildering to the newcomer, we shall explain each one in turn.

Capacity

The capacity of a cell is the amount of electrical energy which it can deliver. This is simply the product of its rated discharge current (A) and discharge time (h) and is usually quoted in ampere hours (Ah). To be meaningful, however, capacity must be stated for a particular discharge rate. Depending upon the application envisaged, the cell is normally rated for discharge periods of between two and ten hours.

Energy content

The energy content of a battery is specified in watt hours (Wh), and is the product of the cell's capacity (Ah) and the average voltage (V) on discharge. As an example, consider a nickel cadmium battery which comprises three individual series connected cells (each having a nominal discharge voltage of 1·2V). If the cells are rated at 450mAh (at the five hour rate) the battery will nominally be capable of delivering a load current of 90mA over a continuous five hour period. During this time the average voltage of the battery will be 3·6V (falling to approximately 2·7V at the end of the period) and its useful energy content will be:

$$(0{\cdot}450 \times 3{\cdot}6) = 1{\cdot}62\text{Wh}$$

Style of cell	Nominal capacity (Ah)	Approx. dimensions (diam. × height) (mm)	Approx. weight (g)	Approx. internal resistance when fully charged (mohm)	Approx. peak short circuit current (A)	Comparable zinc carbon primary cell
AAA	0·18	44·5 × 10·5	10	80	20	HP16
AA	0·5	14·5 × 50·5	24	24	35	HP7
C	2·0	26 × 49	17	70	70	HP11
D	4·0	33·5 × 61	7	150	110	HP2

Table 2. Characteristics of commonly available nickel cadmium cells

Efficiency

The watt hour efficiency is the ratio of the energy realised upon discharge to that which is required to fully charge the battery. If, in the previous example, the battery required eight hours to charge at an average terminal voltage of 3·9V and at a constant current of 100mA, the energy required to charge the battery is:

$$(3{\cdot}9 \times 0{\cdot}1 \times 8) = 3{\cdot}12\text{Wh}$$

The watt hour efficiency, expressed as a percentage, will thus be:

$$(1{\cdot}62/3{\cdot}12) \times 100 = 52\%.$$

Charge/discharge rate

Charge and discharge currents are often specified in terms of that which will completely discharge the battery concerned in a continuous one hour period. This is referred to as the 'C-rate' (or 'C/1 rate') and multiples, or sub-multiples, of this are a convenient method of specifying charge and discharge rates. Thus 10C is the current which will discharge the battery in six minutes whereas C/10 is the current which will discharge the battery in ten hours.

Chemical action

Modern nickel cadmium cells featuring a totally sealed construction are a development of open style cells. These were designed to permit the release of gases produced during charge and discharge, and required periodic topping-up of the electrolyte in much the same manner as automotive lead-acid batteries. With sealed batteries it is not, of course, possible to replenish the active materials. Whereas this results in a virtually maintenance free battery, it carries the penalty that care must be exercised in the use of the batteries in order to avoid permanent damage.

An approximation of the chemical action of a nickel cadmium cell is given by:

$$2NiO(OH)+Cd+2H_2O \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftharpoons}} 2Ni(OH)_2+Cd(OH)_2$$

The dilute potassium hydroxide (KOH) electrolyte does not appear in the formula. However, it should be noted that water is produced during charging, and is absorbed from the electrolyte during discharge.

On discharge, the nickel hydroxide positive mass changes from $2NiO(OH)$ to $2Ni(OH)_2$ whilst the metallic cadmium negative mass oxidises to produce cadmium hydroxide, $Cd(OH)_2$, at the negative electrode. On charge, the positive mass is converted to nickel hydroxide whilst the cadmium hydroxide changes to cadmium, releasing water into the electrolyte in the process.

The foregoing only applies whilst material is still available for conversion, i.e. before total charge or discharge has occurred. When all available material has been converted, either oxygen or hydrogen gas is evolved depending respectively upon whether material is first completely converted at the positive or negative plate.

Cells are normally designed so that only oxygen is evolved. This is accomplished by incorporating an amount of surplus cadmium hydroxide in the negative plate. Thus, when the positive plate is fully charged, the charge on the negative plate is still incomplete.

The oxygen released at the positive plate during periods of excess charge reacts with the metallic cadmium at the negative plate to produce cadmium hydroxide as follows:—

$$O_2 + 2H_2O + 2Cd \longrightarrow 2Cd(OH)_2$$

Hence the oxygen evolved can be effectively recombined avoiding the need to ventilate the cell so that the gas may escape. To aid the recombination process, the plates of the cell are separated by a very thin porous membrane which assists the passage of oxygen within the electrolyte.

To safeguard the cell from the effects of excessive discharge, cadmium hydroxide is added to the positive plate so that oxygen recombination is again possible, this time at the positive plate.

CHARACTERISTICS OF NICKEL CADMIUM BATTERIES

The terminal voltage of a single nickel cadmium cell is usually assumed to be 1·2V though, as one might expect, there is some variation during the discharge period. Unlike some other types of cell, nickel cadmium types exhibit a remarkably constant output voltage during discharge. After falling initially from approximately 1·3V, the cell voltage remains within about 5% of 1·25V for more than 75% of the discharge period.

A typical set of discharge curves for a cylindrical nickel cadmium cell are shown in Fig. 3. This clearly shows the

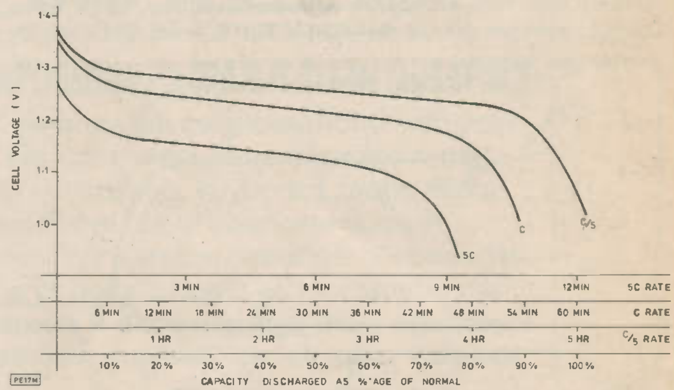


Fig. 3. Typical discharge characteristics for a cylindrical nickel cadmium cell

effect of three discharge rates, C, 5C, and C/5. It should be noted that this cell is normally rated for a five hour discharge period and its performance over shorter periods reveals less capacity as the discharge rate is increased. In this particular case, and assuming a useful end voltage of approximately 1V, the capacity is reduced by approximately 10% and 25% at the C and 5C rates respectively.

Nickel cadmium cells exhibit an extremely low value of internal resistance (0·05 ohm for a typical 1Ah cell) and this makes them eminently suited to applications which require the delivery of high currents for short periods.

The ability of a nickel cadmium cell to retain its charge is very much dependent upon the temperature at which it is stored. Mass plate cells exhibit markedly better charge retention abilities than their sintered counterparts, and both types rapidly lose charge as the storage temperature is increased, as shown in Figs. 4(a) and 4(b).

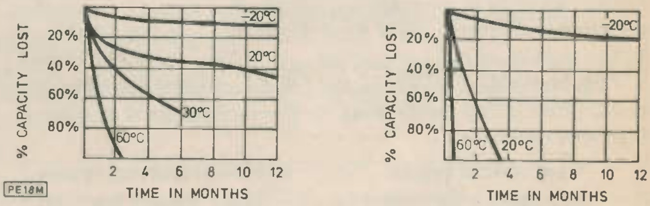


Fig. 4(a). Charge retention characteristics for mass plate cells. Fig. 4(b). Charge retention characteristics for sintered plate cells

The ability of a cell to accept a charge is also highly dependent upon temperature. Charge acceptance is extremely limited at temperatures above 45°C and, furthermore, the cell's ability to recombine oxygen is reduced at low temperatures. The recommended temperature range for charging nickel cadmium cells is thus between 10°C and 35°C.

The internal resistance of nickel cadmium cells increases as the temperature is reduced. Sintered cells offer an inherently lower internal resistance than mass plate types and are thus better suited to low temperature applications. Furthermore, nickel cadmium cells normally exhibit a negative temperature coefficient of voltage in the region of 4mV per °C. Thus a cell which produces an off-load terminal voltage of 1·25V at 20°C will produce only some 1·17V at 0°C.

COMPARISON OF ZINC CARBON AND NICKEL CADMIUM CELLS

On load, the voltage of a zinc carbon cell varies from approximately 1·5V when new to 1·2V towards the end of its service life. This compares with 1·3V falling to 1V for a nickel cadmium cell, as depicted in Fig. 5. From this it will be

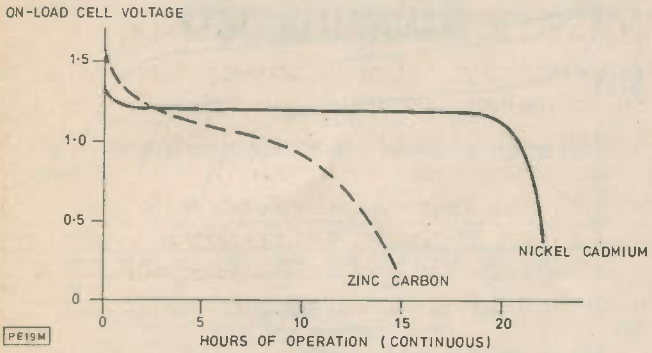


Fig. 5. Comparison of nickel cadmium and zinc carbon cell discharge characteristics

seen that, in the case of the zinc carbon cell, the fall-off in voltage during the service life is much more gradual. Whilst an ability to maintain a constant voltage during discharge may be considered highly desirable, it does mean that it is rather more difficult to ascertain the state of a nickel cadmium cell than a zinc carbon type.

Zinc carbon cells benefit greatly from periods of rest during discharge. They are thus very much better suited to intermittent use, particularly where high discharge rates are involved. Nickel cadmium cells are, by contrast, capable of continuously delivering high output currents.

It is generally thought that nickel cadmium replacements for zinc carbon batteries will become cost effective after the first twenty charge/discharge cycles. Thereafter, and provided one has a suitable charger available, the nickel cadmium cell can be expected to provide reasonable service for a minimum of several hundred further cycles with only a minor fall-off in cell capacity. Beyond this, a 20% reduction in cell capacity is normally expected after about five hundred cycles. However, a great deal depends upon the life history of the individual cell concerned.

Applications in which nickel cadmium batteries should be considered prime candidates for the replacement of zinc carbon types include:—

Cylindrical types	**Stacked button types**
Emergency lighting	CMOS memory back-up
Portable power tools	Miniature radio equipment
Motorised equipment	Portable test gear
Cordless domestic appliances	

In certain applications, however, the lack of impending warning of battery failure may prove sufficient to outweigh the advantages of nickel cadmium cells. A good example of this is an intermittently used hand torch. Due to limitations of charge retention such an item cannot be relied upon when fitted with nickel cadmium batteries. Zinc carbon batteries are much to be preferred in this particular application.

CMOS MEMORY BACK-UP

In recent years CMOS static memories have become increasingly popular with the microprocessor system designer and, to conclude the first part of this two-part series, we shall briefly discuss a typical application of nickel cadmium batteries in providing back-up for such memories.

CMOS memories, unlike their NMOS counterparts, require a supply current of only a few microamps. It thus becomes feasible to incorporate a battery within the equipment to supply power to the memory devices so that data will not be lost when the primary mains supply is interrupted. At this stage, it is, perhaps, worth pointing out that all we are trying to do is preserve the contents of the read/write memory, and no attempt is made to power the rest of the circuitry (CPU, read-only memory, etc).

The minimum voltage at which most CMOS memories will reliably retain their contents is normally 2V, hence three nickel cadmium cells connected in series will usually be adequate for this particular application. Furthermore, the chosen type of cell will usually be the button variety since these exhibit better charge retention characteristics than their sintered plate counterparts.

DISCHARGE CHARACTERISTIC

The typical discharge characteristic of a three-cell stacked button cell battery supplying a load current of 20μA is shown in Fig. 6. From this it should be obvious that the contents of a CMOS memory will be protected for several months provided that its demand for current is 20μA, or less. Furthermore, if the charge current is kept below the C/10 rate, the battery may be left permanently connected in circuit.

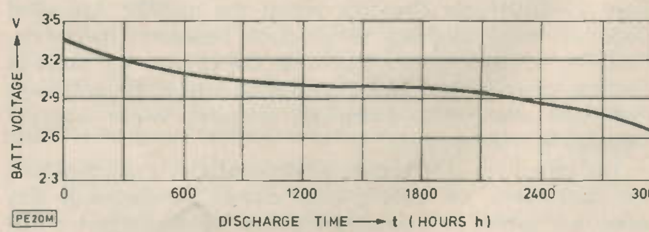
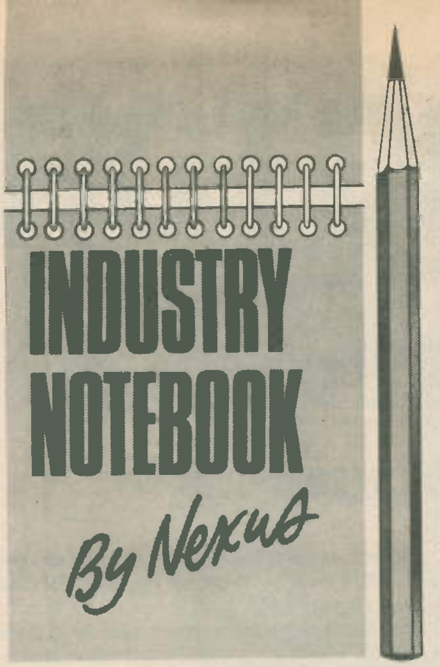


Fig. 6. Typical discharge characteristics for a three-cell stacked button cell battery with a constant 20μA discharge current

Since the fully charged voltage of a three-cell battery is less than 5V, the battery may be trickle charged directly from the main 5V supply rail, thus greatly simplifying the charging arrangements. The battery may conveniently be fitted directly to the p.c.b. using solder tags and several manufacturers supply nickel cadmium batteries specifically for this purpose.

NEXT MONTH: More sophisticated chargers for nickel cadmium batteries will be discussed and full constructional details of an automatic constant current charger will be provided.



Jobs Confusion

By far the most vexing problem of the 1980s is unemployment, stubbornly staying at three-million-plus despite attempts at reduction. The old smokestack industries continue in decline, now overtaken by the high-technology sunrise industries of electrical and electronic engineering. The Engineering Employers Federation report that the broad electrical and electronics sectors have remained constant in jobs since 1982 while in the same period the workforce in mechanical engineering has decreased by 88,000, equivalent to a 10 per cent cut. In the last five years the electrical and ancillary industries have overtaken the mechanicals and instead of being 20 per cent smaller are now an estimated 15 per cent larger.

Volume is still rising fast in the industries but this is not matched by an increase in jobs. If we look at Thorn EMI there are all the signs in the annual report of business expansion with turnover up over £100 million to £2·82 billion. But the number of employees world-wide dropped from 91,544 to 89,051 reflecting gains in productivity rather then employment. The situation for jobs is even worse when one remembers that a lot of Thorn EMI business is in the service sector in which expansion was expected to create many new openings in this area.

If we narrow our view to electronic engineering it is not the shortage of jobs but the shortage of qualified people that is the overriding problem. A recent report from the Engineering Council which looked at grass-root school level stated there is widespread confusion among pupils on the nature of the engineering profession and about the opportunities it offers. There is, apparently, less hostility to engineering than has been popularly supposed from either teachers or pupils — the problem being not in general attitude but in widespread ignorance.

Much has already been done to promote engineering among the young but it has been fragmented. The Engineering Council recommends a stronger fully coordinated programme to educate both teachers and pupils. Isolated promotions such as the WISE (Women in Science and Engineering) bus now touring the country have their place but should be only part of a larger programme. The WISE initiative, incidentally enjoyed financial backing from Acorn, Thorn EMI and Esso as well as a personal launch by the Prime Minister who, herself, had a scientific education.

Concern

Yet another concern is that once a supply of well qualified engineers is available there remains the menace of the brain-drain which reached distressing proportions in the 1960s when the elite got on their bikes to the nearest airport to disappear, mostly, in the direction of the United States. The attraction is still there and not always for instant extra cash but often for better equipped labs and greater future opportunity.

We tend to think of electronics engineering in hardware design terms. Arts graduates were considered unsuited. Attitudes in the industry are now changing and it is argued that many arts people can get into electronics through software.

On the employers side much greater attention is being paid to general quality of character in engaging people. Claimed qualifications are more likely to be checked than hitherto and character defects searched for, aided in some companies by the analysis of handwriting by outside graphologists (with or without the applicants knowledge) and, in very sensitive areas, by Polygraph. Recent revelations of widespread corruption in Rolls-Royce and other companies is accelerating the move to more positive and continuous vetting.

But while potential crooks and trouble makers are definitely not wanted there is a crack in the door for a few of the mentally disturbed. There is a school of thought that believes that a manic depressive in the overactive phase can be highly creative, so much so that the depressive phase is worth tolerating. This, of course, is the age-old image of the mad inventor or, in the arts, the creative genius with only a hairline separating him from insanity.

Who owns Whom?

It is difficult to keep pace with an electronics industry that has always been subject to dynamic changes. Who would have imagined five years ago that mighty EMI would be merging with Thorn? Or five months ago that Thorn EMI would own Inmos?

As I write, STC is courting ICL and GEC still has high hopes of acquiring British Aerospace. Racal has greedy eyes on Chubb now that the big Decca acquisition has been satisfactorily absorbed. The figures involved are quite astronomical but show the strength of successful companies. STC's offer of close on £400 million for ICL was considered not enough and Racal's £146 million for Chubb is likely to result in further bids if others join in.

Plessey has beefed up electronic warfare ability by acquiring 35 percent of the Italian EW company Elettronica with an option to go up to 49 percent. Elettronica in return will have a similar stake in a new joint company to be set up in the UK. Plessey has also bought out Microtechnology in the United States, a custom chip plant, in a £12 million operation.

Dragon Data, the Wales-based computer company which had cash-flow problems has been bought from the receiver by a Spanish consortium. The Dragon 32 and 64 computers will now be made in Spain but the Kenfig, Wales, plant is to continue making the Touchmaster pressure sensitive pad and graphics tablet.

Zehntel Inc. has bought Columbia Automation of Windsor, thus strengthening its own involvement in ATE while at the same time opening up the US market for Columbia ATE via Zehntel's marketing network.

Deals

These are just a few of the deals made or in progress at the moment. Arguments on who owns a particular company at a particular moment are fruitless. Is Racal-Milgo Inc. in Florida less of an American company because of British ownership? But who owns Racal Electronics PLC? A broad spectrum of banks, insurance companies, pension funds, unit trusts and individual investors who may be British or foreign.

In this respect it is interesting to note that a City consortium which has just invested over £1 million in Prism Technology Holdings includes among its members the Coal Board's investment arm. And, of course, cash-rich companies like GEC don't leave it in the bank but put it to work through investment elsewhere as in the recent Distillers share purchase.

Who makes What?

Who makes what is equally difficult to track down, as is who designs what. The antenna systems for the RAF earth terminal due for completion in June 1985 are coming from the Harris Corporation in the USA under a 6 million dollar contract awarded by Plessey on behalf of the Ministry of Defence.

In fact, there is a whole complex of subcontracting in manufacture and cross-licensing of designs. Sir Clive may design his Sinclair computers but other companies manufacture them. If we come down to component level it is anybody's guess. ITT Cannon who have just spent another £6 million on a new design and production plant at Basingstoke are turning out five million connectors a year with a fair proportion ending up in Japanese and US equipment, just as in British equipment we are likely to find many foreign-made components.

It all sounds a terrible mess. But it works. Compare this free-for-all with the rigid state control of industry in the Soviet Union. One can only feel sorry for the comrades.

SEMICONDUCTOR CIRCUITS

TOM GASKELL BA(Hons) CEng MIEE

2-PUSHBUTTON LOCKS (LS7228 AND LS7229)

LAST month we looked at the MM53200N encoder/decoder i.c., a device which had obvious applications in security systems. These i.c.s were used in pairs, one acting as an encoder and the other as a decoder. This month's featured i.c.s are new devices from LSI Computer Systems, the LS7228 and LS7229. These two i.c.s are superficially quite similar to the MM53200N, although their practical uses are somewhat different and they have a number of unique applications as '2-pushbutton locks' or address decoders.

The LS7228 and LS7229 are PMOS i.c.s which are recent additions to the popular LS7225 family of combination lock i.c.s featured in the very first *Semiconductor Circuits* back in May 1983. The block diagram is shown in Fig. 2, and covers both the 7228 and the 7229. There are two main inputs, the 'zeros' input, pin 14, and the 'ones' input, pin 13. The i.c.s are operated by codes entered at these input pins. Each complete code consists of nine input pulses applied to one or other of the inputs as shown in Fig. 3. An input to pin 13 corresponds to a logic 1 in the code, and an input to pin 14 corresponds to a logic 0.

The entered code is compared to the locally programmed code at pins 1 to 9 in a sequential manner. If there is an error in the incoming code compared with the locally programmed code then the circuitry is disabled and further code entries have no effect. A new code may be entered only after a delay time determined by an external R/C time constant. When a correct code entry is made the output pin goes to a high level (logic 1) for a period T_{op} indicating that the lock has operated.

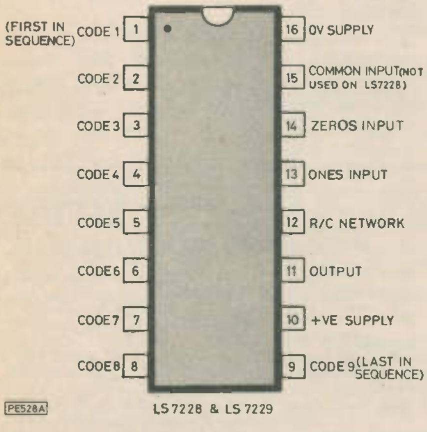


Fig. 1. Pinout and specification

INPUTS TO THE I.C.

The difference between the two i.c.s lies in their input signal conditioning circuitry. The LS7229 is designed to accept switched inputs from two single-pole double throw momentary action pushbutton switches. The input signal conditioning circuitry is designed to eliminate contact bounce from the zeros and ones inputs, since any bouncing or spurious pulses would prevent an otherwise valid code from being correctly interpreted by the i.c. The LS7228, on the other hand, is intended for use with pulse train inputs, i.e. logic inputs with 'clean' bounce-free edges. Hence, on the LS7228 the common input, pin 15, is not used and should be left unconnected. Note that internal pull-down resistors are fitted to all three inputs, avoiding the need for any external biasing resistors.

When power is first applied to the circuit, the i.c. goes into a 'standby' mode, consuming only 15µA of supply current. Each time an input (either zeros or ones) is activated an external capacitor C_t is charged up, which in turn causes the rest of the i.c.'s internal circuitry to be turned on. (See Fig. 2.) When the input is

Characteristic	Notes	Minimum Value	Typically	Maximum Value	Units
Supply Voltage	Spec's are over full supply voltage range unless otherwise stated	2·5		15	V
Quiescent Current	'Standby' Mode			15	µA
Temperature Range		−25		+70	°C
Input Voltages, Pins 1 to 9 (Code Inputs)	For Logic 1 Level	(+ve supply −0·5)		(+ve supply)	V
	For Logic 0 Level	0		(+ve supply −2·5)	V
Input Voltages, Pins 13, 14, 15 (Serial Inputs)	For Logic 1 Level, +ve supply = 5V	4·0	4·3	5·0	V
	For Logic 1 Level, +ve supply = 9V	7·6	8·0	9·0	V
	For Logic 1 Level, +ve supply = 15V	13·6	14·0	15·0	V
	For Logic 0 Level, +ve supply = 5V	0	0·5	1·5	V
	For Logic 0 Level, +ve supply = 9V	0	1·0	2·0	V
	For Logic 0 Level, +ve supply = 15V	0	2·0	4·5	V
Input Current, Pins 1 to 9	Inputs at 0V (Spec. is for *each* Input)			−5	µA
Input Current, Pins 13 & 14	Inputs at +ve supply (Spec. is for *each* Input)		3	5	µA
Input Current, Pin 15	Input at		1·5	3	µA
Output Current, Pin 11	O/P Voltage = (+ve supply −1·5V), +ve supply = 5V	8·0	14·0	20·0	mA
	O/P Voltage = (+ve supply −1·5V), +ve supply = 9V	14·0	26·0	36·0	mA
	O/P Voltage = (+ve supply −1·5V), +ve supply = 15V	20·0	38·0	53·0	mA
External R at Pin 12		33k		3·3M	Ω
Input Inter-pulse Time	T_{ip}—See Fig. 3	30		T_{op}	µs
Output Delay	T_{od}—See Fig. 3	20	40	70	µs
Output Pulse Width	RC is value of ext. components at Pin 12		1·25RC		s
Input Pulse Width (with C at Pin 12 = 0·01µF or less)	T_{IW} (See Fig. 3), +ve supply = 5V	80			µs
	T_{IW} (See Fig. 3), +ve supply = 9V	120			µs
	T_{IW} (See Fig. 3), +ve supply = 15V	200			µs

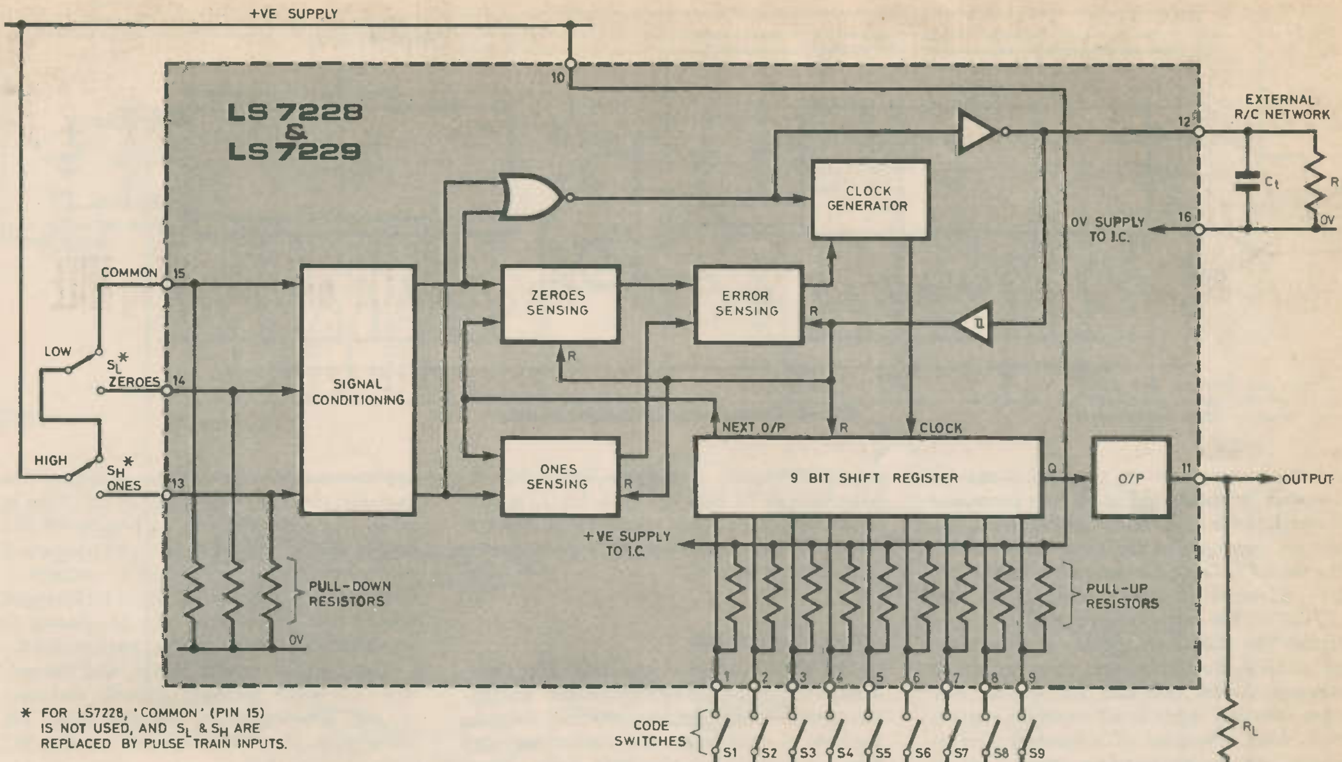


Fig. 2. Block diagram

released, or drops to logic 0, C_t discharges via R_t, and when the voltage on C_t reaches a logic 0 level the internal circuitry is reset and the i.c. goes back into its standby mode. Hence, each sequential code entry must be made within the time period determined by the time constant $R_t \times C_t$.

INTERNAL CODE COMPARISONS

Each time an input is activated, a 9 bit shift register is clocked on by one position. The inputs to this shift register are taken from pins 1 to 9, the local programming inputs. At each clock pulse the next code bit in the sequence is fed out of the shift register into the zeros and ones sensing circuitry. Any deviations from the correct code are detected by the zeros or ones sensing circuitry as soon as the next input is activated, causing the clock generator to be inhibited by the error sensing section, thus preventing further code comparisons. C_t and R_t must then be allowed to discharge before the circuitry is reset and code comparisons can start again. If a correct code sequence is satisfactorily entered, the Q output of the shift register goes to a logic 1, causing the i.c. output to go high. This output requires an external pull-down resistor to 0 volts in order to achieve an output voltage swing, i.e. to drive other logic devices. The output pulse slope is not very fast, so the i.c. might not satisfactorily drive some logic i.c.s such as flip-flops or counters without buffer gates being used in between. The output can source fairly high currents, however: up to 38mA typically from a 15 volt supply. The output pulse length (in seconds) is approximately 1·25 times the external R/C time constant $R_t \times C_t$, measured in ohms and farads (or megohms and microfarads, which is easier to calculate) respectively. If the output needs to be maintained at a high level for some time, a 10th code entry must be made and held on continuously at either the ones or the zeros input.

The code switch inputs, pins 1 to 9, need only to be pulled down with suitable switches to 0 volts, since they have their own internal pull-up resistors to the positive supply rail. Naturally, they can be programmed with logic signals from other circuitry if required, or hard wired if only one fixed code is normally wanted. A logic 0 or a connection to 0 volts corresponds to a logic 0 or low level in the code, and a logic 1 or an open circuit corresponds to a logic 1 or high level in the code.

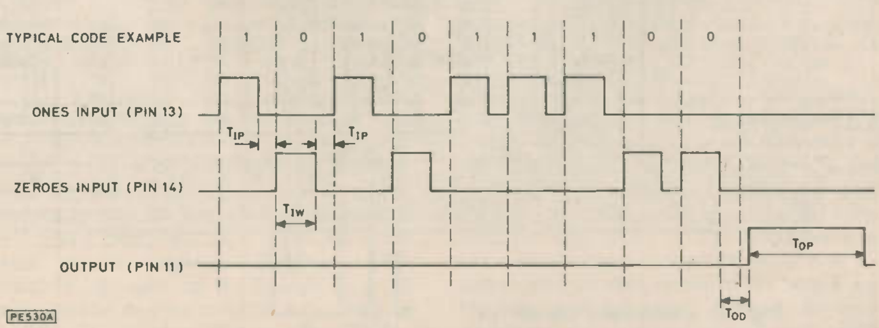


Fig. 3. Timing diagram (typical example)

USING THE I.C.S

As with the other i.c.s in this family, the LS7228 and LS7229 are very straightforward to use. The external R/C time constant is usually chosen to allow a time window of several seconds for each code entry. This then requires a wait of several seconds after the entry of one code before the next is tried, preventing an unauthorised person quickly trying all 512 possible combinations. Beware of potential problems of leakage current preventing proper operation at pin 12, which may be caused by using a large electrolytic capacitor with a high value resistor. (The resistor should always be in the range 33k to 3M3.) If this does seem to be a problem, the leakage current through the capacitor should be lowered; try a tantalum type, or use a lower capacitance value.

The code entry switches for the LS7229 are normally momentary action pushbuttons with changeover contacts, labelled '1' and '0', 'high' and 'low', or similarly. These are pressed in the appropriate sequence to actuate the lock. Take care to avoid spurious entry of code; the smallest error causes the system to inhibit and reset. Even just touching the bare terminals where wires connect from the switches to the i.c. while pressing the switches prevents proper operation. For longer codes, and the resultant

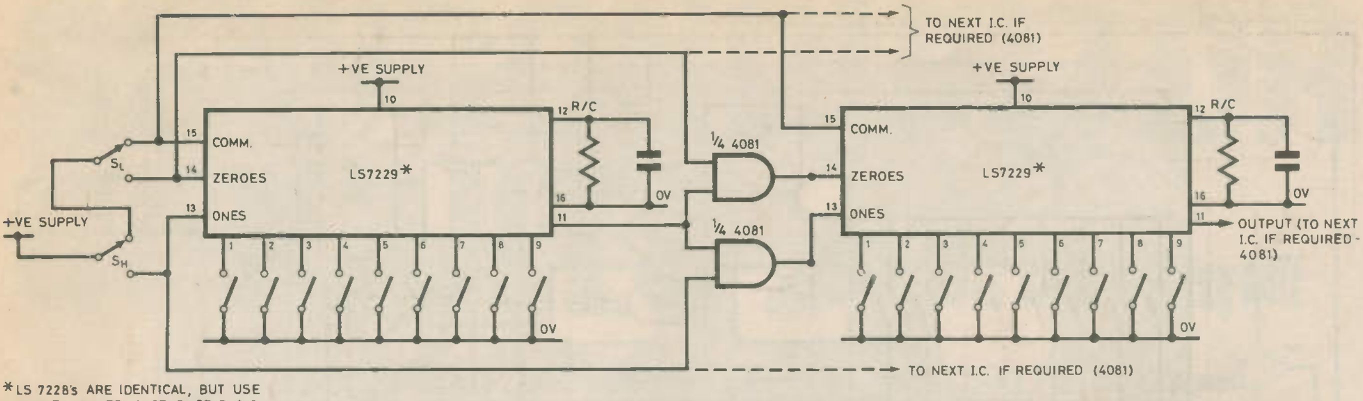


Fig. 4. Cascading for longer codes

higher security, two or more i.c.s can be cascaded as shown in Fig. 4. The zeros and ones inputs are AND-ed with the output of the first i.c. then fed into the second, and so on. For the LS7229 all the common pins (pin 15) are connected together, whereas for the LS7228 all the common pins are left unconnected. The code then consists of 18 sequential entries—not the easiest thing to try to remember when unlocking the system! For more complex 'multi-level' systems, one i.c. could feed a number of secondary i.c.s in parallel, each responding to a unique 9 bits of code after sharing a common first 9 bits of code. As can be seen in Fig. 4, LS7229s can be used with logic inputs, even though they are intended for use with switches, if the common input is wired suitably.

APPLICATIONS

The obvious areas of application for these devices are in car and house burglar alarms, electronic locks on computers, electromechanical door locks, and similar security-based systems. They also have some unique applications as serial address decoders. For example, consider using a pair of LS7228's in series on a serial data line, such as an RS-232 line, to decode incoming data and compare it with a local code, either pre-set by switches or controlled by computer. It could be arranged that further data would only be allowed to pass after the correct code had been received.

These are interesting, useful, and inexpensive i.c.s which are both versatile and easy to use. They can be obtained from **TK Electronics**, 11-13 Boston Road, London W7 3SJ. (01-579 9794).

COMBINATION LOCK

THE applications project this month uses a single LS7229 as a 2-pushbutton lock with some extra circuitry to enhance its operation and provide a toggling lock/unlock action. The code is entered with switches S10 and S11. Pressing S10 enters a low code bit and generates a low audio tone, whereas pressing S11 enters a high code bit and generates a high audio tone. This helps the user to memorise the correct code, and gives the project its name! When a correct code has been entered, a 'warbling' tone is heard for a short period and the output of the circuit changes state. When power is first applied, the output is at a low level and the 'lock on' l.e.d. is illuminated. The first correct code received turns the lock off, the next one turns it on again, the next off, and so on.

CIRCUIT DESCRIPTION

IC1, with its associated external components (Fig. 5), has already been described in detail. Note the pull-down resistor R2 on the output, and the values of R1 and C1 giving a time delay of approximately 5 seconds. C1 is a tantalum bead to help keep leakage down.

The two audio oscillators are formed by IC2c, IC2d, R12, R13 and C8 for the higher tone, and IC2a, IC2b, R14, R15 and C9 for the lower frequency tone. These are turned on by the appropriate switch action via IC3d and IC3b. The oscillators are also turned on by the action of the very low frequency oscillator formed by IC4c, IC4d, R5, R6 and C6. This very low frequency oscillator is turned on for ap-

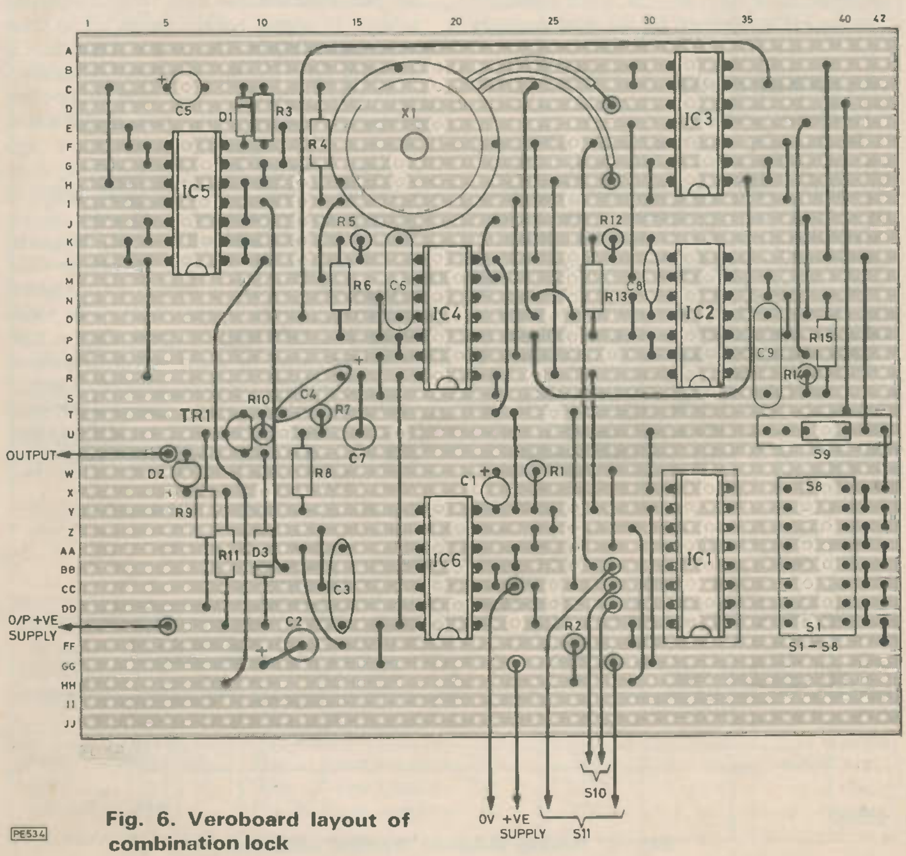


Fig. 6. Veroboard layout of combination lock

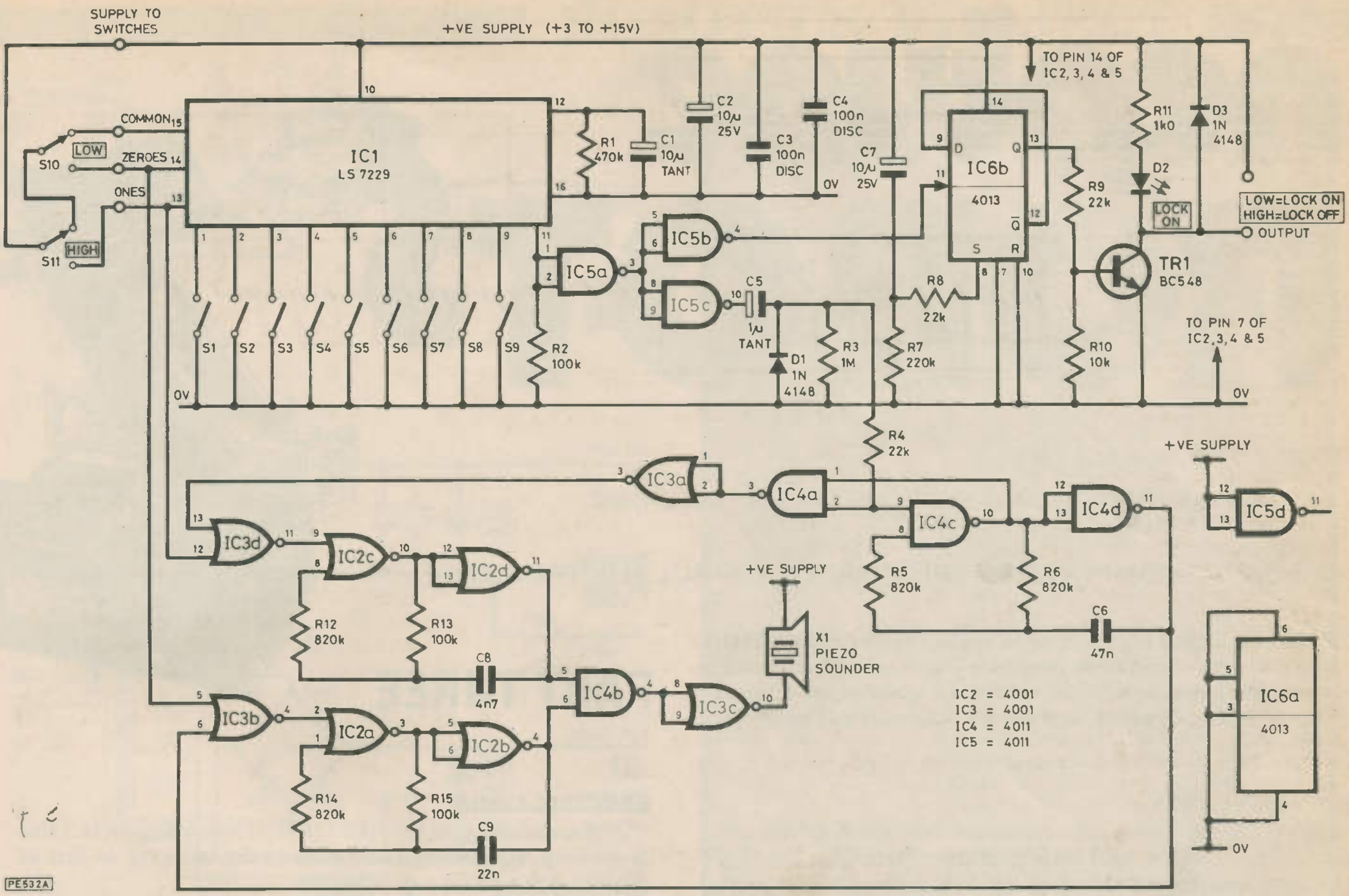


Fig. 5. Circuit diagram of the electronic 'high low' combination lock

proximately 1 second when a correct code has been received; the output of IC1 is fed via IC5a and IC5c to the pulse deriving circuit of C5, D1 and R3, which produces a pulse only 1 second in duration even though the output pulse from IC1 is several seconds longer than that. (R4 protects the inputs of IC4c and IC4a under fault or power-down conditions.) IC4a gates one output of the low frequency oscillator with its enable input in such a way that the control lines to IC3d pin 13 and IC3b pin 6 are normally at logic 0 when the low frequency oscillator is turned off. When it turns on, however, these two feeds to IC3 are low frequency square waves of opposite polarity; the one second long 'warble' therefore consists of a short burst of high frequency tone followed by a short burst of low frequency tone, then high again, then low again, etc., all at the repetition rate of the low frequency oscillator. IC4b combines the two audio frequency tones, and IC3c drives the piezo sounder with the resultant waveform.

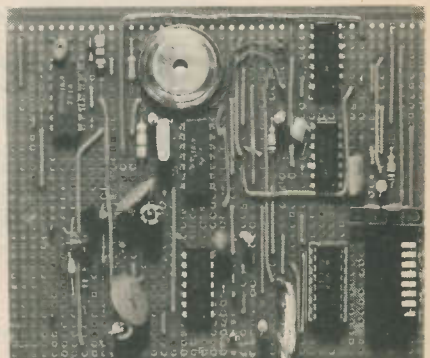
The output of IC1 also feeds the clock of IC6 (pin 11) via IC5a and IC5b. IC6 is a D-type flip-flop connected as a divide-by-two counter so that the first correct received code will unlock the circuit, and the next will lock it again, etc. The output of IC6 turns on TR1, which in turn lights up the 'lock on' l.e.d. D2 and provides an open collector for turning on a relay or operating other circuitry. (Extra buffering should be provided if a high-power relay or solenoid is to be driven.) C7, R7 and R8 provide power-on reset for IC6.

CONSTRUCTION

Fig. 6 shows the Veroboard layout of the circuit. Nine-way d.i.l. switches are difficult to obtain, so an 8 way SPST pack has been used for S1 to S8, and a sub-miniature slide switch for S9. These should be closed for a low code bit, or open for a high code bit. Switches S10 and S11 are momentary action changeover switches, and are shown in their normally closed or resting position. The piezo sounder X1 can be any typical low current type suitable for use with CMOS logic. (As sold by Maplin Electronic Supplies, CIRKIT (Ambit International), and many others.) The power supply can be any stabilised supply in the range 3 to 15V, or even a battery.

To vary the high frequency tone, change the value of R13 or C8, and for the low frequency tone change R15 or C9. The speed of warbling is varied by changing R6 or C6, and the duration of warble by C5 or R3. To adjust the entry time allowed for each bit of the code, alter the value of R1 or C1. Remember that this time allowance is also the delay time required between code entries, so if a second entry is required soon after a first entry has been completed, the appropriate time, defined by R1 and C1, must be allowed between them. Unlike the MM53200N last month, there is no serious restriction on the mark/space ratio of the incoming waveforms to IC1.

If the input pulses obey the specific timing restrictions shown in Fig. 3 and specified in Fig. 1 (which only really cause any restrictions if the inputs are from a logic system, rather than from switch contacts), and fall within the overall time period of R1 × C1, then that code entry will be satisfactory. This all helps to illustrate the simplicity and effectiveness of the LS7228 and LS7229, both of which are interesting additions to the range of electronic lock devices manufacturered by LSI Computer Systems.



neptune ROBOTS

RICHARD B. H. BECKER —
SYSTEM DESIGN AND MECHANICAL ENGINEERING.

TIM ORR — COMPUTER INTERFACE AND CONTROL ELECTRONICS.

PART THREE

THE ELECTRO-MECHANICS of the robots was the subject of Part One of this series, and Part Two considered the computer interfacing in detail. This month, the action of the solenoid driver boards is explained, and the p.c.b. layouts and parts lists are given.

POWER SUPPLY

The power for the solenoid-operated valves is unregulated and comes from T500, a 200VA toroidal transformer. See Fig. 3.1. Having a separate transformer keeps switching transients away from the sensitive control circuitry. S1 isolates the solenoid current to enable the robot to be locked motionless until the computer is set up and sending suitable control signals. T501 provides the power for the +5V, −5V, +15V and −15V regulators which are on the computer interface board. The voltage dependent resistor is for reducing mains-borne transients which otherwise might affect the logic components on the interface board or the computer.

SPECIFICATION

The specification of the NEPTUNE II robot is given in Table 1, showing repeatability to be close to the limits for an arm of this size with a 12-bit control system.

SOLENOID DRIVER BOARDS

Each axis has its own solenoid driver board. See Fig. 3.3. A desired position voltage (VOØ to 6) is sent to this board together with the position feedback voltage. The hydraulic valves are then opened and closed so as to servo that axis of the robot arm into a position where the desired position voltage = feedback voltage. This is a closed loop servo system. The arms move towards, and

Table 1: NEPTUNE II specification

AXIS Ø (waist)	Angular movement 180°. Height of axle centre above top of base 170mm.
AXIS 1 (shoulder)	Angular movement 165°. Arm length between axle centres 410mm.
AXIS 2 (elbow)	Angular movement 165°. Arm length between axle centres 347mm.
AXIS 3 (wrist pitch)	Angular movement 180°. Length between axis 3 and axis 4 axle centres 202mm.
AXIS 4 (wrist yaw)	Angular movement 180°. Height of axis 5 axle above axis 4 pitch line 67mm.
AXIS 5 (wrist rotation)	Angular movement 310°.
AXIS 6 (gripper)	Jaw opening 55mm. Jaw pressure 40 newton. Distance between end of jaws and axis 4 axle 160mm.
REPEATABILITY	2mm.
LIFTING CAPACITY	2500gm.
REACH (from axis 1 axle centre)	1119mm.
BASE DIMENSIONS	Overall width 474mm. Overall depth 408mm. Overall height 199mm.
CONTROL SYSTEM	All axes servo controlled with servoing performed by the control electronics. Position defined by 12 data bits giving angular resolution of 0·025% (8 bits and 0·4% for Neptune I).
COMPUTER INTERFACE	Parallel. Robot addressed as if part of computer memory. Connects to expansion port (1MHz bus on BBC).
SOFTWARE	Accepts commands in BASIC or machine code.
SOFTWARE PROVIDED	Extensive package of BASIC programs including direct control from computer keyboard, control by simulator, sequence storing, replay, sequence editing, sequence storage on disc or tape, multi-speed control, self calibration and graphical illustration of robot dynamics.

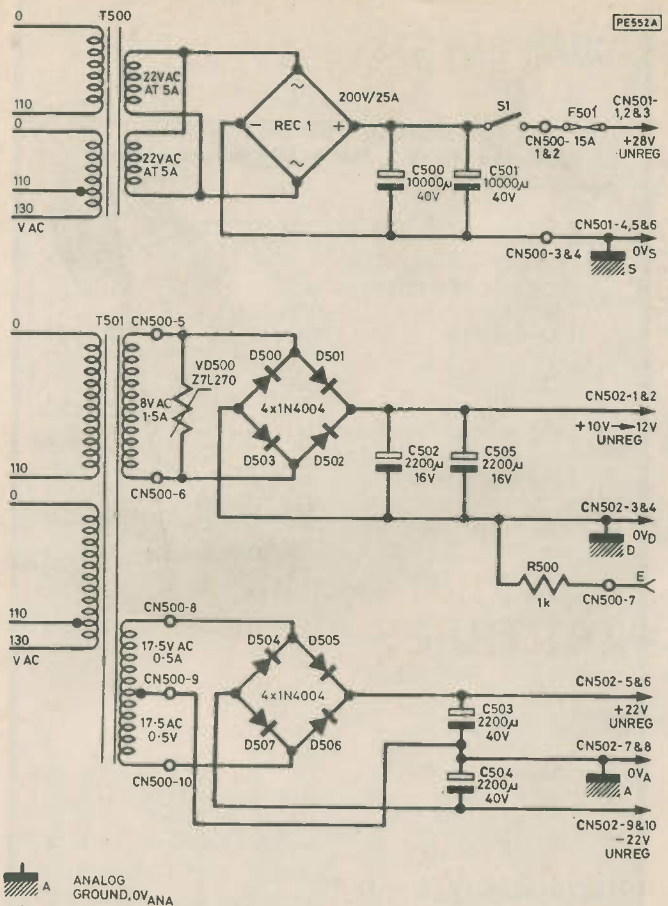


Fig. 3.1. Power supply circuit diagrams for Neptune

COMPONENTS . . .

NEPTUNE POWER SUPPLY as shown in Fig. 3.1

Resistor

R500	1k

Capacitors

C500,501	10,000µ 40V electrolytic (2 off)
C502,505	2,200µ 16V electrolytic (2 off)
C503,504	2,200µ 40V electrolytic (2 off)

Semiconductors

REC1	25A 200V bridge
D500–507	1N4004 (8 off)
VD500	Z7L270 varistor

Miscellaneous

CN500	10-way terminal block
CN501	6-way 0·156in MOLEX
CN502	10-way 0·1in MOLEX
F501	15A 1¼in fuse
T500	Toroidal transformer primaries: 0–110, 0–110–130V secondary: 0–22V at 8A
T501	Laminated transformer primaries: 0–110, 0–110–130V secondaries: 0–8·0V at 1·5A 17·5–0–17·5V at 0·5A
fuseholder clips	(2 off)

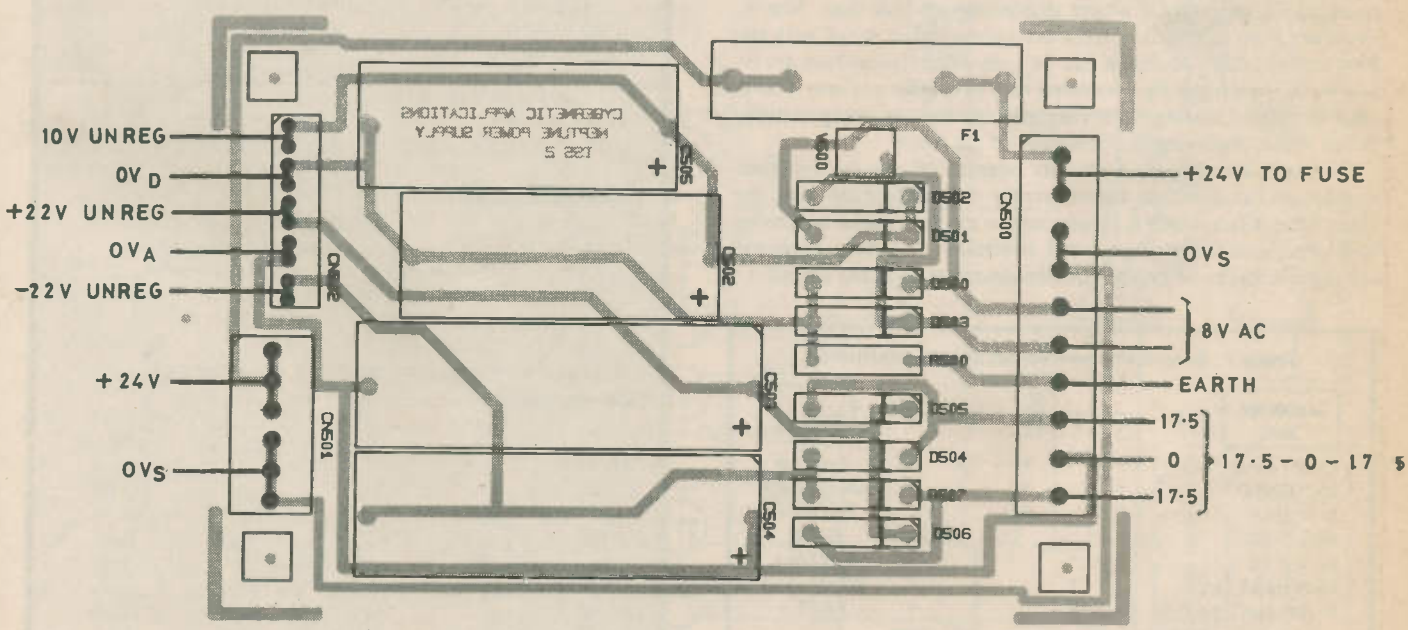


Fig. 3.2. Component layout and wiring for the power supply board

eventually stop at, a position determined by the magnitude of the input (desired) position voltage.

The robot has three speeds (fast, medium and slow) and a stop position. The speed changes are selected by the difference between the position voltage and the feedback voltage.

The decision-making electronics is divided into three similar sections. Each section controls a hydraulic valve for both direction and speed control. The circuit operation can best be explained by examining one of these sections: IC402, TR400 to TR409. The input voltage (DAC output VOØ to 6) is fed into one side of the op-amp. The feedback voltage (measured voltage, M) is fed to the other side. The function of this circuit is to determine if M > DAC or if DAC > M. If M > DAC then the hydraulic ram should retract, and if DAC > M then the hydraulic ram should advance. This is the direction controller and is the most sensitive of the three circuits. There is a position where DAC = M. The axis is then in its stop mode.

The op-amps are used as comparators with both an offset and a Schmitt trigger action. The offset is used to control the size of the magnitude comparison. If the offset is 2mV, then M will have to be bigger than DAC by 2mV for the test M > DAC to be true. TR400 and TR401 are two current sources which sink current into R423 and R421, respectively. The current (approximately 1mA) multiplied by the resistor value generates the voltage offset. The voltage is automatically added to the M and DAC voltages on one side of the comparators. On the other side of the comparators is the opposite signal with no offset. Thus the M > DAC and the DAC > M comparisons are produced, where > implies "greater than with the offset added".

Hysteresis was added to the comparison to prevent dither and instability. Differential transistor pairs (TR402, 403 and TR404, 405) are used to provide positive d.c. feedback around the op-amp. The magnitude of the hysteresis was chosen to be relatively smaller than the offset voltage so as not to significantly affect the magnitude comparisons. The op-amp outputs are used to drive transistors TR406 to TR409. These devices (ZTX651) have a V_{CEO} voltage of 45V, a continuous current rating of 2A and an h_{FE} in excess of 100 at 1A current. Furthermore they are small and cheap. They are used to turn on the hydraulic solenoid valves which take a current of about 300mA.

When the transistors are on they saturate at less than 100mV, resulting in an internal power dissipation of less than 30mW, therefore they run cool. L.e.d.s are connected in series with the base current drive so that it can be seen which transistors are on (Table 2), which can be translated into hydraulic actions. This is very beneficial during fault diagnosis as well as being instructional whilst observing the operation of the robot.

The two speed control circuits operate in exactly the same manner as the direction controller, the only difference being the size of the offset which is larger for the medium speed controller and larger still for the fast speed controller. Also they drive the speed control valves rather than the direction control valves.

Table 2: Solenoid chart for all speed positions

Comparison Test	S6	S5	S4	S3	S2	S1	Action
M ⋙ DAC	*	*		*		*	FAST ↑
M ≫ DAC		*		*		*	MEDIUM ↑
M > DAC		*		*			SLOW ↑
M = DAC							STOP
M < DAC			*		*		SLOW ↓
M ≪ DAC			*		*	*	MEDIUM ↓
M ⋘ DAC	*		*		*	*	FAST ↓
	Medium Speed	Direction				Slow Speed	

COMPONENTS . . .

NEPTUNE SOLENOID DRIVER BOARDS

as shown in Fig. 3.3. Note: There is one board per axis

Resistors

R400,403,408,409, 413, 416,434,437,450,453, 463–465	10k (13 off)
R402,405,407	100k (3 off)
R404	47k
R406	18k
R410–412,414,415, 417–419,431–433,435, 436,438–440,447–449, 451,452,454–456	3k3 (24 off)
R420,422	1Ω2 (2 off)
R424,425,427,428,445, 461	1k2 (6 off)
R426,429,446,462	27k (4 off)
R430,441,443	10 (3 off)
R457,459	39 (2 off)
Axis variables R401,421,423,442,444, 458,460	see table
(¼W 1% 50ppm)	

Capacitors

C400	10n polyester
C401	100n polyester
C402,403	1µ 63V electrolytic (2 off)

Semiconductors

D400,401,407,413,418, 420,424,426	1N4148 (8 off)
D402,415,421	3V3 400mW (3 off)
D403–406,409–412,416, 417,422,423	1N4004 (12 off)
D408,427	Red l.e.d. (2 off)
D414,428	Green l.e.d. (2 off)
D419,425	Yellow l.e.d. (2 off)
IC400–404	RC4558 (5 off)
TR400–405,410–415, 417–422	BC212L (18 off)
TR406–409,416,423	ZTX651 (6 off)

Miscellaneous

CN400,401	3-way 0·1in MOLEX (2 off)
CN402	6-way 0·156in MOLEX
CN403	26-way shrouded header
VR400	10k preset
8-pin d.i.l. socket (5 off)	

Table of axis variable resistors for solenoid driver boards

Axis	R401	R421,423	R442,444	R458,460
0	20k	4Ω7	82	330
1	22k	2Ω7	82	330
2	22k	2Ω7	82	330
3	22k	4Ω7	82	330
4	16k	16	100	390
5	12k	10	100	390
6	18k	22	150	560

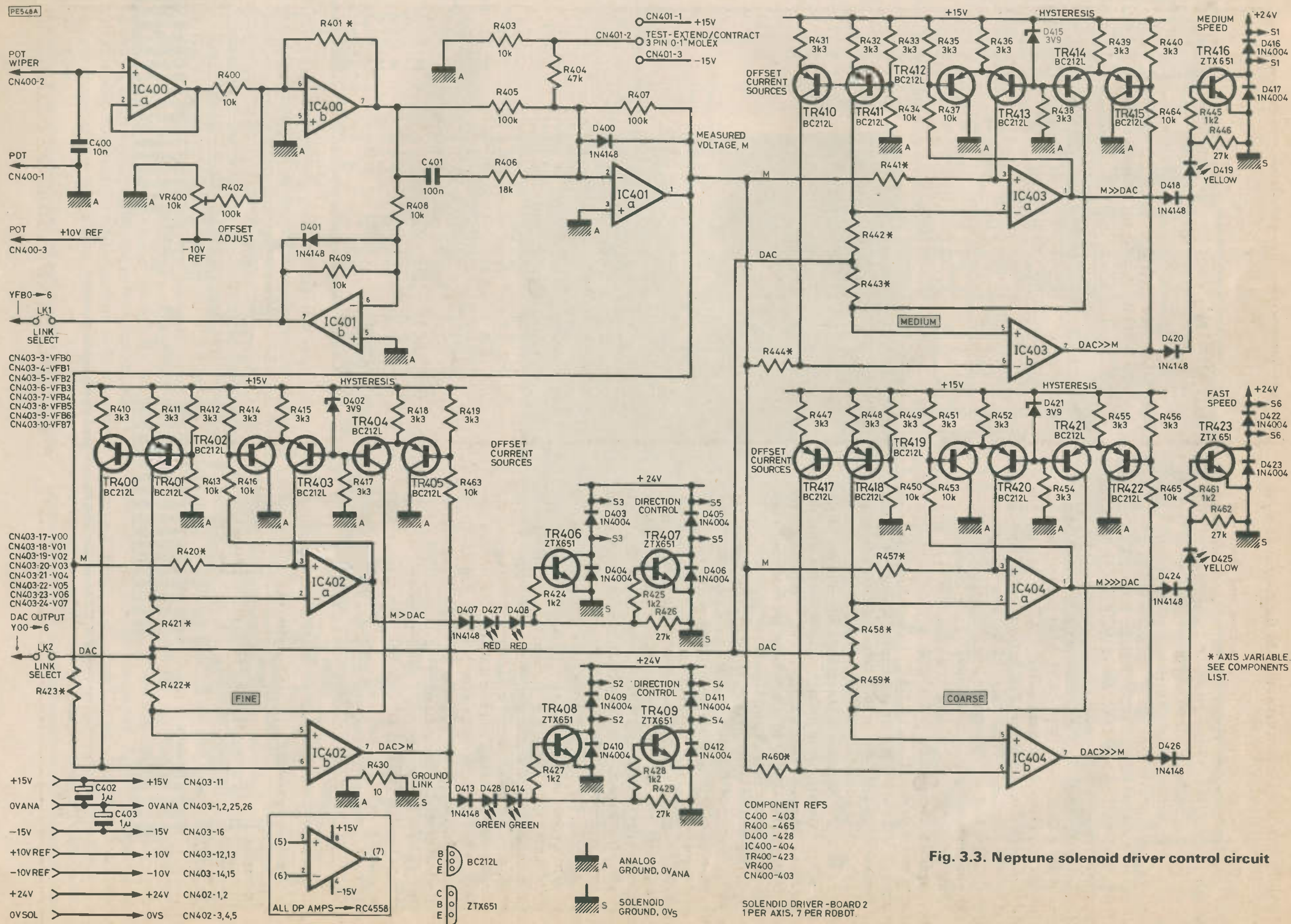


Fig. 3.3. Neptune solenoid driver control circuit

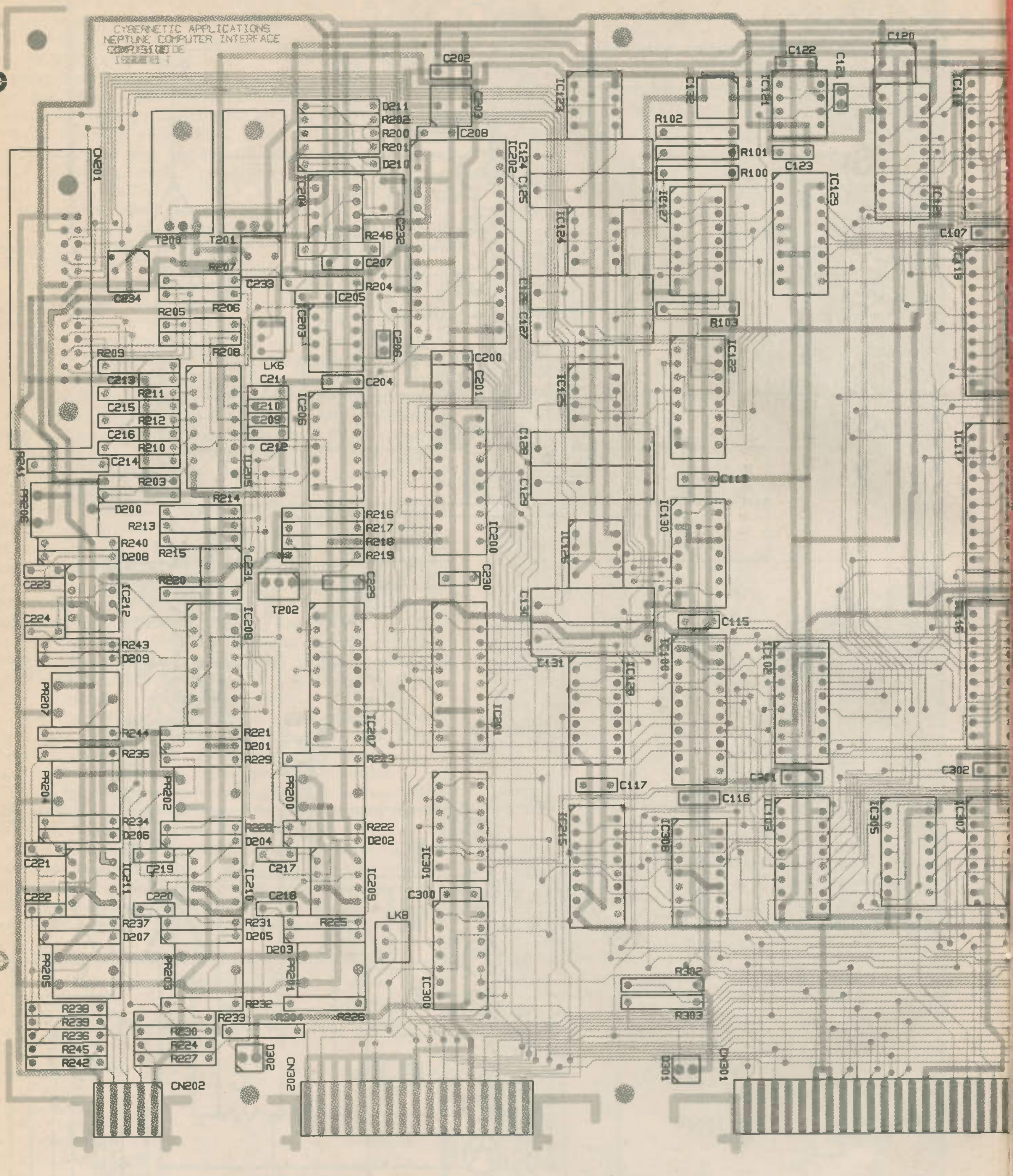


Fig. 3.4. Control and interface board component layout

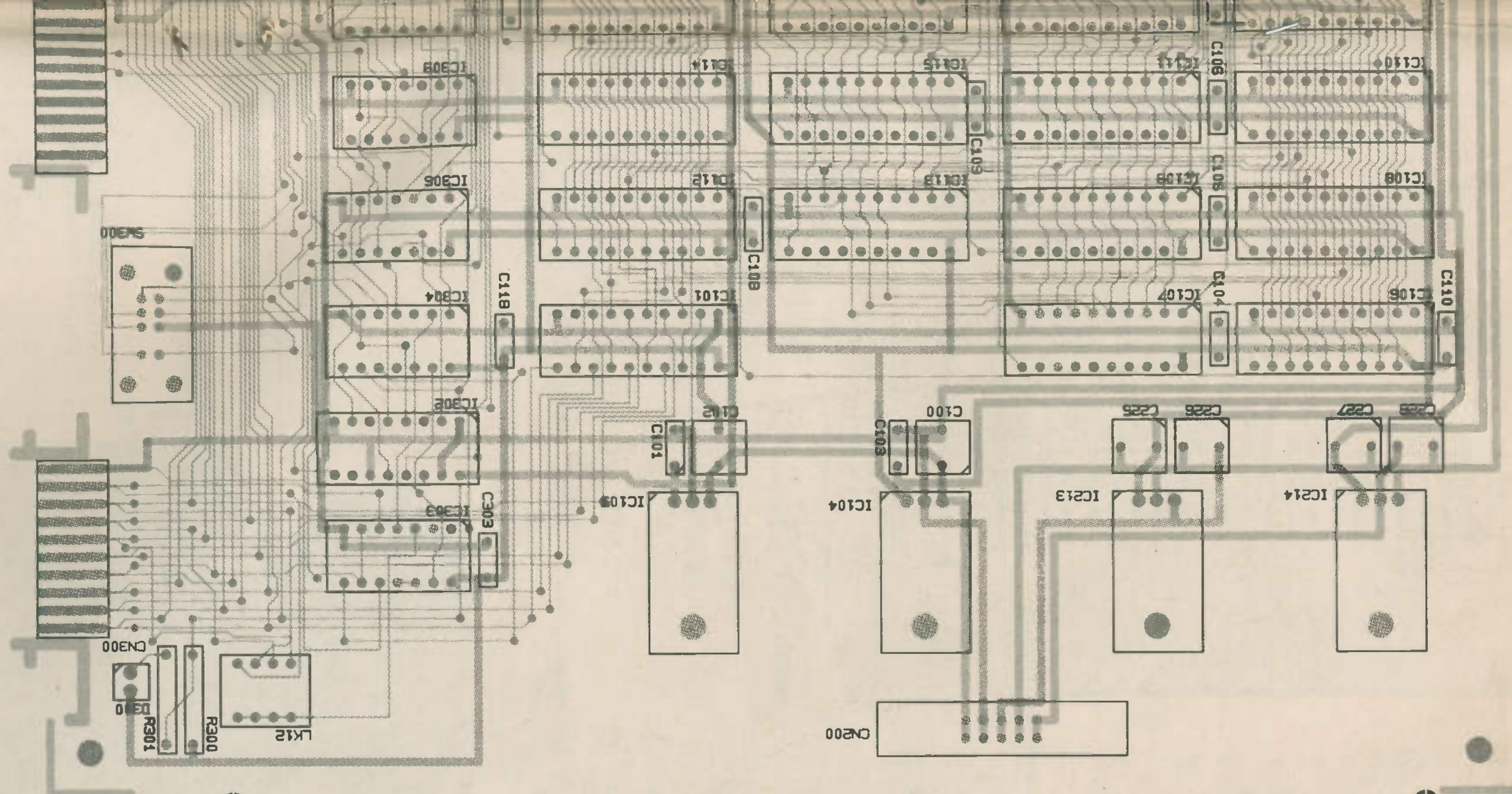
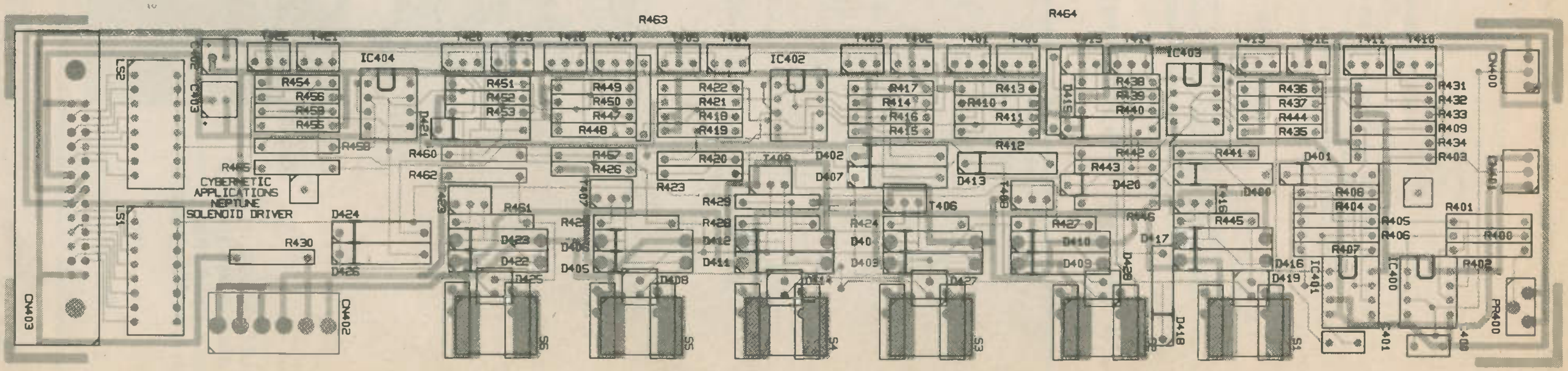


Fig. 3.5. Component layout for the solenoid driver board



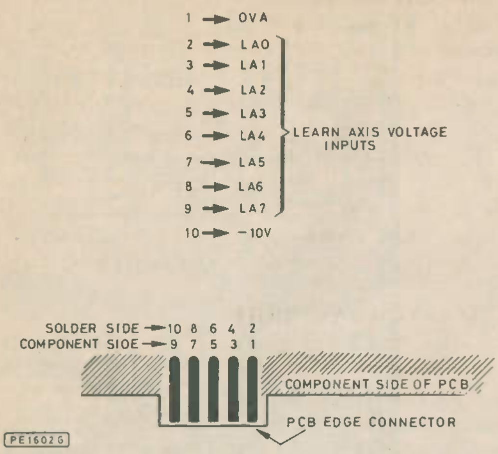


Fig. 3.8. Printed circuit board edge connector details

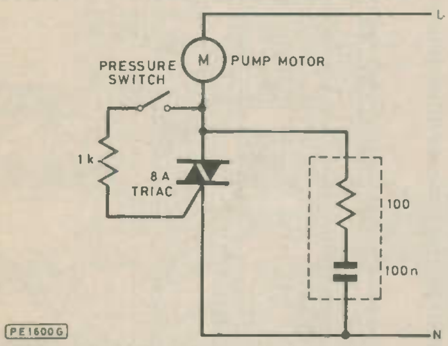


Fig. 3.6. Pump drive circuit diagram

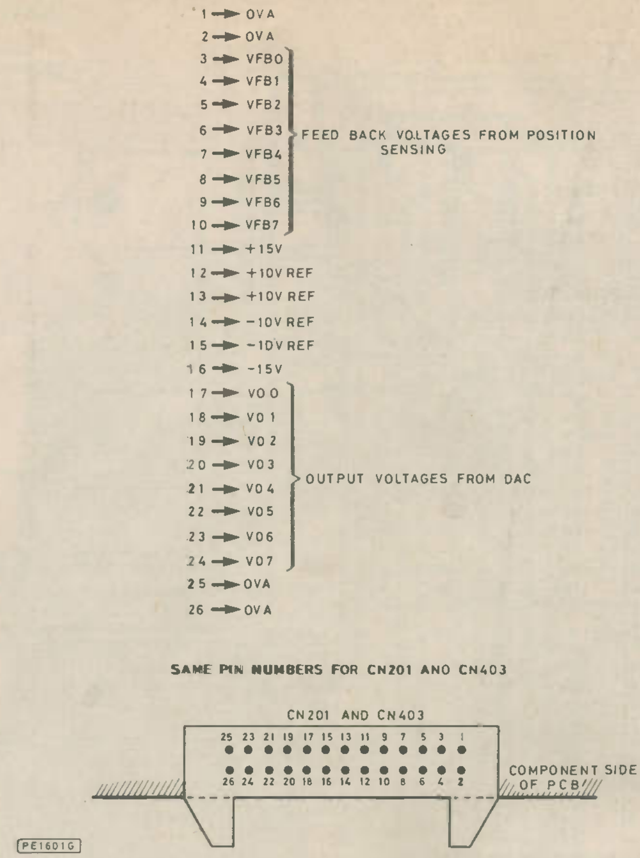
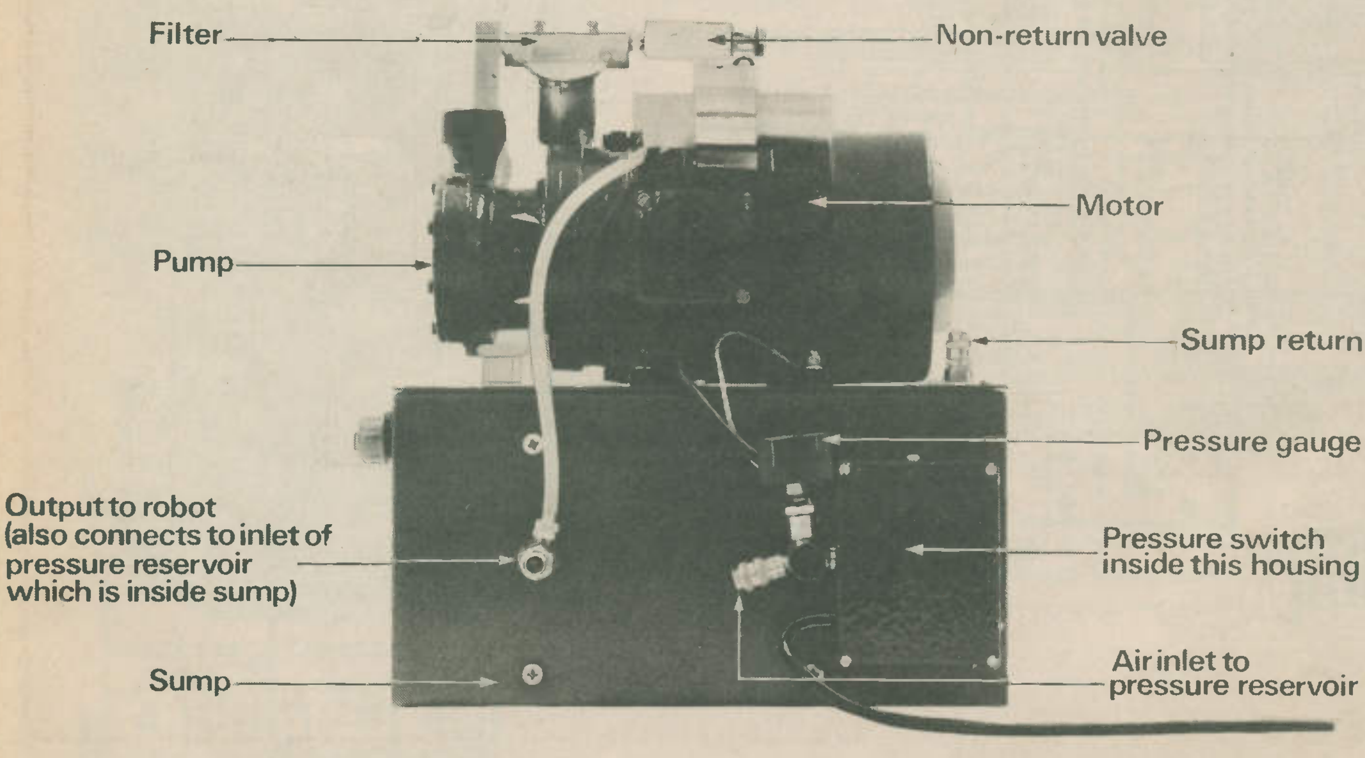


Fig. 3.7. Interface connection details



COMPONENTS . . .

NEPTUNE COMPUTER INTERFACE BOARD
refer to Fig. 2.4

Resistors

R100–102	4k7 (3 off)
R103	820

Capacitors

C100,102,120	1µ 25V tantalum (3 off)
C101,103,104–119, 122,123	47n 25V ceramic disc (20 off)
C121	15p ceramic
C124–131	3n3 polystyrene (8 off)
C132	10µ 25V tantalum

Semiconductors

IC100,101	74LS244 (2 off)
IC102,103,129	74LS138 (3 off)
IC104,105	7805 (2 off)
IC106–119	74LS374 (14 off)
IC120	AD7541
IC121	NE5534
IC122	4051B
IC123–126	TL082 (4 off)
IC127	7407
IC128	74LS02
IC130	74LS393

Miscellaneous

8-pin d.i.l. socket (5 off)	20-pin d.i.l. socket (16 off)
14-pin d.i.l. socket (3 off)	Heatsink bracket
16-pin d.i.l. socket (5 off)	

NEPTUNE COMPUTER INTERFACE BOARD
refer to Fig. 2.6

Resistors

R300,302	4k7 (2 off)
R301,303,304	330 (3 off)

Capacitors

C300–302	47n 25V ceramic disc (3 off)

Semiconductors

D300–302	Red l.e.d.
IC300,303,305	74LS04 (3 off)
IC301,304	74LS21 (2 off)
IC302	74LS153
IC306	74LS11
IC307	74LS27
IC308	74LS74
IC309	74LS20

Miscellaneous

S300	RS334–117
14-pin d.i.l. socket (9 off)	
16-pin d.i.l. socket	

NEPTUNE COMPUTER INTERFACE BOARD
refer to Fig. 2.7

Resistors

R200	47
R201,202,205–216,219	10k (15 off)
R203,221	6k8 (2 off)
R204,220	100 (2 off)
R217,224,227,230,233, 236,239,242,245	100k (9 off)
R218	47k
R222	82k
R223,226,229,232,235, 238,241,244,	1M (8 off)
R225,231	91k (2 off)
R228	75k
R234	150k
R237,240,243	180k (3 off)
R246	1k
($\frac{1}{4}$W 1% 50ppm)	

Capacitors

C200,202,204,205,208, 229,230	47n 25V ceramic disc (7 off)
C201,203,231,232	10µ 25V tantalum (4 off)
C206	27p ceramic
C207	10n polyester
C209–216	1n polyester (8 off)
C217–224	4n7 polyester (8 off)
C225–228	1µ 25V tantalum (4 off)

Semiconductors

D200,201	1N4004 (2 off)
D202–209	1N4148 (8 off)
D210,211	5V1 400mW (2 off)
IC200,201	74LS244 (2 off)
IC202	AD574
IC203	NE5534
IC204,209–212	RC4558 (5 off)
IC205,208	4051B (2 off)
IC206	7407
IC207	74LS374
IC213	7815
IC214	7915
IC215	74LS138
TR200	TIP31A
TR201	TIP32A
TR202	BC182L

Miscellaneous

VR200–207	47k preset (8 off)
CN200	10-way 0·1in MOLEX
CN201	26-way shrouded header
8-pin d.i.l. socket (6 off)	
14-pin d.i.l. socket	
16-pin d.i.l. socket (3 off)	
20-pin d.i.l. socket (3 off)	
28-pin d.i.l. socket	

PUMP MOTOR DRIVE

Refer to Fig. 3.6 and photograph.

To prevent large switching currents from reducing the life of the pressure switch a triac is used to supply current to the pump motor. With the switch closed the triac will be triggered when the mains voltage reaches about 20V, causing 20mA to flow through the gate via the 1k resistor. After triggering there is only about 1V across the triac so the resistor dissipation becomes negligible, but heat is generated in the triac and this is cooled by bolting to the aluminium switch housing box via an insulating washer. Suppression is provided by the 100 ohm/100n network.

PRINTED CIRCUIT BOARDS

Double-sided plated-through p.c.b.s are used for the computer interface board and the solenoid driver boards of which there are six for NEPTUNE I and seven for NEPTUNE II. The power supply uses a conventional single-sided board. Layouts are Figs. 3.2, 3.4, 3.5 respectively and signal directories Figs. 3.7, 3.8.

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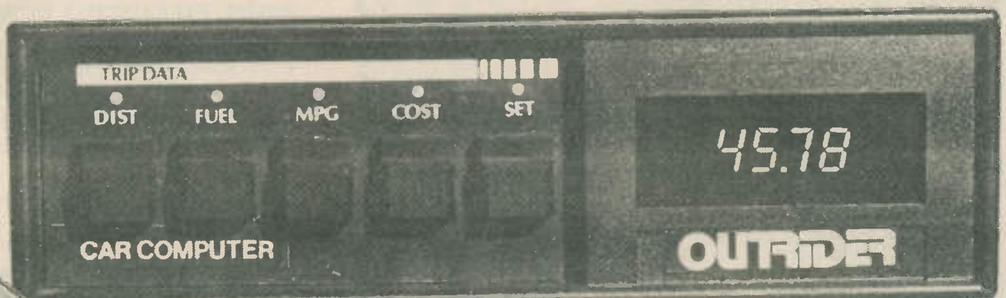

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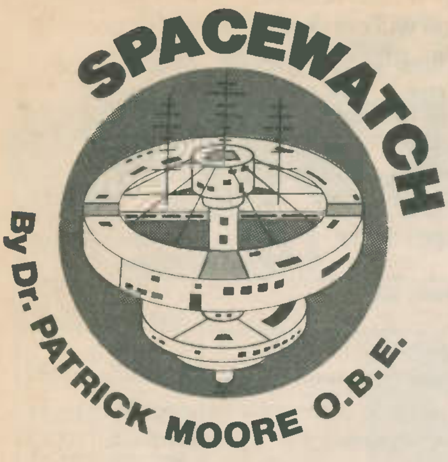


ASTRONOMERS ARE HUMAN

Astronomy is an exact science, involving measurements which are today almost unbelievably accurate. Yet mistakes can, and do, occur. I well remember the meeting of the Royal Astronomical Society in 1952, in which the German-born, American-based astronomer Walter Baade read a short paper in which he showed that there had been an error in the distance-scale of the outer galaxies, which were twice as far away as had been believed—a slight mistake of at least 100 per cent. This error was due to the fact that the measurements depended on short-period variable stars which turned out to be twice as bright as anyone had believed, and were therefore twice as remote.

A different case has just come to light, this time involving a simple but disastrous mistake in arithmetic. It concerns the mass of what is believed to be a Black Hole in the middle of a galaxy known as NGC 4151.

NGC 4151 lies in the little constellation of Canes Venatici, the Hunting Dogs, not far from the Great Bear. It is by no means conspicuous (the 39-cm reflector in my observatory can show it, but only as a dim blur), and it is around 50,000,000 light-years away.

It is what is termed a Seyfert galaxy, with a condensed centre and only weak spiral arms. Seyferts are active, and many of them are variable; it is usually thought that in the centre of such a system there is a Black Hole, formed by an old, collapsed star now pulling so strongly that not even light can escape from it.

NGC 4151 shows distinct variations, and they come from the heart of the galaxy, where the Black Hole presumably lies. It was studied by instruments on board the very successful *IUE* or International Ultra-violet Explorer satellite, and it was found that as the nucleus brightens, the effects spread out into the spiral arms of the galaxy. But there are delays; obviously the outburst reaches the nearer spiral arms first. The ultra-violet spectra of the separate arms were studied, and the times when brightenings were observed gave a clue to the distances of the various arms from the centre of the outburst.

At the Royal Greenwich Observatory, a team of eminent astronomers analyzed the results obtained from the *IUE*. The situation seemed quite clear-cut, and for the first time they were able to announce a value for the 'weight' (more accurately, the mass) of the Black Hole in NGC 4151. Things were helped by the fact that the galaxy is close as Seyferts go, and it shows well-defined features.

The results were remarkable. The Greenwich team announced that the central Black Hole must have a mass between 50 million and 100 million times that of the Sun.

AMATEURS LEAD THE WAY

The results, published in the *Monthly Notices* of the Royal Astronomical Society, caused a great deal of interest, but at this juncture two amateur astronomers came into the picture. One was R. F. Wood, a member of the British Astronomical Association—probably the world's leading observational society, with a mainly amateur membership together with a sprinkling of professionals. (Let me add that no actual qualifications are needed for membership; all that one needs is interest and enthusiasm—anyone who is interested can obtain full details from the Secretary at Burlington House in Piccadilly.) The other was a Swiss, Dr. Y. N. Chen.

Wood and Chen re-checked the calculations, and found that something was badly wrong. Their results indicated that the mass of the Black Hole had been underestimated by a factor of ten. The real value should be between 500 million to 1000 million times the mass of the Sun.

Wood passed on his comments to the British Astronomical Association, and they were relayed to Greenwich. Lesser men would have attempted a "cover up". The Greenwich team did not. They promptly and generously admitted the error. What had happened was that they had used a wrong value for the gravitational constant. It had slipped through both the authors of the paper and the various referees who had checked it.

The whole episode is, in its way, a tribute to both the Greenwich team and to the amateurs—and it stresses yet again that in astronomy, unlike most sciences, the amateur has a valuable and continuing role to play.

Can we be sure that a Black Hole is really responsible for the variations in NGC 4151, and in other Seyfert galaxies and quasars? It would be premature to claim that we are certain about it, and so high a value for the mass is undoubtedly staggering. Yet there is no doubt that the variations occur, and now that the arithmetic has been corrected the results seem positive enough. The next step must be to check with other external systems showing fluctuations of the same kind, and see whether the results are consistent.

Black Holes themselves remain enigmatical. What happens inside the 'event horizon' is extremely difficult to decide, mainly because we have no hope of obtaining any direct information. Does the old, collapsed star crush itself out of existence altogether? And is there any truth in the rather wild speculations about going into a Black Hole and emerging either in a different part of our universe, or in a different universe altogether?

Perhaps the new telescopes—the 15-metre, the Hubble Space Telescope and others will help in finding out. Meanwhile, the case of NGC 4151 has taken its place as one of the more bizarre episodes in the history of astronomy.

THE SKY THIS MONTH

During the earlier part of this year we had a splendid display of bright planets in the evening sky. However, all good things come to an end, and by now the display is more or less over for the time being. Venus, Mars, Jupiter and Saturn are all above the horizon after sunset, but all are low down and badly placed. Note, however, that Mars and Jupiter will be only 2 degrees apart on October 13. (This is four times the apparent diameter of the full moon—which, surprisingly, is not very much; the Moon looks much smaller in the sky than most people imagine.)

Jupiter is of course much brighter than Mars, as it generally is; only on rare occasions can Mars become the more brilliant of the two, and it will not happen again until 1988. Moreover Mars is fiery red, while Jupiter is yellowish, though many observers will class it as white.

Among the stars, the so-called 'Summer Triangle' of Vega in Lyra, Altair in Aquila and Deneb in Cygnus is still prominent, though Altair has become rather low in the west by late evening. (I plead guilty to bestowing the nickname of the 'Summer Triangle' on these three; I first used it in a Sky at Night *programme more than a quarter of a century ago, and it has become semi-official, though of course to Australians and South Africans it should be the 'Winter Triangle'!)*

Ursa Major, the Great Bear or Plough, is at its lowest in the north, though it remains well above the horizon. The Square of Pegasus is high in the south, and well below it you will be able to make out Fomalhaut, southernmost of the first-magnitude stars, which the IRAS infra-red satellite showed to be associated with material which may be a planetary system in the process of formation. It has now been found that many other stars are similarly associated; some of these are similar in type to the Sun.

In the east, look for the lovely glow of the Pleiades or Seven Sisters, the brightest open cluster in the sky. It is in Taurus, the Bull, the first to appear of Orion's retinue.

DISC DRIVES *Explained!*

MICHAEL TOOLEY BA **DAVID WHITFIELD** MA MSc CEng MIEE **PART 3**

THIS month we are reviewing two 5·25in. disc units from the top end of the market. In these reviews we have concentrated on the user's view of the units when used in conjunction with a BBC Micro. Both of the units reviewed this month are of the 40/80-track switchable variety, and therefore before looking at how they behave in practice, we will be looking first at the principles of switchable drives.

40/80-TRACK SWITCHABLE DRIVES

The relative arrangement of tracks on 40-track (48t.p.i.) and 80-track (96t.p.i.) drives was described in Part 1, and is shown again in Fig. 1. As we can see from the figure, the even-numbered 96t.p.i. tracks are totally positioned within the space of the wider 48t.p.i. tracks. The odd-numbered 96t.p.i. tracks, however, overlap two adjacent 48t.p.i. tracks.

If we can arrange for an 80-track drive to step two tracks each time (i.e. 1/48th of an inch), we will be able to read whatever is written on a 40-track disc using an 80-track drive. This is exactly what is possible on so-called 40/80-track switchable drives. Basically these are 80-track drives, but with additional circuitry which may be switched in to cause each head step pulse from the computer to move two 1/96 inch tracks, rather than one. Thus, as long as the computer knows that we are reading a 40-track disc, and the appropriate switch settings are used, the drive will behave as if it is a 40-track unit. This is a very useful feature, particularly since quite a lot of software is currently supplied on (cheaper) 40-track discs. It is usual for drives in a twin-drive package to be separately switchable to allow direct transfer between 40-track and 80-track discs.

The track width of the read/write head in a 40/80-track unit still corresponds to 96t.p.i., and so it is not possible to use a switchable drive to write a disc to be read on a 40-track drive. This is because the odd-numbered tracks on the 80-track format overlap two adjacent 48t.p.i. tracks. When the wanted 96t.p.i. track is read back on a 40-track drive, the read head will also pick up whatever data is on the two adjacent tracks. Unless the disc was completely clean when the tracks were written (and we should note that manufacturers usually write data onto discs during testing), this will corrupt the read data. Normally the only chance of successfully producing a 40-track disc on a switchable unit which is readable on a 40-track drive is to clean the disc first in a magnetic bulk eraser.

The switchable hardware option is often available at a modest or even no extra cost. In some cases, however, the extra cost may be as much as £20 or even £30 per drive. Before making a decision on whether to buy a switchable drive, therefore, it is worth considering an alternative method of achieving the same effect as that just described. Instead of using hardware to effect the double-stepping, the same result can be achieved in software. Whether this can be done on a particular system depends on the flexibility and facilities of the DFS in the computer. The Watford Electronics DFS for the BBC Micro, for example, provides the

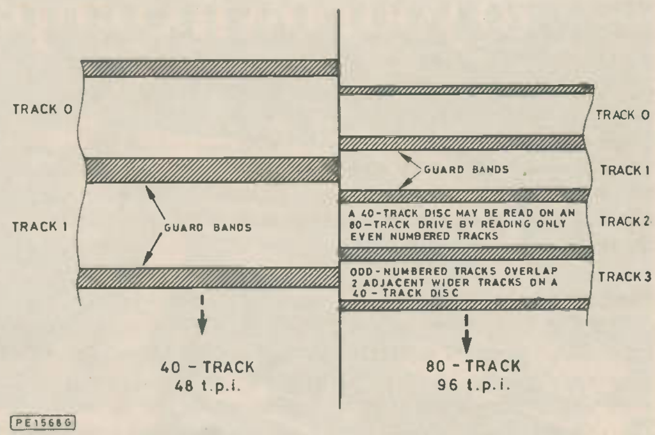


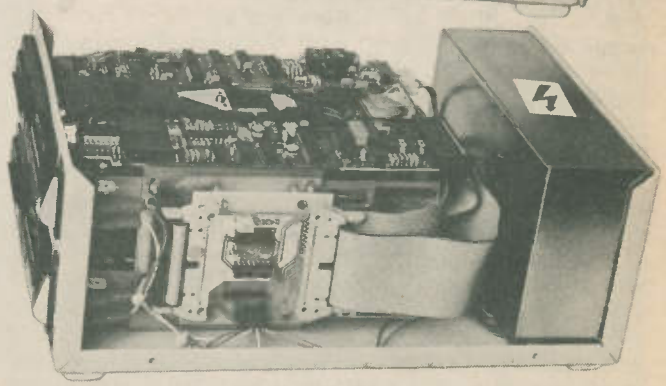
Fig. 1. Relative track arrangement for 40- and 80-track discs

double-step option as a standard facility (*FX110) which can be turned on and off for each drive separately. Alternatively, it may be possible to intercept the appropriate part of the DFS and write your own routine to produce the same result.

The final option is to build your own 40/80-track switching unit. What is required is some hardware inserted in circuit in the disc cable, positioned between the computer and the drive. The signals which must be intercepted are the step pulse and the drive select signal(s). It should be borne in mind that these are open-collector signals (see Part 2). Anyone with a suitable circuit is invited to submit it for publication in PE's *Micro-Bus*.

CUMANA CD 800/S *Reviewed*

Cumana's selection of disc drives for the BBC Micro is one of the largest on the market today. Their range stretches from a basic single 40-track single-sided drive, right up to a twin switchable 40/80-track double-sided unit with integral power supply (our review unit). Cumana were one of the first suppliers of disc drives for the BBC Micro, and probably the first to supply proper documentation. Since then, they have built up considerable experience in the floppy disc market. Their current range includes almost every combination of 40/80/switchable, single/double-sided drives, with and without power supplies. Many models are now available in the high street chain stores, and a sample has even been seen on sale recently in the stationers at London's Heathrow Airport!



Inside the Box

The Cumana CD800/S is a dual double-sided switchable drive which comes well packed in an attractively presented box measuring approximately 39 x 26 x 21cm. If you are not familiar with disc drives, be warned that disc drives are deceptively heavy items! Inside the box we find the drive unit itself, complete with an integral mains lead and 13A plug, a disc interface cable for the BBC Micro, a user manual, an 80-track utilities diskette, and a guarantee card. The unit is guaranteed for 12 months, and comes ready set up and tested. It must be said that the overall presentation leaves a very good impression. The user manual in particular is well above average, being a quality printed 72-page book which includes numerous examples, photographs and illustrations. Indeed the manual is good enough to be available separately, and indeed it is stocked by many dealers as a standard reference for users of floppy discs with the BBC Micro. The only additional items required in order to set the unit to work, assuming that the computer has a suitable disc interface and software, will be a selection of blank diskettes.

First Impressions

The first impression of the CD800/S is of a very neat unit which is attractively styled to match the BBC Micro. The two slimline drive units are horizontally mounted, and are stacked one above the other in a metal case. The upper drive is labelled 1, and the lower one is labelled 0, rather than vice versa as one might instinctively expect. If preferred, this arrangement can be altered by changing the drive selection links inside the case, a procedure which is well covered in the manual.

The unit measures approximately 20 x 12 x 32cm, and sits on four rubber feet. The disc cable is secured inside the case, and comes out through the base towards the rear. The 3-core mains cable exits through a cable clamp at the rear. Both mains and disc interface cables are approximately 1 metre long. This is a useful and generous length for the disc bus (the maximum allowed with most drives is usually only slightly longer than this), but the mains lead is rather a mean length. Actually mounted on the rear panel is an illuminated mains rocker switch and mains fuse. Ventilation slots are provided in the case on the base and sides, an arrangement which minimises the risk of foreign bodies getting inside.

On the front panel, each drive is provided with an l.e.d. select indicator to show when it is being accessed by the computer. On the right of the front panel are two switches to control the 40/80-track selection of the drives. The two drives are clearly labelled with their drive identities.

Setting Up

Setting the unit to work is simply a matter of connecting the disc interface cable to the computer, and connecting the unit to the main supply, or is it? The first problem, paradoxically, is that the manual is rather *too* detailed and thorough to answer this question quickly. What is really needed at this stage is a simple set of instructions telling us what to do with the unit we have. In practice, the procedure *is* as simple as the one just suggested. However, the manual is written to cover the whole Cumana range, and so it contains a lot of detail which does not apply to the unit you have. What would be helpful at this stage would be a summary (a single insert sheet would suffice), giving specification and setting up procedure for the drives in a particular unit. This would avoid the need, for example, to remove the unit's cover to be certain that the drive units in the CD800/S are in fact from Mitsubishi. Cumana's own product data sheet actually appears to be quite suitable in this respect, but unfortunately it is not included with the unit.

Table 1. Mitsubishi M4853 Specification

Track density	96t.p.i.
Recording method	FM or MFM
Track-to-track seek time	3msec
Settling time	15msec
Head load time	50msec
Motor start time	250msec
Weight	1·5kg
Power supply +12V	1·3A (av)
Power supply +5V	0·5A (av)
Rotational speed	300r.p.m.

As we have said, the Cumana units come ready tested and set up, so setting them to work is quick and easy. The final step in setting up (unfortunately not covered by the manual) is to tell the BBC Micro how fast the drives are capable of being driven. This is done by setting links inside the micro to define the head load time (0 to 16msec), head settling time (16 to 50msec) and the step time (4 to 24msec). By default, the links are unmade, corresponding to settings of 16msec, 20msec and 24msec, respectively. These settings are 'play-safe', and are suitable for all modern drives. By setting up the system to match the drives' capabilities, however, we can obtain the maximum access speed. Table 1 shows that the Mitsubishi drives can be used at maximum speed (links 3 and 4 made), giving a dramatic performance improvement in disc access speed when compared with the default settings.

The manual contains a detailed and interesting discussion of the internal link settings for the drive units themselves. This includes close-up photographs, and is one of the clearest discussions we have seen of the trade-offs which can be made in setting up a disc drive.

Getting Started

At this stage the guidance provided by the manual is excellent. We are taken step by step through the switch on, start up, booting and disc formatting procedures. Subsequent chapters clearly explain the workings of Acorn's disc filing system (DFS) for the BBC Micro. Indeed, so thorough is the coverage that the user will probably not need to refer to the DFS manual provided with the disc interface to be able to get started with his newly-expanded system. Every stage is illustrated by examples, and the possible causes of common errors are explained.

The utilities disc contains programs for formatting 40-track and 80-track discs, and a disc verifier. These, usually quite standard items, are worthy of note, since they are really quite interesting to run. Initially, 40 or 80 numbered blank vertical bars are displayed, arranged as a triangular pattern with each bar shorter than its predecessor. These bars represent the tracks to be formatted, and they are filled in as formatting proceeds. Each successfully formatted and verified track is coloured green, and an audible bleep is produced. As formatting progresses, the pitch of the bleep rises. If the formatter makes any re-tries when verifying a track, noise is mixed in with the bleep, and the track is coloured yellow on the display; such a disc should be considered to be possibly unreliable. A track which fails verification after ten re-tries is deemed to have a hard error, and the track is coloured red; such a disc should be discarded.

At the end of successfully formatting a disc, the program plays the first two bars of Beethoven's Fifth Symphony, or, if the formatting fails, the Funeral March is played instead! Trying to format an already formatted disc produces a warning, whereas trying to format a write-protected disc produces the Funeral March. All-in-all the formatters are well thought out programs, interestingly implemented. After formatting, each side of an 80-track disc is capable of storing 200 Kbytes using the standard single density disc interface, giving the unit an overall capacity of 800 Kbytes. With double-density recording, the capacity is increased to 1·6 Mbytes.

If, at any time, you wish to verify a disc (i.e. re-calculate the checksums and compare them with the ones stored on the disc), a verifier program written in Basic is provided. This is a useful utility not provided by the standard DFS (although it is built into the Watford DFS, together with the formatters and other extra facilities), and it displays the track numbers as they are verified.

In Use

Discs are loaded into the drives by sliding them in through the slot (label upwards) until they latch in place; this is most easily done by pushing them with a thumb or forefinger. The top flap of the door mechanism is then pressed down to lock the disc in place. The drives are designed so that the rotational motor is turned on whenever a disc is inserted, and stays on until the door flap is closed; this assists in correctly locating the disc on the hub. To remove a disc from the drive, the bottom part of the door flap is depressed. This trips the disc eject mechanism, which releases the disc and pushes it out by approximately 4cm. This is very convenient to use, and it makes changing discs a simple operation.

In use, the stepping motor can be quite noisy, particularly when moving across the full disc surface. The rotational motor, on the other hand, is very quiet. The rear of the unit (which is where the fully shielded power supply is located) becomes warm to the touch, but there is no significant temperature rise, even after prolonged heavy use.

The 40/80-track facility works well in practice. As mentioned earlier, this is primarily a read-only facility, which is usually used for loading software supplied on 40-track discs onto 80-track working discs. Tests show that we can create discs on 40-track drives, and read them back without trouble on the CD800/S, set in 40-track mode. The 40/80-track hardware and software switching techniques were compared using the software switch provided by the Watford DFS, and found to be quite compatible. Whether the extra cost of the hardware switching is justified probably depends on whether you already have an equivalent software facility, and how often you wish to use 40-track discs.

In six months of extended use, the CD800/S has given no trouble at all, despite being very heavily used. Not a single disc error has been observed, and this augurs well for the long-term reliability of the drives.

Verdict

Once you have discs, the thought of ever going back to cassette tapes seems like a return to the Dark Ages. The Cumana CD800/S represents an ideal complete package for the computer owner looking to move out of the Dark Ages for good. Although the unit is primarily aimed at the BBC Micro, it is also suitable for connection to many other computers by simply changing the disc interface connector. The standard of manufacture and presentation is good, the unit works well, and the manual is the best seen, although a few more details on the Mitsubishi drives would be welcome. In operation the unit is reliable and fuss free, and it represents an ideal way of upgrading to floppy discs. A package to be recommended.

The CD800/S costs £499 plus VAT, and is available from a number of advertisers in *PE*. Further information is available from **Cumana Ltd., Unit 1, The Pines Trading Estate, Broad Street, Guildford, Surrey, GU3 3BH; Tel: 0483-503121.**

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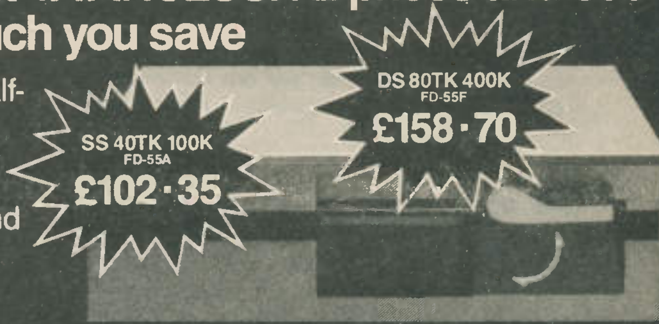

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MAIL ORDER MICROS *Reviewed*

The Mail Order Micros dual disc unit is similar in specification to the Cumana CD800/S, being a dual double-sided switchable drive unit with integral power supply. Many of the same general observations made above apply equally to both the Cumana and the MOM unit, and our comments in the main concentrate on those features which differ in some respect from the Cumana unit.

Inside the Box

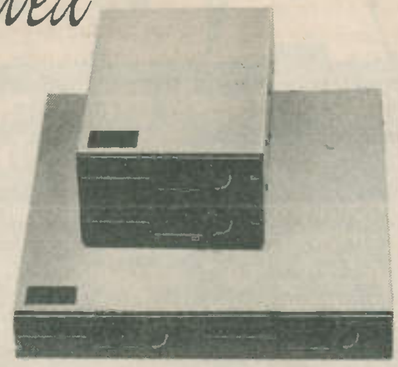
Looking inside the double-box package we find the drive unit, complete with mains cable (but no plug), a disc interface cable fitted with connectors for the drive and the BBC Micro, a manual, an installation instruction summary sheet, and an 80-track utilities disc. The unit comes ready set up, and is guaranteed for 12 months. The 18-page user manual covers both 5·25in. and 3in. units, and contains sufficient information to get started without recourse to the DFS manual. As with the Cumana unit, the only real additional items required to get started (other than a mains plug) are blank diskettes; the summary sheet gives some useful recommendations for the selection of suitable types.

First Impressions

The first impression is of an extremely neat and compact unit, attractively styled to match the BBC Micro. Overall the unit is slightly smaller (18cm wide, 33cm deep and 12cm high) and appears to have cleaner lines than the Cumana unit. This is due in part to the fact that the 40/80-track selector switches are mounted on the rear panel rather than on the front, and in part to the fact that the Teac drives have a less 'fussy' appearance than the Mitsubishi drives. The two slimline Teac FD-55F drive units are horizontally mounted, and stacked one above the other in a metal case. The upper drive is conventionally set up as drive 0, and the lower one is drive 1, although on the review unit they were not actually labelled on the front panel. This arrangement can be changed if necessary, but the manual does not actually contain any details of the link settings for the Teac drives (although this information can actually be found in the Cumana manual!).

The disc interface cable is detachable at both ends, which is a useful feature, and connects to the drive unit via a D-type connector on the rear panel. The cable is a good length at approximately 1 metre, but the 3-core mains lead is much too short at just under 1 metre long. The mains lead is well secured on the rear panel with a cable clamp. Also on the rear panel are the 40/80-track slide-type selector switches (one above the other in the same order as the drives), mains fuse, and illuminated mains switch. Placing the 40/80-track switches on the rear panel certainly gives a neater unit, and minimises the possibility of accidentally changing the setting. If you intend to use the facility a lot, however, your system layout will have to give easy access to these switches.

Small ventilation slots are provided high up on the sides of the case at the rear. These are arranged to minimise the risk of foreign bodies falling into the case and, in view of the very low power dissipation of the Teac drives, are more than adequate. On the front panel each drive is provided with an oblong red l.e.d. to indicate when the drive is selected.



Setting Up

The single sheet summary which is supplied with the unit simplifies setting up quite considerably. The process is simply a matter of fitting a suitable mains plug, and connecting the disc interface cable to the connector on the rear of the case and to the BBC Micro. As with the Cumana unit, however, no technical details concerning the drive performance is provided. The FD-55F drives can, however, be used at maximum speed by the BBC Micro; Table 2 summarises the technical specifications for the FD-55F.

Getting Started

The manual takes us through the basic steps in getting started, formatting and verifying discs. There is then a useful discussion of disc care and storage, write protecting discs, and saving and loading programs. This is followed by a description of the commands which are provided in the standard Acorn DFS. This description is well illustrated with examples, and gives warnings of the consequences of use of various commands. There is a brief introduction to the use of random access files, followed by an explanation of the DFS error messages. Finally an appendix describes how to run cassette-based programs when the disc system is installed.

The 80-track utilities disc contains three programs: a formatter, a verifier and a cassette-to-disc transfer utility. The formatter offers the choice of 35, 40 or 80 tracks on the disc, and the instructions on the screen are reproduced in the manual. At the end of the formatting process, the program displays a count of formatting and verifying errors (hopefully both zero!). As each track is formatted, its number is displayed in a table, and if any errors occur, the affected track is identified by a question mark. Once formatted, and in common with the Cumana unit, each BBC-format 80-track

Table 2. Teac FD-55F Specification

Track density	96t.p.i.
Recording method	FM or MFM
Track-to-track seek time	3msec
Settling time	15msec
Motor start time	400msec
Weight	1·5kg
Power supply +12V	0·25A (av)
Power supply +5V	0·38A (av)
Power consumption	4·9W operating
Power consumption	1·6W standby
Rotational speed	300r.p.m.

disc has a capacity of 400 Kbytes. The verifier program allows us to check for errors on a formatted disc at any time. The program automatically detects whether a 40-track or 80-track disc is present, and reports the number of verify errors detected.

The memory move program is a useful addition which allows a cassette program to be loaded even with the disc interface fitted. This works by loading the program from tape in the normal way (having turned on the cassette filing system first with *TAPE), turning off the DFS, and then moving it down in memory to its correct position.

In Use

This disc loading mechanism on the Teac drives is elegantly simple, easy to use, and effective. The discs are loaded by sliding them in through the slot (label upwards) as far as they will go. This starts the rotational motor to assist the next step. The locking handle is turned down through 90 degrees, until it latches, to engage the disc on the hub. The lever has a wedge arrangement on the rear to gently push in the disc if it has not been correctly seated. When loaded, the lever physically prevents the disc being removed while the heads are loaded. Disc removal is a matter of releasing the lever, which is spring loaded to the open position. The disc itself is not ejected, but it is accessible due to the recessed design of the drive front panel. On balance, the disc loading is easier on the Teac drives, but disc removal is easier on the Mitsubishi drives.

In use, the drives are pleasantly quiet. The rotational motor is slightly noisier than the one in the Cumana unit, but is still quiet. On the other hand, the stepping motors and head load solenoids on the MOM unit are much quieter in operation. The unit runs very cool in operation due to the low power dissipation of the Teac drives. The 40/80-track switching facility works well, and is compatible with discs produced on 40-track drives, and with the software switching alternative provided by the Watford Electronics DFS.

Verdict

After extended use, the MOM unit has proved to be trouble-free. On balance it is slightly smaller and quieter in operation than the Cumana unit, but there is not much to choose between the two. The documentation is good but, in common with the Cumana unit, lacks a few technical details relating to the drives themselves. The unit is more than suitable for the computer owner looking for a complete disc package to complete his system upgrade, and is to be recommended.

The MOM dual disc unit costs £387·55 plus VAT. Further information is available from **Mail Order Micros, 2a, Green Street, Sandbach, Cheshire, CW11 9AX; Tel: 0782-811711.**

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URGENTLY required circuit diagram of Heathkit oscilloscope (0=12u) will return promptly. Send to: Mr. L. Young, 23 Grangefields Road, Jacobs Well, Guildford, Surrey GU4 7NR.

IF anybody wants to give me £2, I will give them a 8·867237MHz crystal in return. Mr. P. Rattray, 20 Upplin Terrace, Kinnoull, Perth PH2 7DG.

WANTED for rebuild any Bang and Olufsen 2000K reel to reels. Paul Vernon, Greenbanks, Cliddesden, Nr. Basingstoke, Hants. RG25 2JL. Tel: Basingstoke 25625 (evenings).

DKTRONICS light pen and software £15. Various stereo headphones each £5. All plus postage. Ralph Lovelock, 14 Knightley Road, Exeter EX2 4SR. Tel: Exeter 75892.

ANOTHER! UK101 8K Cegmon incl. recorder software PSG speech A–D, D–A. Make a silly offer. Dick Davies, 13 Harold Road, London SE19 3PU. Tel: 01-653 4753.

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TELEQUIPMENT oscilloscopes D52 double beam £50, 551 single beam £30. Circuits available. Buyer collects. D. K. R. Russell, 9 South Beach Road, Ardrossan, Ayrshire. Tel: 0294 64144.

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Computer DFM Adaptor

R.A.PENFOLD

. . . Use a little known feature of these machines to turn your micro into an audio frequency meter. It'll take less hardware than you think, and although we've provided software, this can be extended to create a customised 'smart' test instrument.

THE VIC-20, Commodore 64, and BBC model B computers are popular with electronics enthusiasts as all three machines have a user port which gives 8 in/out lines plus handshake lines. A feature of all three machines which is less well known and seemingly little understood is the two 16 bit counter/timers. These can be used in a variety of ways, but the two of most interest are using a counter to act as a divider to give an output at some fraction of the system clock frequency, and using one of them to count pulses from an external circuit.

In this project both these modes of operation are utilised, with one counter providing the clock signal used to generate the gate pulse, and the other being used to count the input pulses. Together with some simple external logic and signal interfacing circuitry this gives a useful d.f.m. for audio frequency use, with three measuring ranges. These have full scale values of 6553·5Hz, 65·535kHz and 655·35kHz, with minimum resolutions of 0·1Hz, 1Hz and 10Hz respectively. A minimum input level of about 15 to 20 millivolts r.m.s. is needed, and the input impedance of the circuit is quite high at about 300k. The software includes a warning routine which indicates an overload if the input frequency is too high for the range in use, and this helps to prevent misleading readings.

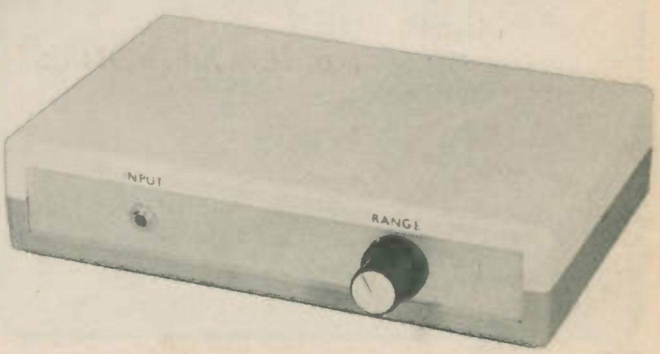
SYSTEM OPERATIONS

Fig. 1 shows in block diagram form the system used in this frequency meter. The input signal is first taken to a buffer amplifier which gives the circuit a high input impedance. This is followed by a voltage amplifier which gives the unit good sensitivity, and then a Schmitt trigger is used to convert the signal to standard five volt logic levels. This circuit also helps to avoid inaccurate readings due to noise on the input signal. The signal is then applied to a gate which, depending on the range in use, is opened for 10 seconds, 1 second, or 0·1 seconds. A 16 bit counter (within the computer) registers the number of pulses let through the gate. If, for example, a one second gate period is used, and 5000 pulses are received by the counter, then the input frequency is obviously 5000Hz or 5kHz. When the other two ranges are in use it is simply a matter of multiplying or dividing by ten the number of pulses received by the counter in order to obtain an answer in Hertz, and this is easily accomplished using software. In fact, on the highest range the answer is converted to kilohertz, which is again easily accomplished using a software routine.

The clock oscillator is the system clock of the computer, and the frequency of this depends on the computer used. This is 1·1082MHz for the VIC-20, 980kHz for the Commodore 64, and 1MHz for the BBC model B. The divide by n counter is the second 16 bit timer/counter of the computer, and it can divide by any integer from 2 to 131070 (double the number written to the counter in other words). In this case the counter is used to divide the system clock to give an output frequency of 50Hz, and this is then divided by a series of external divide-by-ten circuits to give additional frequencies of 5Hz, 0·5Hz, and 0·05Hz. A switch is used to select one of these three signals and connect it through to the control input of the gate.

In operation and with, for example, a 0·5Hz gate signal selected, the gate is continuously switched on for one second while the gate signal is high, off for one second while it is low, then on again for a second, and so on. The gate signal is applied to a digital input of the computer, and this enables the computer to synchronise its operations with those of the external circuit. Basically, what happens is that the counter is loaded with a value of 65535 while the gate is disabled. When the gate is enabled the counter counts downwards, and nothing else happens during this period. At the end of the gate time the control signal goes from the high state to the low one, and this is detected by the computer which then reads the counter, and converts the

CALLING OWNERS OF... VIC 20, BBC, COMMODORE 64



reading into Hertz or kilohertz. The fact that the counter counts downwards is only a minor inconvenience, and deducting the counter reading from 65535 effectively gives the required upwards count. Next the counter is reloaded to 65535 so that it is ready to start another count when the gate signal goes high again. This gives one reading every 20 seconds on *range 1,* one every two seconds on *range 2,* and 5 per second on *range 3* (although on this range the limited speed of the computer may result in only every other reading being processed and displayed).

If the counter reaches zero it returns to 65535 on the next pulse and then starts counting down again. However, a bit of the interrupt register in the interface device of the user port is set high when the count reaches zero, and by monitoring this the software can give an overload warning and suppress incorrect readings.

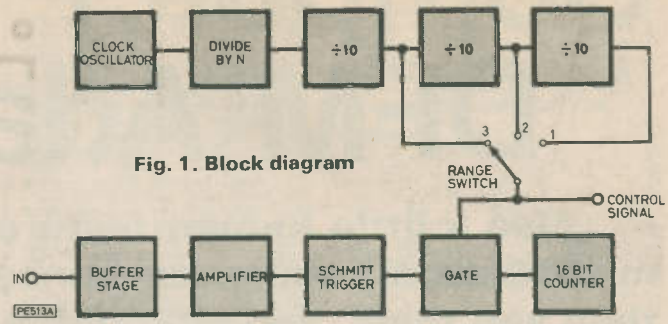


Fig. 1. Block diagram

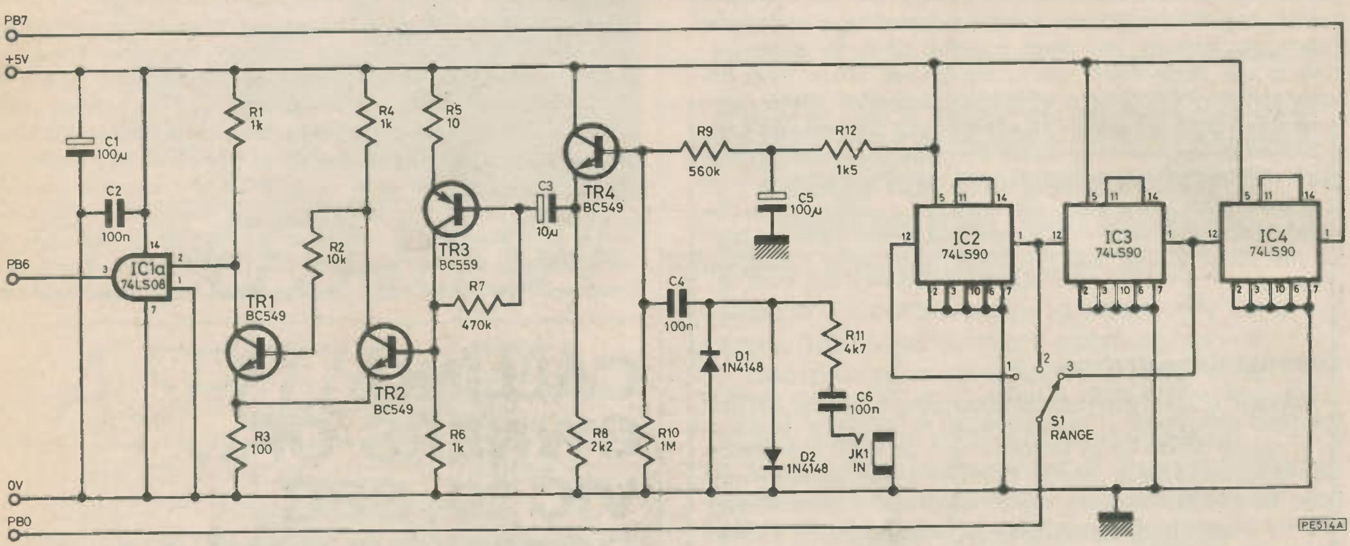
THE CIRCUIT

The full circuit diagram of the frequency meter adaptor appears in Fig. 2. Components R11, D1 and D2 form a simple bipolar clipping circuit which protects the input stage against excessive input signal levels. TR4 is an emitter follower buffer stage, and a filter circuit (R12 plus C5) is included in the bias circuit to prevent noise on the supply lines from being coupled into the input of the circuit. C3 couples the output of TR4 to the base of TR3, and this device is used as the basis of a high gain common emitter amplifier. The output of TR3 is direct coupled to a standard two transistor Schmitt trigger which uses TR1 and TR2.

The gate is one section of a 74LS08 quad 2-input AND gate. Only one of the four gates are needed here, and the other three are simply ignored. An AND gate gives the required action with a low signal at one input preventing a signal applied to the other input from reaching the output, but a high control signal enables a signal applied to the other input to pass through to the output.

IC2 to IC4 are the divide-by-ten circuits, and these are the familiar 74LS90 decade counters. Range switch S1 selects the output from one of these devices and couples it through to the signal gate.

Fig. 2. Full circuit diagram



All three computers have a 5 volt output available at the user port, and this is used to power the circuit.

SPECIFICATION

Full scale ranges:	6553·5Hz 65·535kHz 655·35kHz
Min. resolution:	0·1Hz 1·0Hz 10Hz respectively
Input sensitivity:	20mV r.m.s.
Input impedance:	300k

Software "out of frequency range" warning

CONSTRUCTION

Fig. 4 gives details of the printed circuit board and wiring of the unit. Construction of the board is perfectly straighforward and there should be no problems here. Fit Veropins at the points where off-board connections will eventually be made.

A plastic case having metal front and rear panels, and approximate outside dimensions of 180 by 120 by 40 millimetres is used on the prototype. This is larger than is absolutely necessary though, and the unit could be fitted into a substantially smaller case if desired. Range switch S1 and input socket SK1 are mounted on the front panel. SK1 does

COMPONENTS . . .

Resistors

R1,4,6	1k (3 off)
R2	10k
R3	100
R5	10
R7	470k
R8	2k2
R9	560k
R10	1M
R11	4k7
R12	1k5

All resistors ¼W 5% carbon film

Capacitors

C1	100µ 10V radial elect
C2	100n ceramic
C3	10µ 25V radial elect
C4,6	100n polyester (2 off)
C5	100µ 10V axial elect

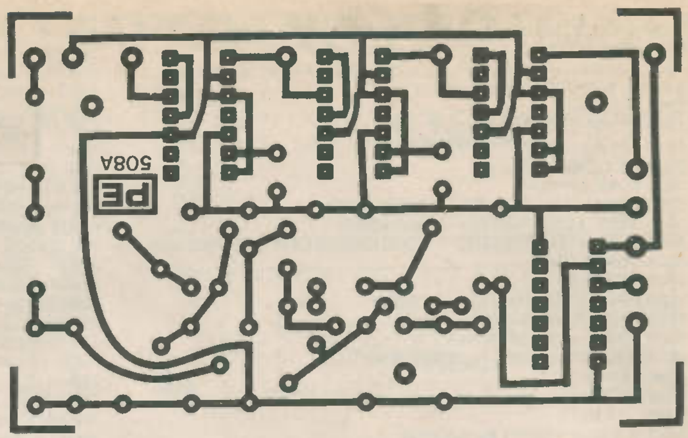
Semiconductors

IC1	74LS08
IC2,3,4	74LS90 (3 off)
D1,2	1N4148 (2 off)
TR1,2,4	BC549 (3 off)
TR3	BC559

Miscellaneous

S1	4 pole 3 way rotary switch
SK1	3·5mm jack socket

Case about 180 × 120 × 40mm
Printed circuit board
Control knob
Computer connector and ribbon cable
Veropins, wire, solder, etc.



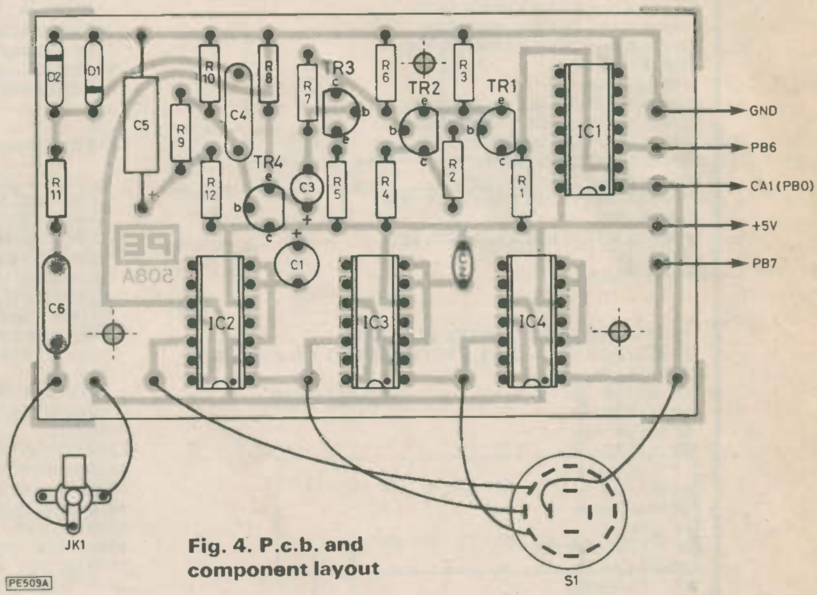
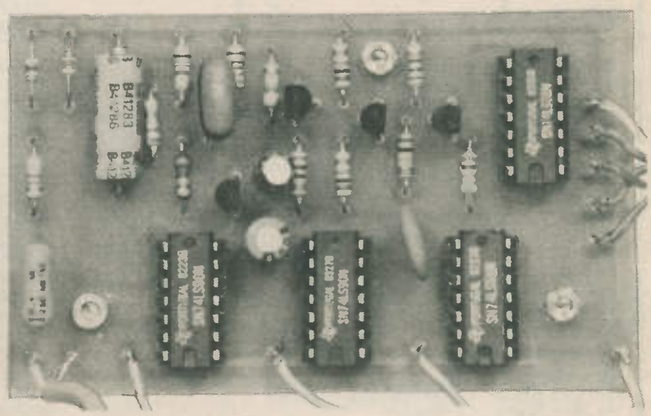


Fig. 4. P.c.b. and component layout

PE509A



SOFTWARE

```
1 REM# # # # # # # # # #
10 REM COMMODORE-64 FREQUENCY METER
20 REM J.W.P. 2/84
30 POKE 56582,72
40 POKE 56583,38
50 POKE 56591,23
60 DEF FNV(C)=65535-(PEEK(56580)+256*PEEK(56581))
70 GOSUB 1000
80 GOSUB 2000
90 R=133
100 GOSUB 3000
110 GOTO 100
120 END
1000 FOR BYTE =2054 TO 2062
1010 READ D
1020 POKE BYTE,D
1030 NEXT BYTE
1040 RETURN
1050 DATA 166,87,164,88,24,32,240,255,96
2000 PRINT"":REM SHIFT/CLR
2010 POKE 87,3:POKE 88,14:SYS 2054:PRINT"FREQUENCY
METER"
```

```
2Ø2Ø POKE 87,5:POKE 88,15:SYS 2Ø54:PRINT"RANGE"
2Ø3Ø POKE 87,12:POKE 88,27:SYS 2Ø54:PRINT"HZ"
2Ø4Ø POKE 87,22:POKE 88,4:SYS 2Ø54:PRINT"CHANGE RANGE WITH FUNCTION KEYS"
2Ø5Ø RETURN
3ØØØ IF (PEEK(56577)AND1)=1 THEN 3ØØØ
3Ø1Ø POKE 5658Ø,255
3Ø2Ø POKE 56581,255
3Ø3Ø POKE 5659Ø,49
3Ø4Ø IF (PEEK(56577)AND1)=Ø THEN 3Ø4Ø
3Ø5Ø IF(PEEK(56577)AND1)=1 THEN 3Ø5Ø
3Ø6Ø IF(PEEK(56589)AND1)=1 THEN GOSUB 4ØØØ:RETURN
3Ø7Ø GOSUB 5ØØØ
3Ø8Ø RETURN
4ØØØ POKE 87,12:POKE 88,17:SYS2Ø54:
4Ø1Ø PRINT"OVERLOAD"
4Ø2Ø FOR W=1 TO 1ØØØ:NEXT W
4Ø3Ø POKE 87,12:POKE 88,17:SYS2Ø54:
4Ø4Ø PRINT"
4Ø5Ø RETURN
5ØØØ GET R$
5Ø1Ø IF R$<>"" THEN R=ASC(R$)
5Ø2Ø IF R>132 AND R<136 THEN RA=R-132
5Ø3Ø IF RA=1 THEN V=FNV(Ø)/1Ø
5Ø4Ø IF RA=2 THEN V=FNV(Ø)
5Ø5Ø IF RA=3 THEN V=FNV(Ø)/1ØØ
5Ø6Ø GOSUB 6ØØØ
5Ø7Ø RETURN
6ØØØ POKE 87,5:POKE 88,22:SYS 2Ø54:PRINT RA
6Ø1Ø POKE 87,12:POKE 88,26:SYS 2Ø54
6Ø2Ø IF RA=1 THEN PRINT" "
6Ø3Ø IF RA=2 THEN PRINT" "
6Ø4Ø IF RA=3 THEN PRINT"K"
6Ø5Ø POKE 87,12:POKE 88,17:SYS 2Ø54
6Ø6Ø PRINT"
6Ø7Ø POKE 87,12:POKE 88,17:SYS 2Ø54
6Ø8Ø PRINT V
6Ø9Ø RETURN
```

```
1Ø REM FREQUENCY METER PROGRAM
2Ø REM FOR BBC MODEL B WITHOUT 2ND. PROCESSOR
3Ø REM J.W.P. 2/84
4Ø ?&FE6B=224
5Ø ?&FE64=16
6Ø ?&FE65=39
7Ø ?&FE62=128
8Ø *FX225,16Ø
9Ø *FX11,Ø
1ØØ PROCscreen
11Ø r=161
12Ø VDU23,1,Ø;Ø;Ø;Ø;
13Ø REPEAT
14Ø    PROCread
15Ø    UNTIL FALSE
16Ø END
17Ø DEF PROCdouble(X,Y,TEXT$)
18Ø VDU 31,X-1,Y
19Ø PRINT CHR$141;TEXT$
2ØØ VDU 31,X-1,Y+1
21Ø PRINT CHR$141;TEXT$
22ØENDPROC
23Ø
24Ø
25Ø DEF PROCscreen
26Ø CLS
27Ø FOR Y=Ø TO 6
28Ø    PRINTTAB(Ø,Y);CHR$132;CHR$157;CHR$131
29Ø    NEXT Y
3ØØ FOR Y=7 TO18
31Ø    PRINTTAB(Ø,Y);CHR$135;CHR$157;CHR$129
32Ø    NEXT Y
33Ø FOR Y=19 TO 23
34Ø    PRINTTAB(Ø,Y);CHR$132;CHR$157;CHR$131
35Ø    NEXT Y
36Ø PROCdouble(14,2,"FREQUENCY METER")
37Ø PROCdouble(15,4,"Range")
38Ø PROCdouble(27,11,"HZ")
39Ø PRINTTAB(5,2Ø);"Change range with function keys."
4ØØ ENDPROC
41Ø
42Ø
43Ø DEF PROCread
44Ø REPEAT UNTIL (?&FE6Ø AND 1)=Ø
45Ø ?&FE68=255
46Ø ?&FE69=255
47Ø REPEAT UNTIL(?&FE6Ø AND 1)
48Ø REPEAT UNTIL (?&FE6Ø AND 1)=Ø
49Ø IF(?&FE6D AND 32)=32 THEN PROCoverload:ENDPROC
5ØØ ?&71=?&FE68:?&72=?&FE69
51Ø PROCrange
52Ø ENDPROC
53Ø
54Ø
55Ø DEF PROCoverload
56Ø PROCdouble(17,11,"OVERLOAD")
57Ø T=TIME:REPEAT UNTIL TIME=T+1ØØ
58Ø PROCdouble(17,11,"         ")
59Ø ENDPROC
6ØØ
61Ø
62Ø DEF PROCrange
63Ø range$=INKEY$(1Ø)
64Ø IF range$<>"" r=ASC(range$)
65Ø IF r>16Ø AND r<164 range=r-16Ø
66Ø IF range=1 reading=FNread/1Ø:@%=&1Ø2Ø1ØA
67Ø IF range=2 reading=FNread:@%=&9ØA
68Ø IF range=3 reading=FNread/1ØØ:@%=&1Ø2Ø2ØA
69Ø PROCprint
7ØØ ENDPROC
71Ø
72Ø
73Ø DEF PROCprint
74Ø PROCdouble(22,4,LEFT$(STR$(range),1))
75Ø IF range=1 symbol$=" "
76Ø IF range=2 symbol$=" "
77Ø IF range=3 symbol$="K"
78Ø PROCdouble(26,11,symbol$)
79Ø PROCdouble(17,11,"         ")
8ØØ PROCdouble(17,11,STR$(reading))
81Ø ENDPROC
82Ø
83Ø
84Ø DEF FNread=65535-(?&71+256*?&72)
```

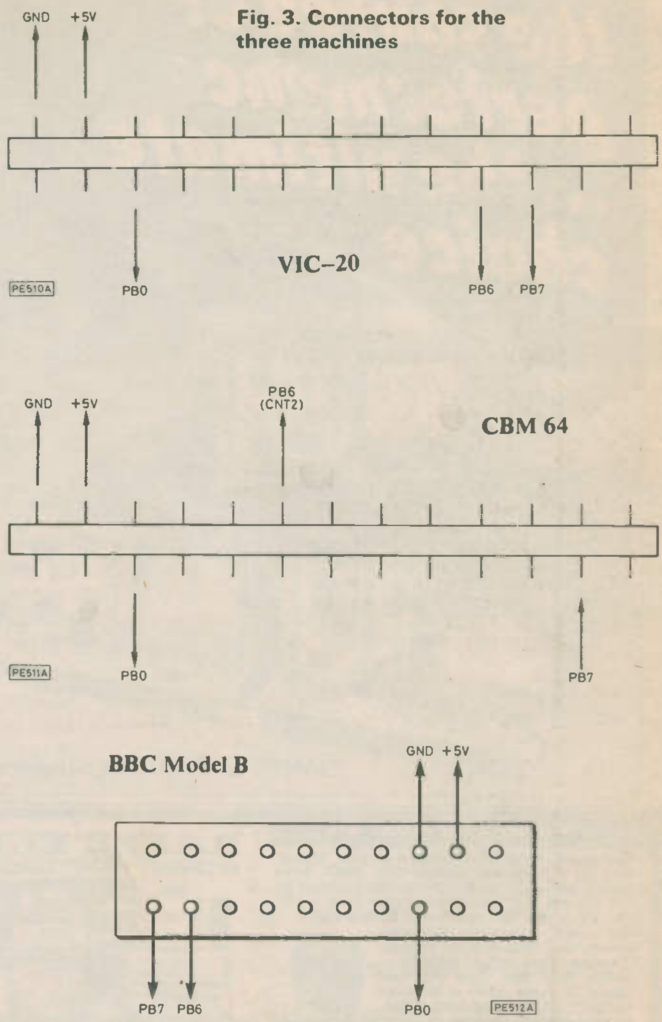
```
1 REM# # # # # # # # # #
5 REM VIC FREQUENCY
7 REM METER 2-84
1Ø POKE 37147,224
2Ø POKE 3714Ø,75
3Ø POKE 37141,44
4Ø POKE 37138,128
55 DEF FNV(C)=65535-(PEEK(37144)+256*PEEK(37145))
6Ø GOSUB 1ØØØ
7Ø GOSUB 2ØØØ
75 R=133
8Ø GOSUB 3ØØØ
9Ø GOTO 8Ø
1ØØ END
1ØØØ FOR BYTE=41Ø2 TO 411Ø
1Ø1Ø READ D
1Ø2Ø POKE BYTE,D
1Ø3Ø NEXT BYTE
1Ø4Ø RETURN
1Ø5Ø DATA 166,87,164,88,24,32,24Ø,255,96
2ØØØ PRINT"":REM SHIFT/CLR
2Ø1Ø POKE 87,2:POKE 88,4:SYS 41Ø2:PRINT"FREQUENCY METER"
2Ø2Ø POKE 87,4:POKE 88,5:SYS 41Ø2:PRINT"RANGE"
2Ø3Ø POKE 87,11:POKE 88,17:SYS 41Ø2:PRINT"HZ"
2Ø4Ø POKE 87,2Ø:POKE 88,2:SYS 41Ø2:PRINT"CHANGE RANGE WITH"
2Ø5Ø PRINTTAB(2)"FUNCTION KEYS."
2Ø6Ø RETURN
3ØØØ IF (PEEK(37136)AND1)=1 THEN 3ØØØ
3ØØ5 POKE 37144,255
3Ø1Ø POKE 37145,255
3Ø2Ø IF(PEEK(37136)AND1)=Ø THEN 3Ø2Ø
3Ø3Ø IF (PEEK(37136)AND1)=1 THEN 3Ø3Ø
3Ø4Ø IF(PEEK(37149)AND32)=32 THEN GOSUB 4ØØØ:RETURN
3Ø5Ø GOSUB 5ØØØ
3Ø6Ø RETURN
4ØØØ POKE 87,11:POKE 88,7:SYS 41Ø2
4Ø1Ø PRINT"OVERLOAD"
4Ø2Ø FOR D=1 TO 1ØØØ:NEXT D
4Ø3Ø POKE 87,11:POKE 88,7:SYS 41Ø2
4Ø4Ø PRINT"         "
4Ø5Ø RETURN
5ØØØ GET R$
5Ø1Ø IF R$<>"" THEN R=ASC(R$)
5Ø2Ø IF R>132 AND R<136 THEN RA=R-132
5Ø3Ø IF RA=1 THEN V=FNV(Ø)/1Ø
5Ø4Ø IF RA=2 THEN V=FNV(Ø)
5Ø5Ø IF RA=3 THEN V=FNV(Ø)/1ØØ
5Ø8Ø GOSUB 6ØØØ
5Ø9Ø RETURN
6ØØØ POKE 87,4:POKE 88,12:SYS 41Ø2:PRINT RA
6Ø1Ø POKE87,11:POKE 88,16:SYS 41Ø2
6Ø15 IF RA=1 THEN PRINT" "
6Ø2Ø IF RA=2 THEN PRINT" "
6Ø3Ø IF RA=3 THEN PRINT"K"
6Ø4Ø POKE 87,11:POKE 88,7:SYS 41Ø2
6Ø5Ø PRINT"
6Ø6Ø POKE 87,11:POKE 88,7:SYS 41Ø2
6Ø7Ø PRINT V
6Ø8Ø RETURN
```

not have to be a 3·5mm jack type, and any two-way audio or RF connector can, of course, be used here. The printed circuit is mounted on the base panel of the case using M3 or 6BA fixings, and the point to point wiring is then added.

The unit is connected to the computer via a piece of five way ribbon cable about 0·5 to 1 metre long, and an exit hole for this is drilled in the rear panel of the case. For the VIC-20 and Commodore 64 computers, a 2 by 12-way 0·156 inqh edge connector is needed to make the connections to the user port. These are readily available, but are not usually fitted with polarising keys. With a little ingenuity it might be possible to add these, or the top and bottom of the connector can be suitably labelled.

Connections to the user port of the BBC model B computer are made via a 20-way IDC header socket. Connection details for all three computers are given in Fig. 3.

Fig. 3. Connectors for the three machines



SOFTWARE

Suggested software for the VIC-20, Commodore 64, and the BBC model B are provided in the accompanying listings. These are self explanatory in use, and do not really require any operating instructions. Do not omit the REM at line 1 of the VIC-20 and Commodore 64 listings: this is used to hold a short machine code routine which prints the frequency reading at a fixed point on the screen.

The way in which the counter/timers are used is fairly simple. If we take the VIC-20 first, this uses a 6522 VIA (Versatile Interface Adaptor) for the user port. The timer/counters are controlled by the auxiliary control register at address 37147. Timer 1 is controlled by bits 6 and 7 of this register, and it is this timer that is used to provide the 50Hz clock signal. The timer can operate in the one shot or free running modes, and in this case bit 6 is set high to select the free running mode. Bit 7 can be set high to provide the output signal on PB7 of the user port, and this is again done here. The timer is loaded in two 8 bit bytes, and these are POKEd to addresses 37140 (least significant) and 37141 (most significant).

Timer 2 is used as the 16 bit counter, and this is controlled by bit 5 of the auxiliary control register. This timer is set to the pulse counting mode by setting bit 5 of the auxiliary control register high. It then counts pulses received on line PB6 of the user port. With bits 5 to 7 of the register set high, this gives a total of 224 (128 + 64 + 32) to be written to the control register. Timer 2 is set to 65535 by writing 255 to both of the 8 bit registers which it comprises, and these are at addresses 37144 (low byte) and 37145 (high byte).

When timer 2 reaches zero it sets bit 5 of the interrupt flag register at address 37149, and an overflow of the counter can be detected by monitoring this bit. The flag is automatically reset when timer 2 is reloaded.

The BBC model B computer also uses a 6522 VIA for the user port, and this is set up and used in the same way as the 6522 in the VIC-20. Of course, the addresses are different, and the 6522 in the BBC machine is at addresses from &FE60 to &FE6F.

A slightly different device is used in the Commodore 64, and this is a 6526. This is an "improved" 6522 which includes a "time of day" clock facility. It has the two 16 bit timer/counters as well, but they are controlled and used in a slightly different manner.

Timer B is used to provide the clock signal, and the appropriate figures for the required division rate are POKEd to addresses 56582 (low byte) and 56583 (high byte). The control register for timer B is at address 56591, and the operating mode is controlled by bits 5 and 6. In this case they are both set low so that the counter uses the system clock as its input signal. Bits 0 to 4 of this register also control the action of the timer, and bit 4 is set high to force a load of the number previously written to the counter. Bit 3 is set low to place the counter in the continuous rather than one shot mode, bit 2 is set high to give a squarewave rather than a pulsed output on PB7, and bit 1 is set high to enable output on PB7. Finally, bit 0 is set high to start the counter. This gives a total of 23 to be written to control register B.

Timer A is used as the 16 bit counter, and it is controlled in a similar way to timer B. Bit 5 is set high so that input pulses on line CNT (and not clock pulses) are counted. Bit 4 is also set high, to load the number written to the counter at addresses 56580 (low byte) and 56581 (high byte). Bit 3 is set low to give continuous rather than pulsed operation, while bits 2 and 1 are set low to prevent output on PB6. Lastly, bit 0 is set high to start the timer, and the start/stop action of the counter is then effectively controlled by the external gate circuit. The interrupt flag of timer A is at bit 0 of address 56589. ★

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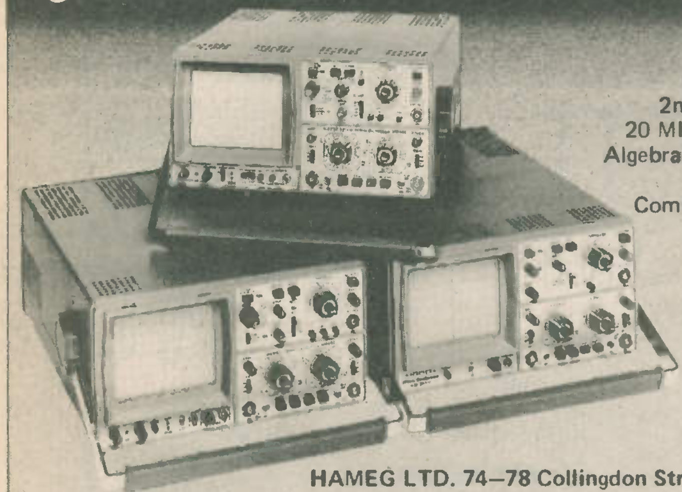

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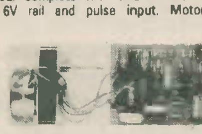

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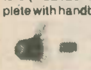

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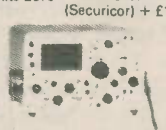

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WW10

Sequential Logic Techniques Part 2

M.TOOLEY BA and D.WHITFIELD MA MSc C Eng MIEE

THE 7447 seven-segment decoder accepts a 4-bit BCD input and produces the appropriate outputs for selection of the segments in a seven-segment l.e.d. display. The truth table for the segment outputs and resulting display is shown in Table 2.1. It should also be noted that a further six redundant display conditions exist for the unused input codes beyond '9' (1010 to 1111). These states are, of course, invalid in BCD counting and we will thus not, at this stage, concern ourselves with the actual patterns produced.

Table 2.1. Truth table for segment outputs of a 7447

BOOLEAN EXPRESSION	DISPLAY	SEGMENT STATES a b c d e f g	BCD I/P $A_3 A_2 A_1 A_0$
$\bar{a}\ \bar{b}\ \bar{c}\ \bar{d}\ \bar{e}\ \bar{f}\ g$	0	0 0 0 0 0 0 1	0 0 0 0
$a\ \bar{b}\ \bar{c}\ d\ e\ f\ g$	1	1 0 0 1 1 1 1	0 0 0 1
$\bar{a}\ \bar{b}\ c\ \bar{d}\ \bar{e}\ f\ \bar{g}$	2	0 0 1 0 0 1 0	0 0 1 0
$\bar{a}\ \bar{b}\ \bar{c}\ \bar{d}\ e\ f\ \bar{g}$	3	0 0 0 0 1 1 0	0 0 1 1
$a\ \bar{b}\ \bar{c}\ d\ e\ \bar{f}\ \bar{g}$	4	1 0 0 1 1 0 0	0 1 0 0
$\bar{a}\ b\ \bar{c}\ \bar{d}\ e\ \bar{f}\ \bar{g}$	5	0 1 0 0 1 0 0	0 1 0 1
$a\ b\ \bar{c}\ \bar{d}\ \bar{e}\ \bar{f}\ \bar{g}$	6	1 1 0 0 0 0 0	0 1 1 0
$\bar{a}\ \bar{b}\ \bar{c}\ d\ e\ f\ g$	7	0 0 0 1 1 1 1	0 1 1 1
$\bar{a}\ \bar{b}\ \bar{c}\ \bar{d}\ \bar{e}\ \bar{f}\ \bar{g}$	8	0 0 0 0 0 0 0	1 0 0 0
$\bar{a}\ \bar{b}\ \bar{c}\ d\ e\ \bar{f}\ \bar{g}$	9	0 0 0 1 1 0 0	1 0 0 1

PE1579G

The 7447 has provision for automatic blanking of the leading and/or trailing edge zeros in a multi-digit decimal number, resulting in an easily read decimal display which corresponds to normal writing practice. In an 8-digit mixed integer fractional decimal representation, using the automatic blanking facility, 0010·0200 would, for example, be displayed as 10·02. Leading edge zero suppression is obtained by connecting the ripple blanking output (BI/RBO) of a decoder to the ripple blanking input (RBI) of the next (lower order) device. The most significant decoder stage should have the RBI input taken to logic 0 but, since suppression of the least significant integer zero in a number is not usually desired (i.e. it is normal to display 0·5 rather than ·5), the RBI input of this decoder stage should be left open, or taken to logic 1. A similar procedure for the fractional part of a display will provide automatic suppression of the trailing edge zeros.

The decoder has an active low input 'lamp test' (LT) which overrides all other input combinations and enables a check to be made on possible display malfunctions. The BI/RBO pin of the decoder can be OR-tied with a modulating signal via an isolating buffer to achieve pulse width intensity modulation. It is thus possible to provide a means of controlling the brightness of the display.

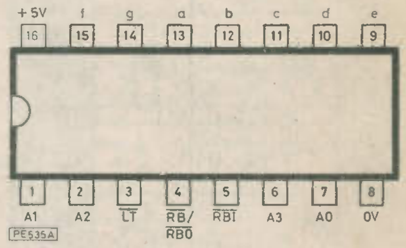

Fig. 2.1. Pin connections for the 7447

We shall now modify the hard-wired seven-segment display and incorporate a 7447 decoder/driver to permit BCD data input. The 7447 should be inserted into socket A, carefully checking that pin-1 is aligned with A1. The following additional links are required:

A3	to S3	(lamp test input)
A8	to 0V	(common)
A9	to B5	
A10	to B4	
A11	to B3	
A12	to B2	
A13	to B1	
A14	to B7	
A15	to B6	
A16	to +5V	(supply)

Now press S3 to generate a logic 1 at the lamp test input. All segments should be extinguished. Press S3 again to generate a logic 0 at the lamp test input. All segments should be illuminated, resulting in a display of '8'. Having confirmed that the lamp test facility is operational and that the 7447 has been wired correctly, we are now ready to connect the BCD inputs. Since all four switches of the Logic Tutor will be required, it is first necessary to remove the lamp test input.

Disconnect the link from A3 to S3 and make the following connections:—

A1 to S3
A2 to S2
A6 to S1 (MSB)
A7 to S4 (LSB)

Switches S1 to S4 now generate the BCD inputs required by the 7447 with S1 being the most significant (A3) and S4 being the least significant (A0). All four switches should be adjusted to produce a logic 0 input (corresponding to a BCD input of 0000) and the resulting display should, of course, be '0'! The four input switches should now be used to generate each one of the further fifteen possible input states in turn. The possible input states (we shall include those states which are not present in BCD counting) and the resulting displays should be checked against those shown in Table 2.2.

Table 2.2. Resulting displays achieved from Fig. 1.10

BCD INPUT S1	S2	S3	S4	DISPLAY
0	0	0	0	0
0	0	0	1	1
0	0	1	0	2
0	0	1	1	3
0	1	0	0	4
0	1	0	1	5
0	1	1	0	6
0	1	1	1	7
1	0	0	0	8
1	0	0	1	9
1	0	1	0	c
1	0	1	1	ɔ
1	1	0	0	u
1	1	0	1	⊑
1	1	1	0	t
1	1	1	1	

PE1580G

DECADE COUNTER STAGE USING 7490 AND 7447 STAGES

Having established that the 7447 is capable of accepting a BCD input and displaying the states '0' to '9' correctly on a seven-segment l.e.d. display, it is but a relatively small step to add a 7490 to produce a complete clocked decade counter stage. The circuit of such an arrangement is shown in Fig. 2.2 in which the BCD output of the counter is taken directly to the BCD input of the decoder/driver.

The 7490 should be inserted into socket D, taking care to align pin-1 with D1. Remove the links from the switches to A1, A2, A6 and A7, and make the following additional connections:—

D1 to D14
D2 to D3
D3 to S1 (reset 0)
D5 to +5V (supply)
D6 to D7
D7 to S2 (reset 9)
D10 to A2
D11 to A1
D12 to 0V (common)
D13 to A6
D14 to A7
D16 to clock

Check that the counter cycles through the states '0' to '9' and then restarts at '0'. It should be noted that changes of state occur on the falling edge of the clock pulse. Check also that a logic 1 from S1 immediately resets the output to '0' whereas a logic 1 from S2 sets the output to '9'. In either case the count being halted for the duration for which the respective switch is depressed, the count resuming on the next falling clock pulse after the switch has been released.

The simple decade counter and display driver arrangement suffers from the disadvantage that the display is constantly changing as the incoming clock changes. With a slow clock this does not, of course, present too much of a problem; however, where the clock is rapidly changing, the constantly fluctuating display may be disconcerting and it would be nice to have a means of periodically 'freezing' the state of the display so that it may be read. The action of holding the display static must, of course, not interfere with the normal counting function which must continue as normal if data is not to be lost. What is needed, therefore, is a means of latching or storing the count and updating the display periodically. The device which we use to satisfy this requirement is a 4-bit data latch of which the 7475 is a prime example.

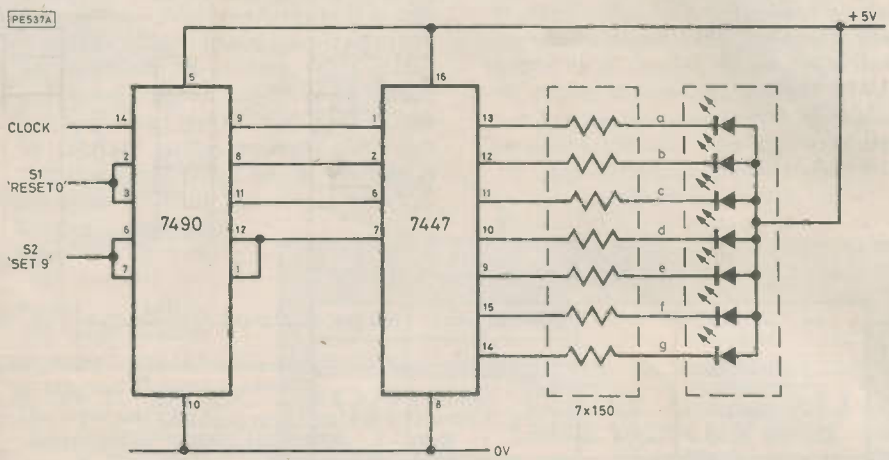

Fig. 2.2. Decade counter using 7490 and 7447 devices

THE 7475 DATA LATCH

The 7475 comprises four individual D-type bistable stages. These stages are arranged in pairs having a common enable input, G. Information present at the D input is transferred to the Q output when the G input is at logic 1 and the Q output will then follow the data input as long as the enable input remains high. When the enable goes low, the information that was present at the data input at the time the transition occurred is retained at the Q output until the enable input is permitted to go high. The internal logic and pin connections of the 7475 are shown in Fig. 2.3.

LATCHED COUNTER USING 7490, 7475 AND 7447

We shall now construct a complete latched decade counter stage by extending the previous arrangement, see Fig. 2.4. The 7475 data latch should be inserted into socket E, checking as usual that pin-1 aligns correctly with E1. Disconnect the following links:—

D10 to A2
D11 to A1
D13 to A6
D14 to A7

Now make the following connections:—

A1 to E16
A2 to E15
A6 to E10
A7 to E9
E2 to D11
E3 to D10
E4 to S3 (latch enable)
E5 to +5V (supply)
E6 to D13
E7 to D14
E12 to 0V (common)
E13 to S3 (latch enable)

Adjust S3 to produce a logic 1 (D7 illuminated) and check that the normal counting sequence is produced. When S3 is taken to logic 0 (D7 extinguished) the latch is enabled and the display will remain frozen for as long as S3 remains at logic 0. When S3 is returned to logic 1, the count is updated such that the current BCD data from the 7490 is latched into the 7447 decoder/driver. It is important to note that the 7490 does not stop counting during the period for which the latch is enabled and that new data can be latched in at any time by means of the enable input, S3.

FREQUENCY AND TIME STANDARDS

A number of practical applications require digital signals of accurately known period or frequency. A typical example is that of a digital clock which counts in increments of one second. Whereas the fundamental 1s timing pulse could be derived from a free-running oscillator, the accuracy and long-term stability is unlikely to prove adequate for serious applications. We shall now examine three possible solutions to this problem.

The first method involves the use of a crystal controlled oscillator operating at a few tens of kilohertz, or more, followed by a divider chain, as shown in Fig. 2.5. The crystal frequency and division ratio being chosen so as to minimise the expense associated with

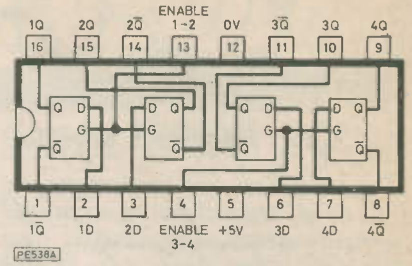

Fig. 2.3. Pin connections and internal logic of the 7475

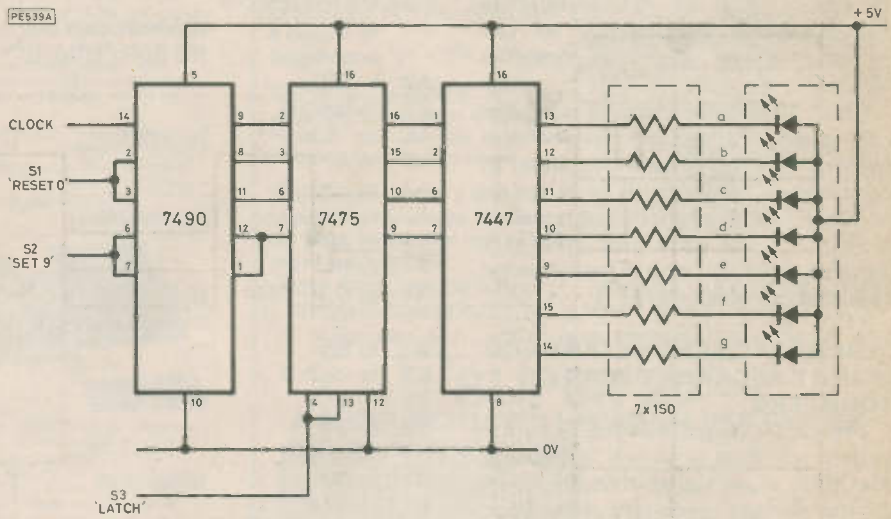

Fig. 2.4. Complete latched decade counter stage

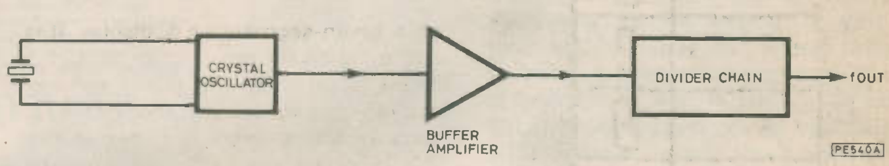

Fig. 2.5. Frequency standard based on a crystal controlled oscillator and divider chain

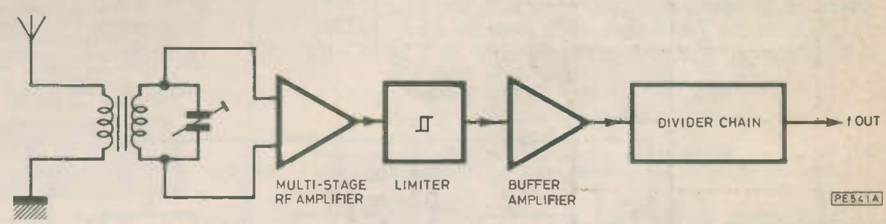

Fig. 2.6. Frequency standard based on an 'off-air' radio frequency signal

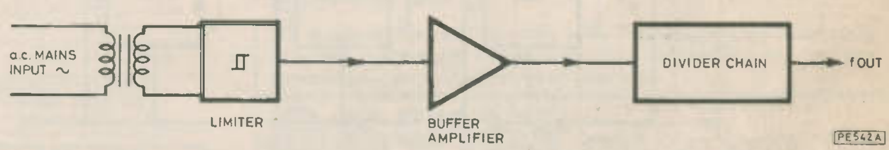

Fig. 2.7. Frequency standard based on the 50Hz mains supply

the quartz crystal unit and the complexity of the divider chain. Typical crystal frequencies and division ratios required for a 1Hz output are shown in Table 2.3.

The second method involves the use of an off-air radio signal of accurately known frequency. The 200kHz long wave BBC transmitter is ideal for this purpose and readily accessible throughout the U.K. It is, of course, necessary to provide RF amplifier circuitry in order to raise the low-level of RF input signal to TTL compatible levels before application to the necessary divider stages, as shown in Fig. 2.6.

The third method involves using the a.c. supply mains and, whilst this method is not as accurate as either of the previous methods, it is relatively simple. A typical arrangement is shown in Fig. 2.7. We shall now look at a practical example using three cascaded 7490 decade dividers.

Table 2.3. Typical crystal frequencies used in frequency and time standards

CRYSTAL FREQUENCY	DIVISOR	OUTPUT FREQUENCY
32·768kHz	2^{15}	1Hz
100kHz	10^5	1Hz
1MHz	10^6	1Hz
2,097152MHz	2^{21}	1Hz
3·2768MHz	2^{16}	50Hz
4·194304MHz	2^{22}	1Hz
6·55360MHz	2^{17}	50Hz
10MHz	10^4	1kHz

CLOCK FREQUENCY STANDARD USING CASCADED DECADE COUNTERS

The circuit diagram of the clock frequency standard is shown in Fig. 2.8. The 50Hz input signal is derived from the low-voltage secondary of the Logic Tutor mains adaptor. This signal is converted to a TTL compatible 50Hz square wave by means of a Schmitt inverter, IC1a, and resistor/Zener diode input clamp. The output of this stage, and of each of the three subsequent decade divider stages, is displayed on the logic level indicators provided on the Logic Tutor. These indicators, D1 to D4, flash at 50Hz, 5Hz, 0·5Hz, and 0·05Hz respectively.

The three 7490 decade counters should be inserted into sockets A, B, and C, whilst the 7414 should be inserted into socket E. In each case check that pin-1 aligns with pin-1 of the respective connector. The following links are required:—

A1	to D1	(D1 indicates the 50Hz output)
A2	to D3	
A3	to logic 0	
A5	to +5V	(supply)
A6	to A7	
A7	to logic 0	
A10	to 0V	(common)
A11	to A14	
A12	to B1	
B1	to D2	(D2 indicates the 5Hz output)
B2	to B3	
B3	to logic 0	
B5	to +5V	(supply)
B6	to B7	
B7	to logic 0	
B10	to 0V	(common)
B11	to B14	
B12	to C1	
C1	to D3	(D3 indicates the 0·5Hz output)
C2	to C3	
C3	to logic 0	
C5	to +5V	(supply)
C6	to C7	
C7	to logic 0	
C10	to 0V	(common)
C11	to C14	
C12	to D4	(D4 indicates the 0·05Hz output)
E2	to A1	(TTL 50Hz)
E7	to 0V	(common)
E16	to +5V	(supply)

In addition, connect a 220 ohm resistor from either side of PL1 (6V a.c. input) to E1 and a BZY88 C4V7 Zener diode from E1 to 0V (the Zener diode should be oriented so that the connection nearest the stripe on the package is taken to E1).

When power is applied, D1 will appear to be illuminated permanently but at reduced brightness. This is simply due to the fact that it is flashing on and off very rapidly and the approximate 50% duty cycle is responsible for the reduction in light output. The other l.e.d.s will be noticeably flashing with D2 at 5 times per second, D3 at 2 seconds per cycle, and D4 at 20 seconds per cycle. If desired, times for D3 and D4 may be checked using a stopwatch.

The versatile nature of the 7490 allows us to modify the simple frequency/time standard to provide a number of useful outputs. Suppose our digital clock required accurate pulses at 10Hz (tenths of seconds), 1Hz (seconds), and 0·1Hz (ten seconds). This could be easily achieved by making the first stage a divide-by-five rather than a divide-by-ten.

The following modifications are required:

Remove links from	A12 to B2
	A12 to D2
	A11 to A14
Reconnect	A11 to D2
	A11 to B1

This gives outputs at 50Hz, 10Hz, 1Hz, and 0·1Hz on D1 to D4, respectively.

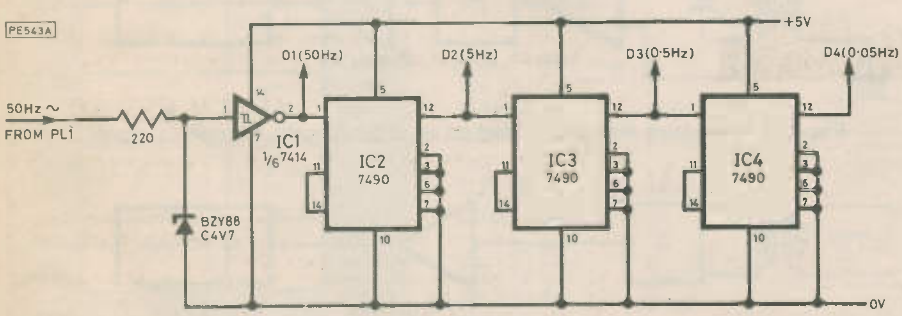

Fig. 2.8. Simple frequency standard based on three 7490 decade dividers

Constructor's Note
Logic Tutor Board p.c.b's, components and constructional details are available from Howard Associates, 59 Oatlands Avenue, Weybridge, Surrey KT13 9SU (0932 42376).

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SPECIFICATIONS:

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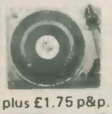

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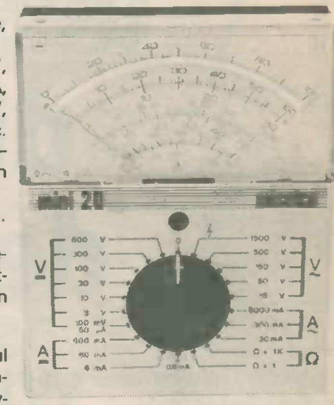

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the single-arm manipulator with multiple joints, as widely used in automatic spot welding of car bodies for example.

SMALL ROBOT STRUCTURES

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

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

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

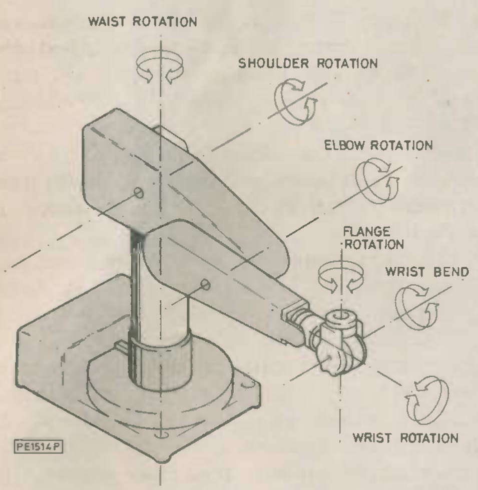

Fig. 1. Level of articulation and joint rotations (axes of movement) available in a typical industrial robot—the Puma 260, a light-duty machine made by Unimation (Europe) Ltd. The manipulator arm members are driven by d.c. servomotors position controlled by the user's software program held in a 16K RAM

ROBOTS, *AUTOMATION* AND PRODUCTIVITY

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

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

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

HISTORICAL DEVELOPMENT

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

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

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

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

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

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

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

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

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

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

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

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

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

CONTROL AND SENSING SYSTEMS

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

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

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

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

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

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

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

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

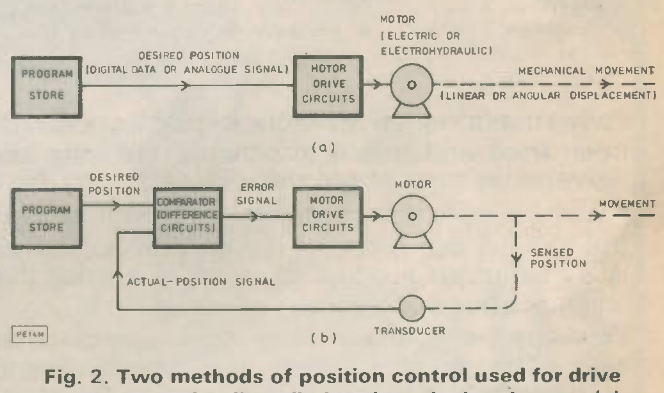

Fig. 2. Two methods of position control used for drive motors or hydraulic cylinders in articulated arms: (a) open-loop, and (b) closed-loop. (For simplicity, diagrams do not show whether functional blocks and signals are analogue or digital)

BUYER'S GUIDE...
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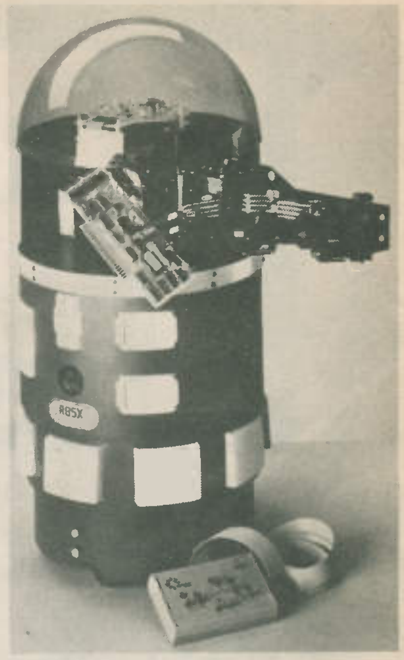
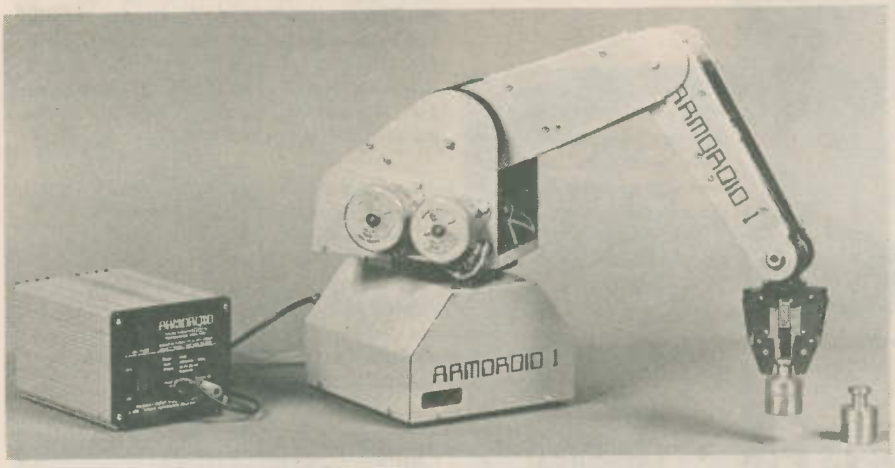
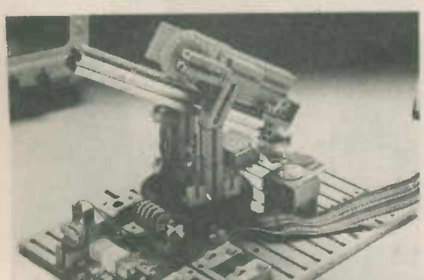




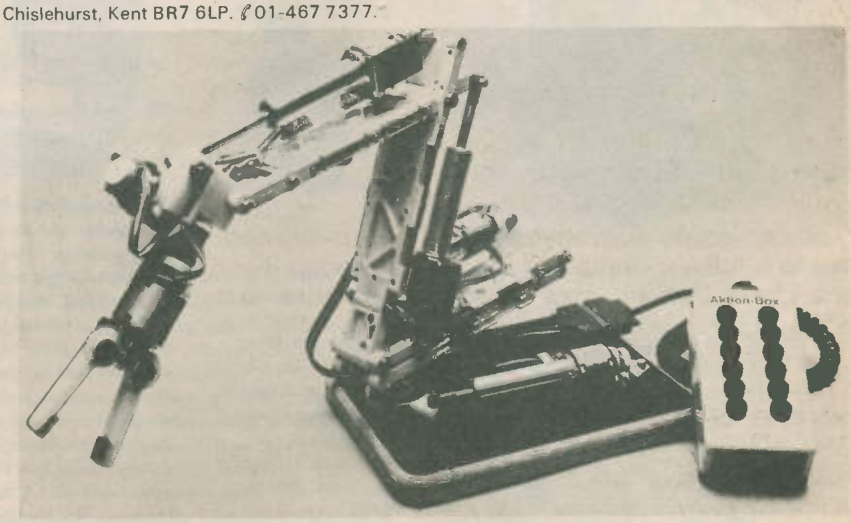
Armdroid I has 5 axes plus 3-finger gripper (6 stepper motors with open loop control) capable of lifting 300g. Supplied with PSU and software for BBC, Commodore 64 or Spectrum, but will interface to any micro with 8-bit parallel port. Microswitches to aid positional sensing are optional. Hand-held manual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

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



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

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



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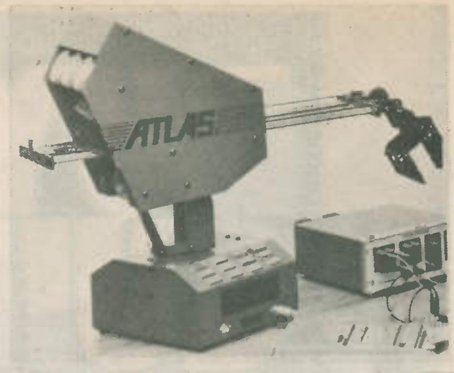
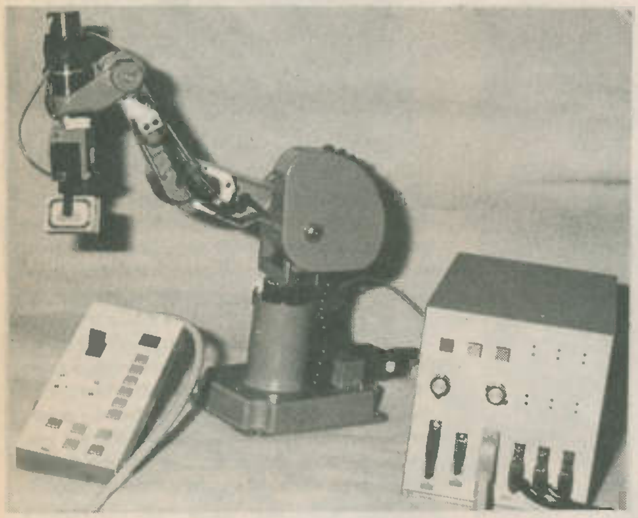
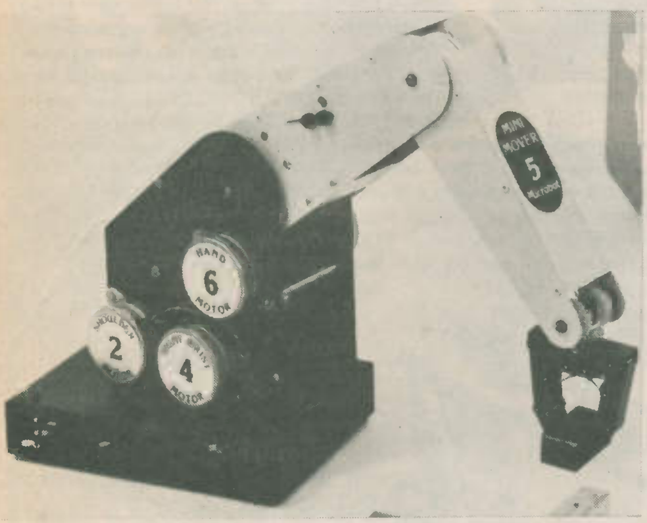


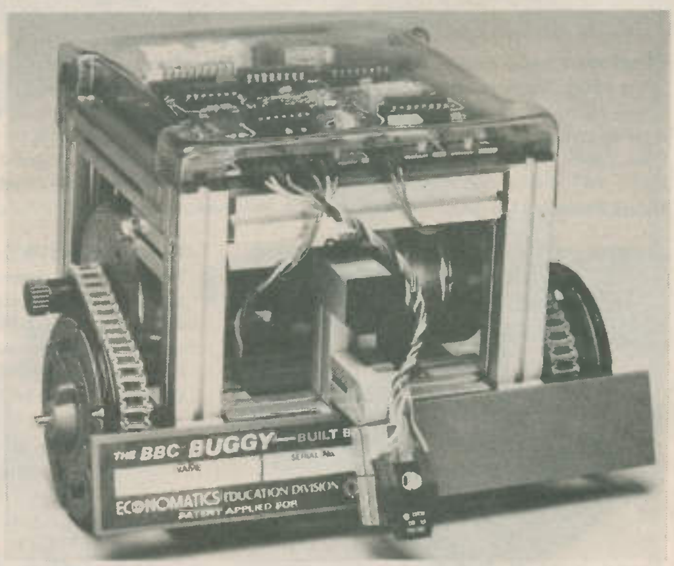
Atlas is a self-contained stepper motor driven robot with onboard micro. It has 5 axes plus one supplementary function. The teaching console provides automatic editing. The robot is readily dismantled to allow students to study its mechanisms. Maximum payload is 1kg, Resolution better than 0·1mm and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



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



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



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

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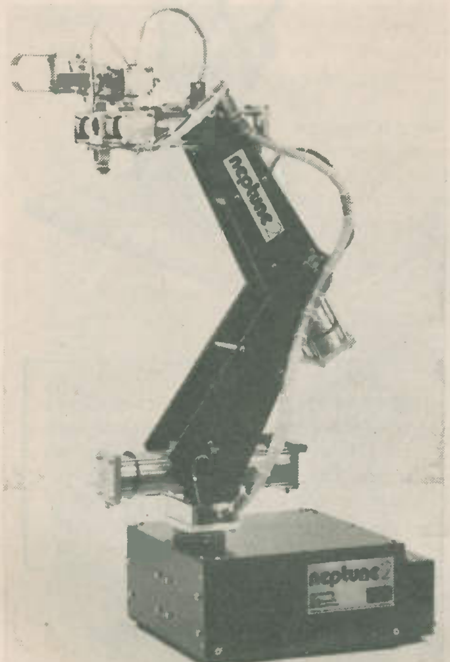
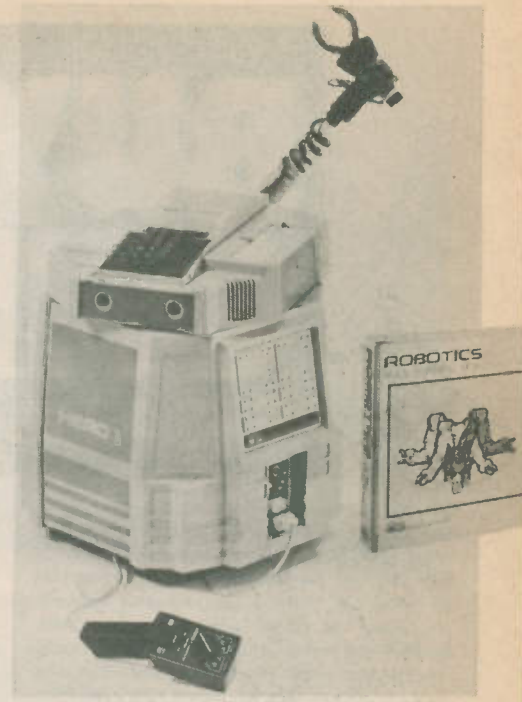


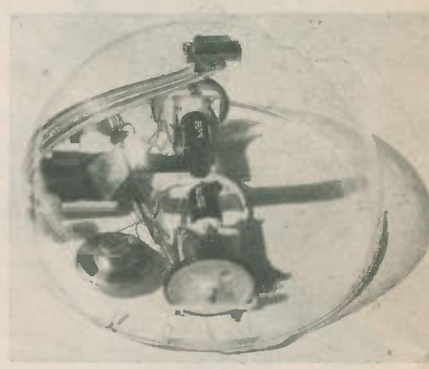
Neptune Models I and II (currently published in Practical Electronics) are electro-hydraulically powered robots. Neptune I has 6 servo-controlled axis movements and Neptune II has 7. These systems use water as the hydraulic medium; they are sold in kit form. Assembly time is minimised by the use of a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

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

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



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



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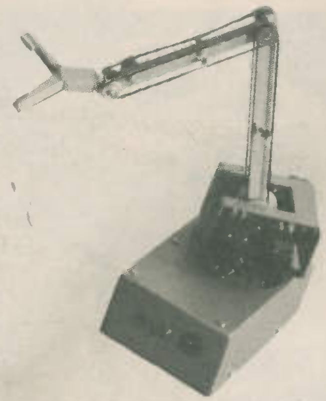
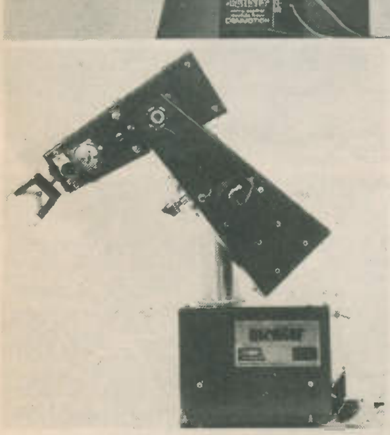
Alfred (featured currently in Everyday Electronics) is powered by six servomotors, five of which provide axis control, and one of which is mounted on the forearm (but not shown in photo) to control the gripper. Power is transmitted along the plastic arm by toothed belts, producing a highly articulate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



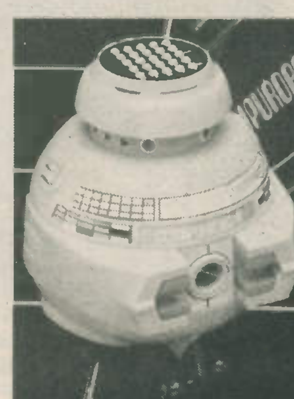


Beasty Arm is powered by 3 radio control type servomotors using the well known 'Beasty'—a matchbox sized motor controller which communicates with a BBC micro serially (theoretically allowing optical, and even radio link-ups). The standard arm uses a hook, although a gripper can be added. Arm lengths,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

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

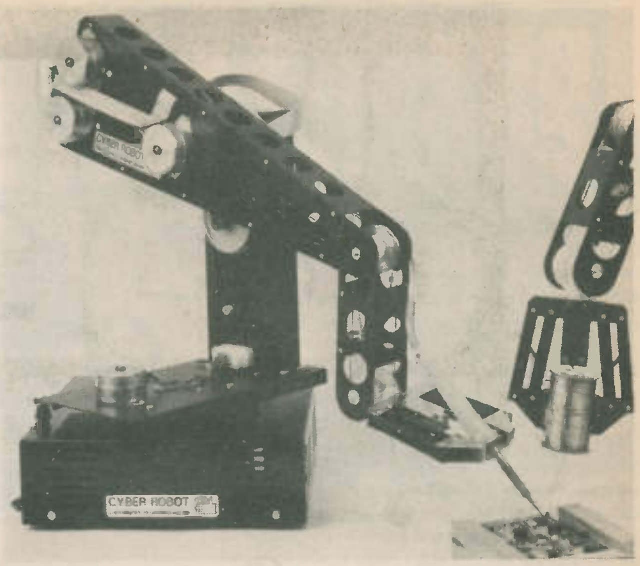
MA2000 Open University robot has 6 axes, powered by d.c. servo motors, plus a pneumatic gripper (for which a compressed air cylinder, or compressor is required). Supplied in wooden case which converts into operating base, keypad, and controller interface for BBC Model B and the University's Hektor micro.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

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

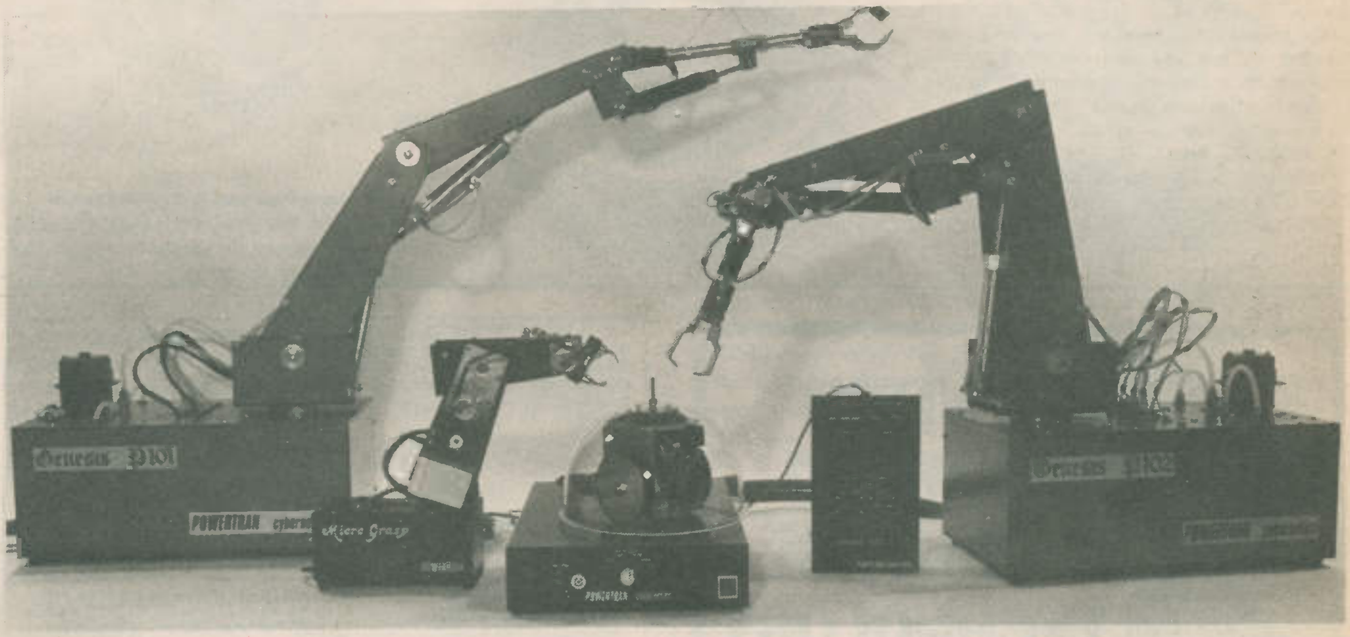


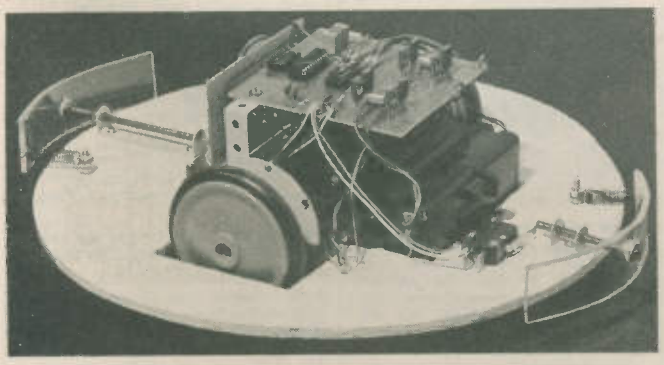
George can be programmed with up to 48 steps, and will go forwards, backwards, hold, turn, or curve left, or right, and retract. He has 3 speeds and 9 time intervals, and incorporates a light beam and sounder. A demo' program is provided. George is 168mm high. Price £23·95. Available through retail outlets.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

BUYER'S GUIDE... SMALL ROBOTS



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





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

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

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

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

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

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

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

BUYER'S GUIDE... SMALL ROBOTS

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

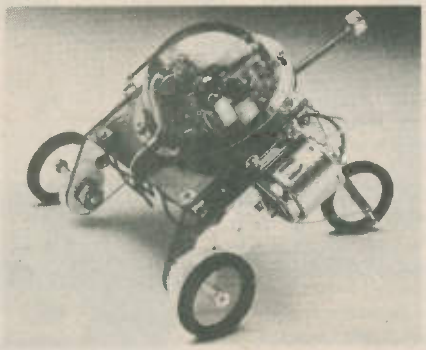
MV913 Line Tracer is guided along a line by an infra-red sensor. It has 3 wheels driven by 2 d.c. motors. Price £17·99.

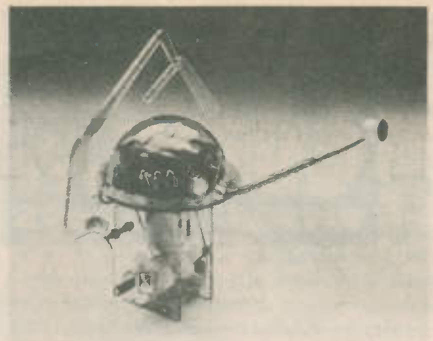
MV915 Piper Mouse uses a sound sensor to follow instructions issued by its owner using a whistle. Has 3 wheels driven by 2 d.c. motors. Price £19·99.

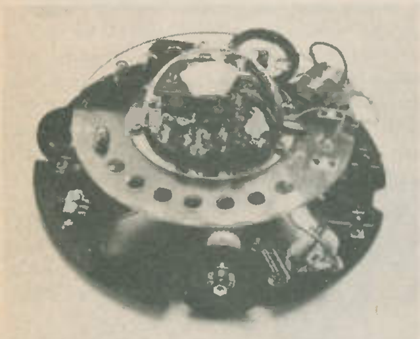
MV918 Memocon Crawler contains RAM to remember and follow instructions entered through a keyboard. Has 3 wheels driven by 2 d.c. motors. Price £34·99.

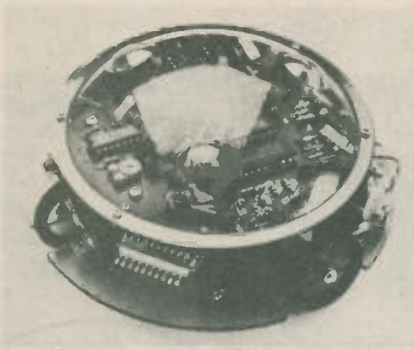
MN919 Monkey romps along a tightrope, activated by a clap of the hands, or other fragor. Driven by 2 cranked gripper arms. Price £9·99.

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



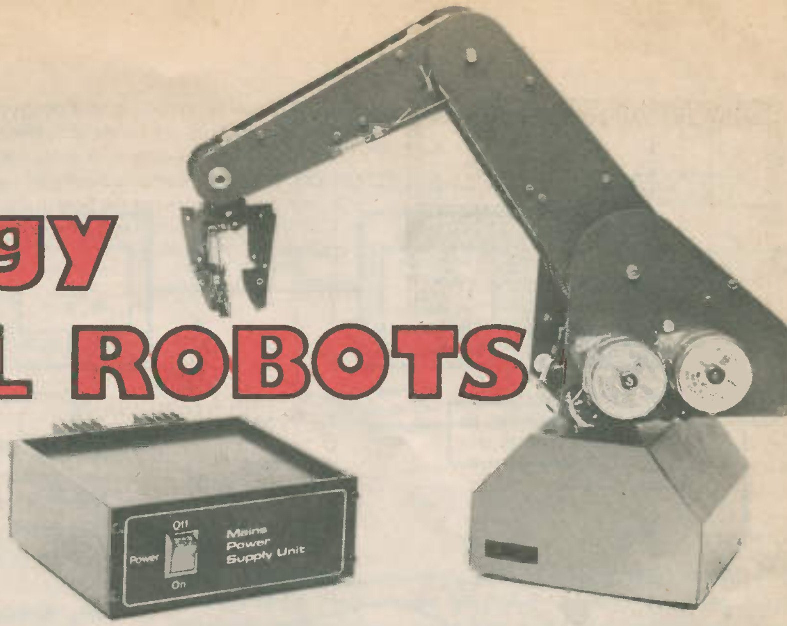






Prism Micro Products Ltd., Prism House, 18-29 Mora St., City Rd., London EC1V 8BT. ✆01-253 2277. Movits are available through High Street hobby and toy stores.

The Technology of SMALL ROBOTS



Tom Ivall

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

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

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

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

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

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

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

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

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

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

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

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

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

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

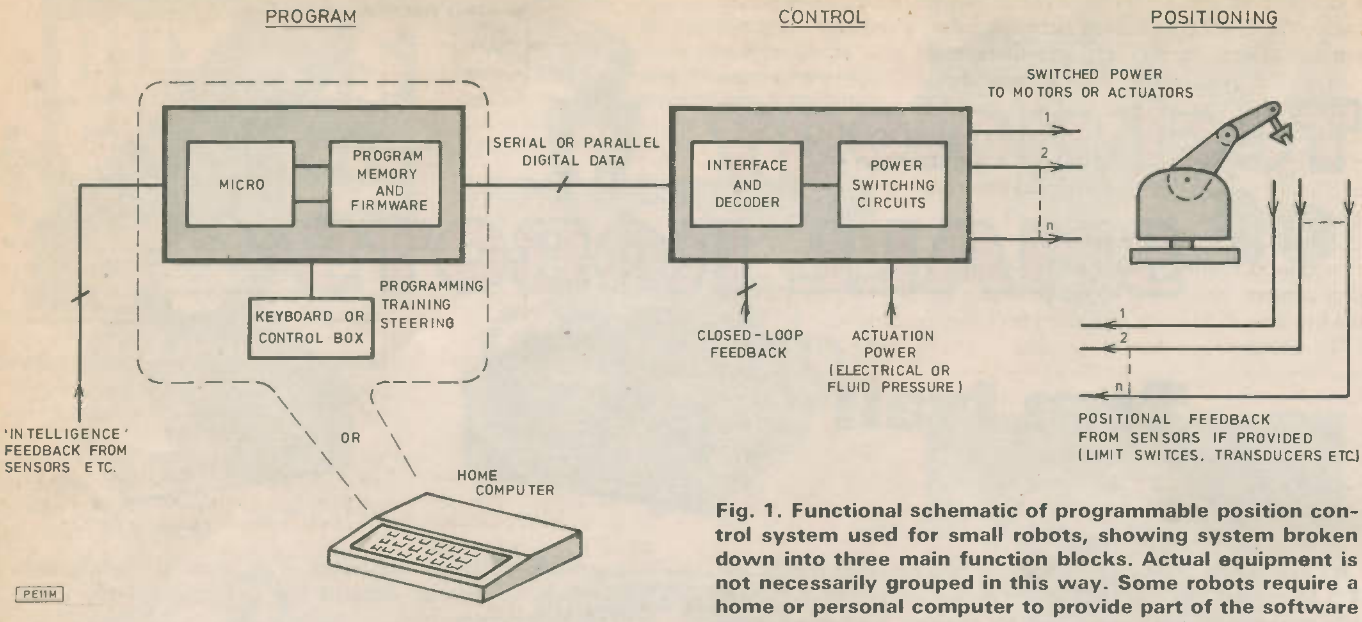


Fig. 1. Functional schematic of programmable position control system used for small robots, showing system broken down into three main function blocks. Actual equipment is not necessarily grouped in this way. Some robots require a home or personal computer to provide part of the software programmable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

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

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

MECHANICAL STRUCTURE OF ARM

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

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

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

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

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

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

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

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

DRIVE SYSTEMS

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

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

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

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

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

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

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

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

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

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

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

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

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

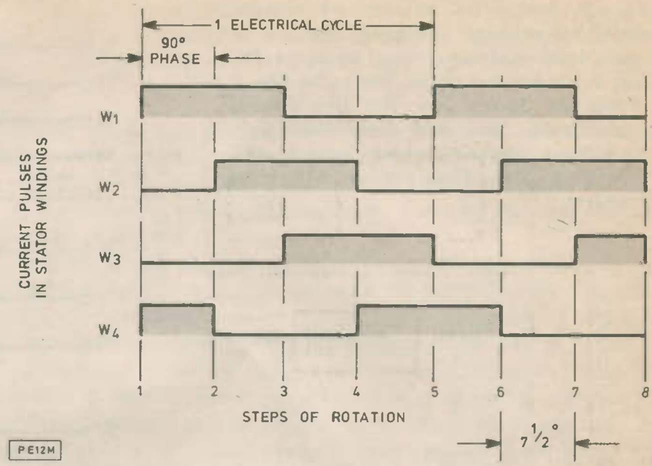


Fig. 2. Energising current pulses applied to the windings, W_1 to W_4, of a four-phase stepping motor, showing phase relationships between pulse sequences for steady incremental rotation in $7\frac{1}{2}$° steps

CONTROL SYSTEMS

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

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

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

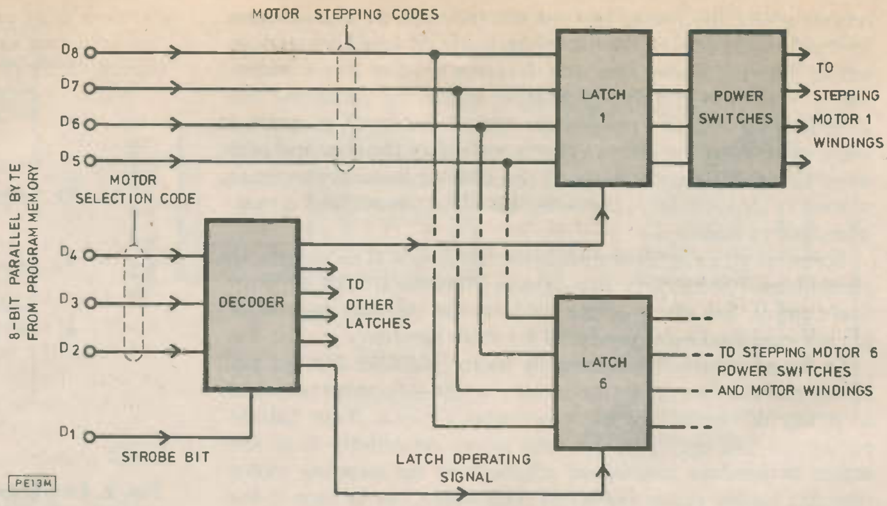
Encoded position-control data arrives as 8-bit parallel bytes on lines D_1 to D_8. Each 8-bit byte contains three distinct groups of information. D_2 to D_4 is a three-bit code which tells the control system which one of the six stepping motors to select. D_5 to D_8 is a four-bit code which causes the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

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

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

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

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



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

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

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

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

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

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

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

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

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

SOFTWARE PROGRAMMING

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

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

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

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

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

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

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

E 80 MOVE

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

300 W 200 S GO

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

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

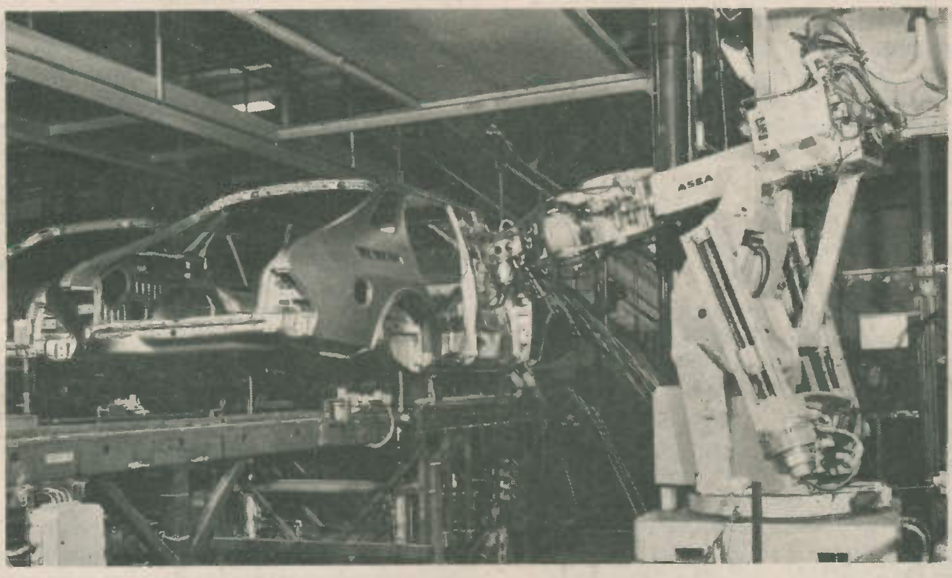
Of course, the robot doesn't really decide. It implements a generalised decision made in advance by the human programmer: e.g. that the instruction sequence in branch A of the program will be carried out if, say, a certain sensed value is greater than x, or the instruction sequence in branch B if this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

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

robotics

Supplement to PE & EE November 1984

SMALL ROBOTS & Their



BIG BROTHERS!

TOM IVALL

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

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

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

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