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INSIDE MICROCONTROLLERS
Harvard and Von Neumann - Architects of the Future

MULTI CHANNEL CONTROL CENTRE
Cut out the cable chaos

INFRA-RED REMOTE CONTROL
A new design with three output options

DC VOLTAGE CONVERTERS
Capacitive power supply circuits

PLUS
- Simulation Software
- GCSE Environmental Sensor

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FOR ENTHUSIASTS BY ENTHUSIASTS NEXUS

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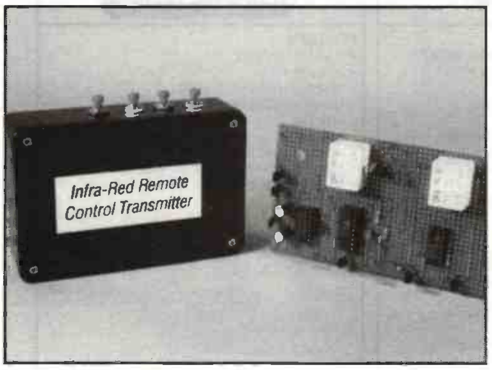
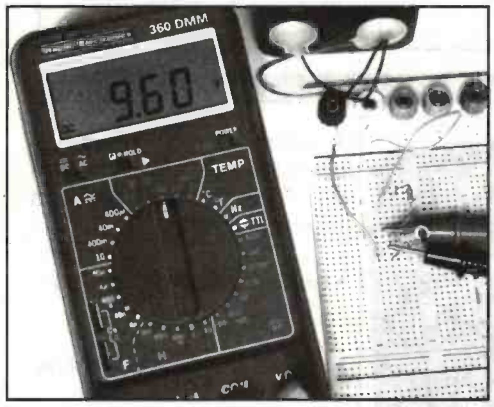
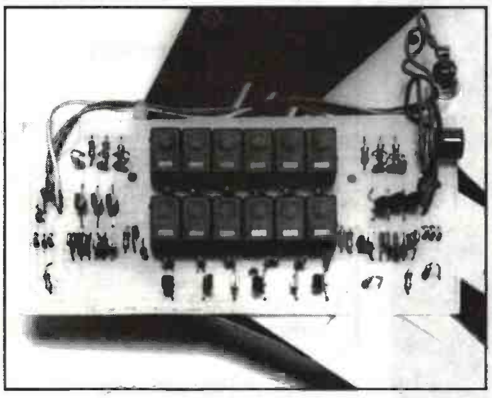
Volume 27 No.1

& Features Projects

Next Issue 30th January 1998







Inside Microcontrollers 13
Love them or loathe them, programmable microcontrollers are the success story of electronics in the 1990s, whether you look at industry or personal design. Robin Abbott describes the underlying architectures of some of the most popular microcontroller families.

Infra-Red Remote Control System 27
This is a remote control system with three output options for different uses: one to initiate action, one to switch a relay on and off, and one for experimenters. The four-channel control can be modified to accommodate up to 12 or 15 channels.

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Ray Marston describes the principles behind the conversion of DC voltage to a reversed polarity supply or a higher voltage, with 23 examples of practical applications circuits and a little bit of history.

"Six-and-Two" Multi-Channel Control Centre 47
Cut out the tangle - Terry Balbirnie's desktop multi-plug system gives you sockets for six pieces of equipment to be switched on and off from a central point, and allows two pieces to be powered continuously.

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Owen Bishop continues his journey into digital circuit simulation with a look at a number of different SPICE programs, including ICAP/4, B2 SPICE and MICRO-CAP IV/V.

GCSE Grounding: Universal Sensor Module 65
Terry Balbirnie continues his adaptable circuits for students doing GCSE projects. In this issue: a sensor module suitable for use with many different kinds of input to measure environmental conditions.

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Terry Balbirnie discusses the concept of

Round the Corner 74

DIGITAL MULTIMETERS

CM2300 DIGITAL MULTIMETER

FEATURES:
- 3.5 LCD DISPLAY
- HEIGHT 12mm
- MAX READING 1999
- HV INDICATION FOR HIGH VOLTAGE
- SINGLE MANUAL ROTARY SWITCH FOR FUNCTION AND RANGE OPERATION
- ALL RANGES OVERLOAD PROTECTED
- 10A DC CURRENT TEST,
- DC VOLTAGE 2V/20V/200V/500V,
- AC VOLTAGE 200/500V
- DC CURRENT 200mA,
- RESISTANCE 2kΩ /20kΩ /200kΩ /2MΩ
- SUPPLIED WITH TEST PROBES

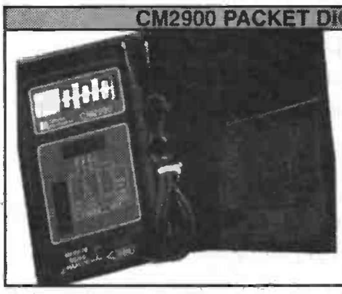
ORDER CODE: CM2300
PRICE: 975p

CM2400T DIGITAL MULTIMETER WITH TEMP MEASUREMENT

FEATURES:
- 3.5LCD DISPLAY
- HEIGHT 12mm
- MAXIMUM READING 1999
- 10A DC CURRENT TEST
- DC VOLTAGE 200mV/2V/20V/200V/1000V
- AC VOLATE 200/750V,
- DC CURRENT 0.2mA/200mA/20mA/200mA/20A
- RESISTANCE 200Ω /2KΩ /20KΩ /200KΩ /2MΩ
- SUPPLIED WITH TEST PROBES
- TEMPERATURE MEASUREMENT
- CONTINUITY TEST
- DIODE TEST & CONTINUITY CHECK
- ALL RANGES OVERLOAD PROTECTED

ORDER CODE: CM2400T
PRICE: 1450p

CM2900 PACKET DIGITAL MULTIMETER



FEATURES:
- 3.5 LCD DISPLAY
- COMPACT AND LIGHTWEIGHT POCKET SIZE
- MAXIMUM READING 1999
- DC CURRENT 7 RESISTANCE OVERLOAD PROTECTED
- SLIDE SWITCHES FOR FUNCTION AND RANGE OPERATION
- SUPPLIED IN WALLET WITH TEST PROBES
- DC VOLTAGE 2V/20V/200V/500V
- AC VOLTAGE 200V/500V
- DC CURRENT 200mA
- RESISTANCE 2KΩ /20KΩ /200KΩ /2MΩ

ORDER CODE: CM2900
PRICE1150p

CM2700 AUTORANGING DIGITAL MULTIMETER

FEATURES:
- 3.75 LCD DISPLAY WITH DECIMAL POINT
- 33 SEGMENT BARGRAPH DISPLAY
- OVERRANGE INDICATION
- ROTARY SWITCH FOR FUNCTION SELECTION
- AUTO POWER OFF (APPROX 15 mins)
- AUTO POLARITY WITH INDICATION
- DIODE TEST & CONTINUITY TEST WITH BUZZER
- ALL RANGES OVERLOAD PROTECTED
- LOW BATTERY INDICATION
- SUPPLIED WITH TEST PROBES
- DC VOLTAGE: 320mV/3.2V/32V/320V/600V
- AC VOLTAGE: 320mV/3.2V/32V/320V600V
- DC CURRENT A: 320µA/3200µA/32mA/320mA/10A
- AC CURRENT A: 320µA/3200µA/32mA/320mA/10A
- RESISTANCE: 320Ω/3.2KΩ/32KΩ/320KΩ/3.2MΩ/32MΩ

ORDER CODE: CM2700
PRICE: 4050p

CM3230 DIGITAL CAPACITANCE METER

FEATURES:
- 3.5 LCD DISPLAY
- HEIGHT 18mm
- MAXIMUM READING 1999
- CAPACITANCE 9 RANGES FROM 200pF-20000µF
- MEASURING FROM 1pF - 20000µF
- SINGLE MANUAL ROTARY SWITCH FOR FUNCTION AND RANGE OPERATION
- ZERO ADJUST KNOB

ORDER CODE: CM3230
PRICE: 3950p

CM3900A DIGITAL MULTIMETER

FEATURES:
- LARGE LCD DISPLAY
- HEIGHT 18mm
- MASIMUM READING 1999 + UNIT
- SINGLE MANUAL ROTARY SWITCH FOR FUNCTION AND RANGE OPERATION
- AUTO POWER OFF (APPROX 15 min)
- DIODE TEST FUNCTION
- ALL RANGES OVERLOAD PROTECTED
- SUPPLIED WITH TEST PROBES
- DC VOLTAGE: 200mV/2V/20V/200V 700V ACCURACY ±0.5%
- AC VOLTAGE: 200mV/2V/20V/200V/700V
- DC CURRENT A: 200µA/20mA/200mA/2A/20A
- AC CURRENT A: 200µA/20mA/200mA/2A/20A
- RESISTANCE : 200Ω/2kΩ/200kΩ/2MΩ/20MΩ/200MΩ

ORDER CODE: CM3900A
PRICE: 2900p

CM3920 DIGITALMETER WITH TEMP MEASUREMENT

FEATURES:
- TEMPERATURE MEASUREMENT
- DIODE & TRANSISTOR HFE TEST
- LARGE LCD DISPLAY
- HEIGHT 18mm
- MAXIMUM READING 1999 + UNIT
- SINGLE MANUAL ROTARY SWITCH FOR FUNCTION AND RANGE OPERATION
- AUTO POWER OFF (APPROX 15 mins)
- DIODE TESWT FUNCTION
- ALL RANGES OVERLOAD PROTECTED
- SUPPLIED WITH TEST PROBES
- DC VOLTAGE: 200mV/2V/20V/200V/1000V ACCURACY ±0.5%
- AC VOLTAGE: 200mV/2V/20V/200V/700V
- DC CURRENT 2mA/20mA/200mA/20A
- AC CURRENT A: 200mA/20A
- RESISTANCE : 200Ω/2KΩ/200kΩ/2MΩ/20MΩ/200MΩ
- CAPACITANCE: 2nF/20nF/200nF/2µF/20µF

ORDER CODE: CM3920
PRICE: 4100p

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TIP121	35P
TIP122	30P
TIP125	30P
TIP126	40P
TIP127	35P
TIP130	30P
TIP131	30P
TIP132	30P
TIP136	40P
TIP137	65P
TIP162	110P
TIP141	65P
TIP143	75P
TIP145	50P
TIP146	70P
TIP147	80P
TIP150	90P
TIP151	60P
TIP2955	50P
TIP3055	50P
TIPL760	100P
TIPL762A	200P
TIPL763A	200P
TIPL791A	80P
TIS61	15P
TIS90	15P
TIS93	20P
ZTX107	11P
ZTX108	11P
ZTX109	12P
ZTX212	20P
ZTX300	10P
ZTX301	16P
ZTX302	10P
ZTX303	20P
ZTX304	10P
ZTX320	20P
ZTX501	13P
ZTX502	10P
ZTX503	18P
ZTX504	25P
2N696	20P
2N697	22P
2N698	40P
2N78	22P
2N914	28P
2N918	30P
2N930	18P
2N1131	28P
2N1132	28P
2N1304	350P
2N1305	225P
2N1613	24P
2N1711	24P
2N1893	30P
2N2102	50P
2N2218A	24P
2N2219	24P
2N2221	23P
2N2222	23P
2N2243	40P
2N2369	15P
2N2484	15P
2N2646	40P
2N2894	50P
2N2904	20P
2N2905	20P
2N2906	18P
2N2907	18P
2N3019	28P
2N3053	18P
2N3054	40P
2N3055	38P
2N3055H	50P
2N3439	40P
2N3440	45P
2N3441	175P
2N3442	85P

PART	PRICE
2N3553	100P
2N3585	650P
2N3702	9P
2N3703	9P
2N3704	9P
2N3705	9P
2N3706	9P
2N3707	9P
2N3710	12P
2N3711	12P
2N3771	85P
2N3772	90P
2N3773	100P
2N3792	150P
2N3799	18P
2N3819	29P
2N3820	70P
2N3823	40P
2N3866	110P
2N3903	11P
2N3906	11P
2N3924	375P
2N3958	375P
2N4031	25P
2N4033	25P
2N4036	29P
2N4220	175P
2N4347	130P
2N4391	60P
2N4392	50P
2N4393	55P
2N4399	200P
2N4401	12P
2N4403	12P
2N4416	120P
2N4420	75P
2N4427	75P
2N4920	50P
2N4922	30P
2N4923	30P
2N5038	175P
2N5061	20P
2N5088	20P
2N5109	100P
2N5116	175P
2N5154	150P
2N5160	600P
2N5179	40P
2N5192	50P
2N5241	500P
2N5245	45P
2N5294	30P
2N5296	30P
2N5320	50P
2N5322	55P
2N5401	10P
2N5416	40P
2N5448	12P
2N5457	45P
2N5458	55P
2N5460	55P
2N5461	75P
2N5462	45P
2N5484	55P
2N5551	12P
2N5671	350P
2N5672	400P
2N5680	55P
2N5884	175P
2N5886	325P
2N6031	250P
2N6049	55P
2N6059	150P
2N6098	50P
2N6099	45P
2N6107	40P
2N6109	40P
2N6211	400P
2N6248	150P
2N6284	250P
2N6287	225P
2N6292	40P
2N6385	120P
2N6403	160P
2N6427	25P
2N6476	250P
2N6488	90P
2N6491	90P
2N6547	300P
2N6609	375P
2N6660	375P
2N6675	175P
2N6678	225P
4N35	50P

RECTIFIER DIODES

BY127	8P
BY133	8P
BY164	40P
BY179	35P
BY184	32P
BY206	11P
BY207	20P
BY227	19P
BY228	28P
BY298	15P
BY299	18P
BY329-1200	150P
BY448	20P
BYT11	25p
BYT13-1000	30P
BYV96E	25P
BYW96E	36P
BYX10	15P
BYX55/600	25P
OA47	10P
OA91	10P
IN4001	3P
IN4002	3P
IN4003	3P
IN4004	3P
IN4005	3P
IN4006	3P
IN4007	4P
IN4148	2P
IN5400	9P
IN5401	8P
IN5402	8P
IN5403	8P
IN5404	8P
IN5405	11P
IN5406	12P
IN5407	12P
IN5408	12P
RGP10	25P
RGP15	25P
RGP30	16P
SKE4F2/06	60P
SKE4F2/08	80P
SKE4F2/10	100P
SR2M	60P

SATELLITE POWER SUPPLY REPAIR KITS

ALBA	CODE
SAT660	SATPSU2

AMSTRAD	CODE
SRD510, SRD520, SRD540, SRD550	SATPSU3
SRDR45	
SRD500	SATPSU4
SRX320, SRX340, SRX345, SRX350	SATPSU5
SRX100	SATPSU6
SRD600	SATPSU14
SAT250, SR950, SRD700, SRD950, SRX1002, SRX2001, SRX301, SRX501, SRX502	SATPSU16
SRD2000	SATPSU18

BRITISH TELECOM	CODE
SVS300	SATPSU17

BUSH	CODE
IRD150	SATPSU12
IRD155	SATPSU19

CHURCHILL	CODE
D3MAC DECODER	SATPSU7

ECHOSTAR	CODE
SR5500 EARLY PSU WITH ADJ	SATPSU12
6500, SR7700, SR8700	SATPSU13

FERGUSON	CODE
SRD 5, SRD16	SATPSU1
SRV1	SATPSU2
SRDE4	SATPSU11

FINLUX	CODE
SR5700	SATPSU12

GOODMANS	CODE
ST700	SATPSU1

GRUNDIG	CODE
STR1	SATPSU1
GIRD200, FIRD3000	SATPSU2

MANHATTAN	CODE
850, 950	SATPSU1

MASPRO	CODE
SRE250S/1, SRE350S/1	SATPSU1
SRE250S, SRE350S, SRE450S	SATPSU2

MIMTEC	CODE
SOPRENSON TYPE PSU ONLY	SATPSU15

NETWORK	CODE
9000, 9200	SATPSU2

NOKIA	CODE
SAT1500	SATPSU2

PACE	CODE
PRD800, PRD900, PSR800, PSR900	SATPSU1
MRD920, SS9000, SS9010, SS9200, SS9210, SS9220	SATPSU2
D100, D150,	SATPSU6
MSS100	SATPSU8
APOLLO, MSS200, MSS300	SATPSU9
MSS500, MSS1000	SATPSU10

PHILIPS	CODE
STU802/05M	SATPSU1
STU801	SATPSU2

THOMSON	CODE
SRS4	SATPSU2

TOSHIBA	CODE
SAT99, TU-SDU200	SATPSU1

CODE	PRICE	CODE	PRICE	CODE	PRICE	CODE	PRICE
SATPSU1	650p	SATPSU6	650p	SATPSU11	835p	SATPSU16	730p
SATPSU2	650p	SATPSU7	650p	SATPSU12	1735p	SATPSU17	850p
SATPSU3	650p	SATPSU8	730p	SATPSU13	3125p	SATPSU18	1175p
SATPSU4	650p	SATPSU9	900p	SATPSU14	3135p	SATPSU19	650p
SATPSU5	650p	SATPSU10	1230p	SATPSU15	77.5p		

PACE SATELLITE TUNERS

MODELS	CODE	PRICE
PRD800, MSS200 (2GHZ) (221-2077062)	TUNER01	1650p
PRD900, MSS500, MSS1000 (2Ghz) (221-2177012)	TUNER02	1650p

PACE SWITCH MODE TRANSFORMERS

MODELS	CODE	PRICE
PACE9000	PACE9000	800p
PACEPRD800, PRD900	PRD800	550p

SATMETER

THE SATMETER IS A PROFESSIONAL PORTABLE SATELLITE STRNGTH METER DESIGNED FOR THE INSTALLATION AND MAINTENANCE OF SATELLITE TV SYSTEMS. THE SATMETER CAN BE USED AS STAND ALONE METER WITH POWERING THE LNB AS WELL AS IN LOOP. THROUGH OPERATION WITH SATELLITE RX POWERING THE LNB.

ACOUSTICAL SIGNAL: ON SIGNAL STRENGTH
INPUT IMPEDENCE: 75 Ohm
MAX.INPUT SIGNAL: -10 DBM

LED INDICATOR: VERTICAL/HORIZONTAL
POWER AMPLIFIER: 18 DB

FREQUENCY RANGE: 900 TO 2050 MHZ
DETECTION RANGE: -60 TO -10 DBM

ORDER CODE: TOOL 22 PRICE: 8500p

SATELLITE LNB'S

MAKE & MODEL	ORDER CODE	PRICE	MAKE & MODEL	ORDER CODE	PRICE
Cambridge AE22/AE5 0.8dB standard 10.95-ll.70 GHz Gold Range	LNB1	2160p	Cambridge AE7 Twin O/P H+V Both Enhanced	LNB7	4000p
Cambridge AE14 Universal LNB 10.7-11.7/11.7-12.75 GHz	LNB2	2500p	Cambridge AE2 Dual O/P H-V Separate Enhanced	LNB8	3550p
Cambridge AE21/AE5 Single O/P Switching LNB 1.0dB Standard	LNB3	2050p	Grundig Super Universal 'Anis' 10.7-12.75 GHz 0.8dB	LNB9	2600p
Cambridge AE19/AE6 Single O/P Switching LNB 1.0dB Enhanced	LNB4	2050p	Grundig Universal 'Anis' 10.7-12.75 GHz 1.0dB	LNB10	2250p
Cambridge AE23/AE12 0.8dB Enhanced 10.7-11.8GHz Gold Range	LNB5	2160p	Cambridge AE1 Twin O/P H+V Both Standard	LNB11	4000p
Cambridge AE8 Dual O/P H-V Separate Enhanced	LNB6	4000p			

FUSES

	TIME LAG (20MM)		QUICK BLOW (20MM)	
CURRENT RATING	ORDER CODE	PRICE	ORDER CODE	PRICE
100mA	FUSE36	75p	FUSE37	60P
160mA	FUSE01	75p	FUSE17	60p
250mA	FUSE02	75p	FUSE18	60p
315mA	FUSE03	75p	FUSE19	60p
400mA	FUSE04	75p	FUSE20	60p
500mA	FUSE05	75p	FUSE21	60p
630mA	FUSE06	75p	FUSE22	60p
800mA	FUSE07	60p	FUSE23	60p
IA	FUSE08	60p	FUSE24	60p
1.25A	FUSE09	60p	FUSE25	60p
1.6A	FUSE10	60p	FUSE26	60p
2A	FUSE11	50p	FUSE27	60p
2.5A	FUSE12	50p	FUSE28	60p
3.15A	FUSE13	55p	FUSE29	50p
4A	FUSE14	55p	FUSE30	50p
5A	FUSE15	60p	FUSE31	50p
6.3A	FUSE16	60p	FUSE32	50p

NB.
ALL FUSES ARE MADE IN THE UK AND FULLY MEET BS4265 & BS1362 SAFETY STANDARDS AND SHOULD NOT BE COMPARED WITH CHEAP IMPORTED TYPES.

CERAMIC PLUG TOP

CURRENT RATING	ORDER CODE	PRICE
3A	FUSE33	100p
5A	FUSE34	100p
13A	FUSE35	100p

20mm CERAMIC TIME LAG

CURRENT RATING	ORDER CODE	PRICE
6.3A	FUSE38	100p
8A	FUSE39	100p
10A	FUSE40	100p
3.15A	FUSE41	85p
4A	FUSE42	85p
5A	FUSE43	85p

38mm CERAMIC TIME LAG

CURRENT RATING	ORDER CODE	PRICE
10A	FUSE48	815P

32mm CERAMIC SLOW BLOW

CURRENT RATING	ORDER CODE	PRICE
8A	FUSE44	185P
10A	FUSE45	185p
15A	FUSE46	185p
20A	FUSE47	210p

****ALL THE ABOVE PRICES ARE FOR PACKS OF 10 FUSES****

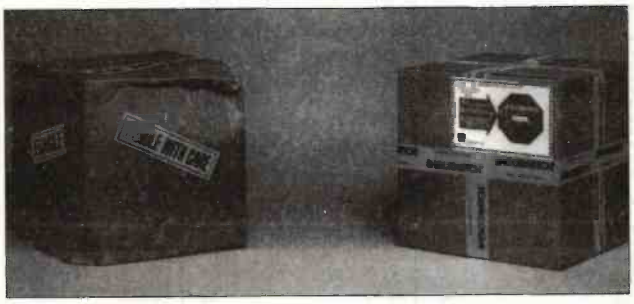
ETI ELECTRONICS TODAY INTERNATIONAL

News...

OVERSEAS READERS

To call UK telephone numbers, replace the initial 0 with your local overseas access code plus the digits 44.

Label licks carrier breakage disasters



An American company have been pleased to achieve zero damage level during shipment of their image scanners.

Previously, 7 out of 10 scanners were arriving at their destinations damaged and inoperative, costing the company, Ricoh Corporation, hundreds of dollars to return and repair the units, or send out an engineer to fix them. They tried a different carrier, with no success (does this sound familiar to anyone out there?) and so they resorted to an adhesive label.

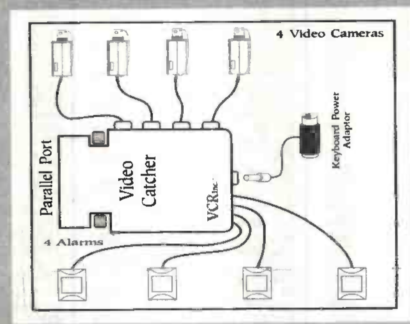
This label does more than carry a warning. The Shockwatch label provides an immediate alert if damage is caused during transit, and makes the carrier liable. Shockwatch is a precision impact detection device housed in the self-adhesive label which fixes directly onto the carton. Once the Shockwatch has been activated, it cannot be reset and therefore encourages safer handling. Ricoh's distribution manager Ken Shcramm said: "What a remarkable turnaround! We have move from a 70 percent dead-on-arrive rate to zero damage for the last five months." You see? They can do it. Now, if someone would develop an adhesive label that tells us where the package actually is, and just when it was left in the corner of the carrier's depot behind a pile of old cartons, or with a neighbour on the wrong side of the street (without authorisation), we might have the carrier business just about licked.

For more information about the Shockwatch, contact Protective Packaging, Dane Road Industrial Estate, Dane Road, Sale, Cheshire M33 7BH. Tel 0161 976 2006, fax 0161 976 3330.

MODSMODSMODSMODSMODSMODS

Some type errors appeared in the Valve Characteristic Tester, Issue 8 (18 July) 1997: In figure 6, page 61, the tantalum capacitor C21 is shown the wrong way round. Figure 8, page 62 and figure 13, page 41, are correct. In the Parts List, R61 is listed as 870k. This should be 820k. The diagrams are correct. In figure 7, page 61, pins 4,5 and 6 of SW1a are shown connected. This should be pins 3,5 and 6. Figures 1 and 10 are correct. The -ve end of the battery is marked SAT. This should read BAT.

Computer-driven video security interface



"Video Catcher" is a control interface that allows the user to connect four video cameras to a computer and monitor up to four camera locations simultaneously.

Designed mainly for security purposes, the Video Catcher has a number of features, some of which could be used in other video monitoring applications. As well as the cameras, up to four alarm switches can be plugged in, which will trigger a computer-generated alarm (standard computer sound or user-specified) if required

The interface is of Canadian design and is NTSC and PAL compatible. The software runs under Windows 3.XX and Windows95 (Catcher Plus under Windows95 only). The software allows up to four camera locations to be monitored on the computer monitor through icon-driven video windows, which can be scaled to any size within the screen, and located on any part of the screen in black and white or full colour (16 million colours per pixel with brightness, contrast, hue and saturation control). The four alarm inputs are self locking, normally-closed or open, and the unit is powered from the PC via a keyboard cable.

The video provides up to 15 frames a second refresh rate, and can be played back at various speeds or frame by frame, and as it is data-stored, the user can move from the start to the end of a sequence quickly. Frames can be printed out if you have a printer, or saved to floppy disk or other available media. Efficient compression allows an average of 280 colour frames on a diskette, and as much as 2.5 days of sequences to a 1 gigabyte hard disk if the system is set up to record at 1 frame per second.

The software provides snapshot capture, timed capture or alarm capture modes, and individual labelling of the four video windows. The host computer can be set up with a modem to contact the user by telephone in the case of an alarm, or to be accessible by phone to the user from a remote site.

Video Catcher is distributed in the UK by Eurotech Media Services Ltd., 15 Douglas Crescent, Houghton Regis, Dunstable, Beds LU5 5AS. Tel 01582 607880 Fax 01582 698152.

ETI ELECTRONICS TODAY INTERNATIONAL News...

AN AFFORDABLE DIGITAL CAMERA FROM MAPLIN

The latest edition of the Maplin MPS (Maplin professional) catalogue includes the Mustek VDC-100 digital camera, which is aimed at allowing keen photographers the chance to experience digital imaging at a realistic price. At under £100, the VDC-100 includes a features allowing the user to store up to 20 full colour images in the camera's built-in memory. Offering 24-bit colour scanning, the camera can take images in high or low resolution, and transferred easily to a home or office PC by the use of a single cable, which is supplied with the camera. The VCD-100 also includes iPhotoPlus OC software, allowing the user to edit and catalogue the images. Easy to use with a focus-free lens and automatic exposure, the camera comes with all the parts needed to get started, including a power adaptor, batteries, a carry pouch, TWAI driver and transfer cable. The price is £99.99 (please see the Maplin catalogue for any VAT or carriage terms that apply). The camera is available at the 40 Maplin stores and three Mondo Maplin superstores in the UK, and by mail order through the MPS catalogue. For further information, mail order details and your nearest store, call 01792 554002.

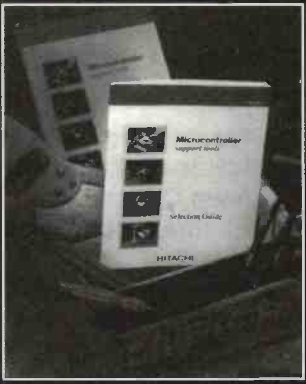
Nautical communications: a History Day at the Museum

Communciations by land and sea has always been vital to the naval and merchant fleets, and essential for safety and security. In February, the Open Museum at the National Maritime Museum, Greenwich, South London will be holding a one-day course, entitled Keeping in Touch, on Saturday 21 February.

The course will explore early methods used in ship to ship and shore to shore communications: flag signalling, the Admiralty telegraph, the early electric telegraph and the wireless telegraph. The speakers will be Dr. Allan Chapman from Oxford Univerisity, David Brown of the Naval Historical Branch, Mary Godwin of Cable and Wireless plc and Jenny Wraight of the Admiralty Library. The Museum can be reached via BR Maze Hill or Greenwich, or via the pier at Greenwich from various London piers, as well as by road.

The fee for the course is £25 (concessions £15). For free prospectus, or bookings, contact Caroline Tilbrook on 0181 312 6747. More information is available on the NMM web stie http://www.nmm.ac.uk.

Microcontroller support brochure for Hitachi devices

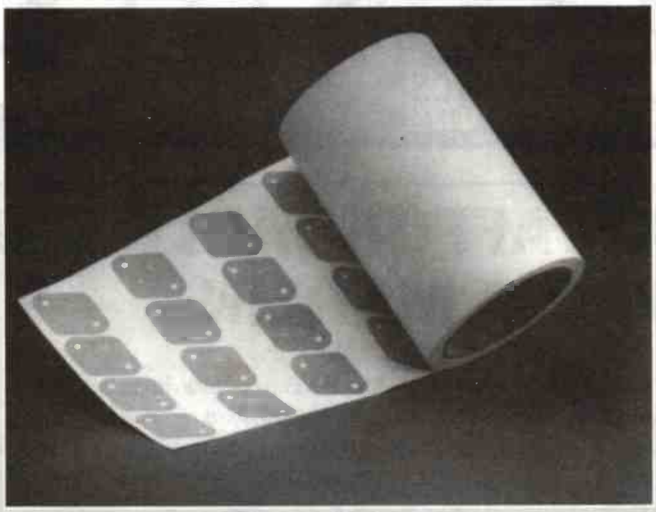


Hitachi have announced a brochure describing the full range of professional support tools for Hitachi microcontrollers. The 58-page brochure covers all aspects of the hardware and software tools which assist engineers in the development of applications based on the H8 and SuperH series of microcontrollers, and is colour coded for quick reference. Tools for all Hitachi's microcontrollers, incuding the H8/300, H8/300L, H8/300H, H8S, SH1, SH2 and SH3 are described.

The support tools described entry-level and high-functionality in-circuit emulators, effect low-cost evaluation boards and on-chip Flash memory microcontroller programming interface and evaluation boards. Software support tools include debuggers designed to provide a consistent interface across all the hardware development systems. Details of the current toolsets available are arranged by type of tool and microcontroller family. Third party support information is provided in another section. The toolsets for each microcontroller family are identified by full part numbers in an availability guide section.

For more information please contact Vince Pitt, Hitachi Europe Ltd., Whitebrook Road, Maidenhead, Berks SL6 8YA. Tel. 01628 585163, fax 01628 585160.

A better washer



Thermaphase Differential Phase Change Thermal Interface is a high-grade washer material for heat management in power semiconductors, microprocessors and other power electronics. The phase-change material is a dry-to-touch solid at room temperature. At temperatures slightly above normal semiconductor operating temperature, the washer material changes to a liquid state of a nature that flows into the microscopic interstices of both the semiconductor and heatsink materials to provide 100% thermal contact. The resulting decrease in thermal resistance cools the semiconductor to below the phase-change temperature of the washer compound, so that it returns to its solid state.

The material is made in an electrically insulating and an electrically conducting version. The thermal resistance of the electrically insulating version can be as low as .170 C/W. The electrically conductive type has a thermal resistance of only .025 C/W.

Thermaphase overcomes some problems with phase-change materials. It becomes liquid only when the semiconductor heats up for the first time; its structure aids the semiconductor to develop enough heat (67 degrees C) to initiate the change from a solid to a flowable form. After this is returns to its solid state and remains solid during all normal semiconductor operation. The new compound used has a large thermal impedance differential. It is not easily rubbed off its carrier when used as a coating, and has a higher resistance to electronics cleaning solvents than older materials. Storage is easier due to lower temperature sensitivity. The current shift towards reducing toxicity wherever possible is indicated by the use only of food grade materials in manufacturing the material.

For more information contact Orcus Inc. Box 307, Stilwell, Kansas 660085, USA. Tel. (00) (from UK) +1 913 397 8225 email: orcusnet@tyrell.net

Handheld Spectrum analyser for field applications

One for drawing to the attention of the engineering purchaser, perhaps, rather than for the birthday list, but Datalines Communications have introduced an innovative new handheld, battery powered spectrum analyser for work in the field.

Aimed specifically at service engineers working on radio service and installation tasks, the analyser covers the spectrum from 100kHz to 2 GHz and is completely portable, powered by internal alkaline batteries or rechargeable nicads. A clear liquid crystal display and straightforward menu structure allow engineers to check radio signals in a wide variety of situations, for example, in a radio tower.

The unit comes complete with a soft carry case and antenna, with a mains adapter, and an RS232 interface for exporting plots to a PC (not included), for a competitive £1295 (ex VAT).

For more information contact Peter Lagesse at Datalines Communications Ltd., Sherwood Place, 155 Sherwood Drive, Bletchley MK3 6RT. Tel. 01908 370011.

MODMODMODMODMODMODMODMODMODMODMODMODMODMODMODMODMOD

In Issue 13 (last month) figure 2 in the 4-Go Rocket Launcher appeared without the component annotations. For a copy of the complete idagram, please contact Sandra our administration assistant (see page 74) or send a self-addressed envelope.

Inside Microcontrollers

Many readers of ETI over the past few years will have noticed that a large number of projects now use microcontrollers. Robin Abbott describes the underlying architectures of microcontroller families useful to one-off designers and industry.

Microcontroller devices allow users to set up complex functionality within a single integrated circuit, in effect as if they had the ability to define their own chips. In this article I shall look at a number of microcontroller families available from different manufacturers and some of their capabilities. I shall be looking not only at the microcontrollers which readers may be familiar with from ETI, but some devices which are mainly intended for a use in commercial or industrial applications.

What is a microcontroller?

A microcontroller is a microprocessor that includes within it the rom, ram and peripheral devices to enable digital control of an application with the minimum of external circuitry. Devices are available with the minimum amount of rom and ram necessary to control the smallest applications, right up to devices with 32 k of rom and 2k of data memory and eeprom (electrically erasable programmable read only memory). Peripheral devices available on microcontrollers are normally, at the minimum, input/output ports, and some type of real time counter/timer. A number of the devices include further peripherals such as:

Eeprom
Analcgue to digital converters (ADCs)
Capture and compare capabilities
Special ports to enable communication with normal microprocessor bosses
PWM digital to analogue output ports
Interrupt facilities
Synchronous and asynchronous communications interfaces
The I2C peripheral control bus
Computer-operating-properly, or watchdog timers
Sleep or power down modes to allow operation in battery operated environments
Analogue comparators for simple analogue to digital conversion

The smallest devices are available in eight pin dual in line packages, the larger devices are available in ball grid arrays with hundreds of pins.

Although many people think that microcontrollers are a relatively recent development, in fact the first microcontrollers were made available in the mid-1970s. In 1976 Intel introduced the MCS-48 which was quite impressive for the time. The eight bit CPU was integrated with 1k words of data memory, input/output ports, and an eight bit timer counter. The device revolutionised system design, and the chip was widely used on a whole new range of different product areas. In 1980, the 8051 architecture was introduced. The other members of this family were the 8751 and the 8031. The specification for these devices is covered in detail later in this article. However the 8051 architecture is still widely available today in a variety of forms, albeit with much greater capability than that found in the original device from 1980.

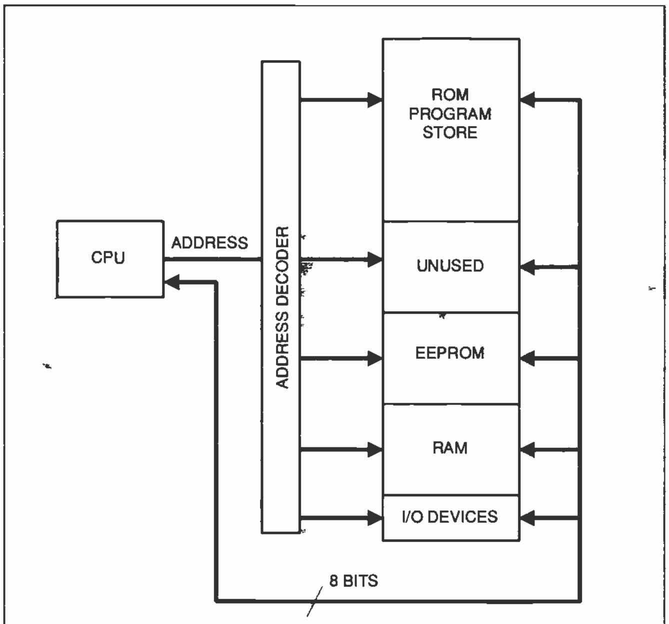
As microcontrollers have been available for so many years, it is interesting that their very wide-scale use in the amateur, educational and smaller commercial markets, has only become evident over the past few years. The main reason for this change is the availability of low-cost simulators, emulators, and development tools for microcontroller devices, and the reduction in price of the chips.

Microcontroller architectures

There are two fundamental types of microcontroller architectures. The first type is the Harvard architecture. The second type is the Von Neumann architecture.

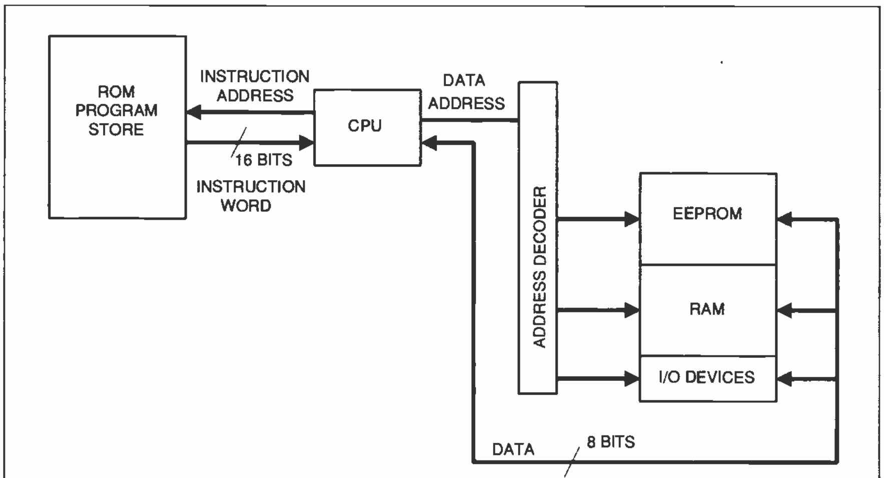
Harvard architecture has been traditional in mini computers and main frames to date and may not be familiar to all readers. The architecture has completely separate buses for the rom or other memory which holds the program, and for the ram which holds data. This enables the processor to read the program instructions at the same time as accessing the data memory, so that many instructions can be executed within a single bus cycle of the micro processor. This is achieved by the processor reading the program memory at the same time as it executes the previous instructions. This is illustrated in **figure 1**, which shows the architecture of Harvard and Von Neumann processors. **Figures 2a and 2b** show operations on the buses as a typical Harvard and Von Neumann processor executes one instruction (in this case an instruction to increment the contents of one data memory location). It is worth noting that although the separate memory spaces allows simultaneous access to program and data memory, not all controllers do actually make use of this capability.

This type of architecture also allows the width in bits of the program memory bus to be wider than that of the data memory bus. Typically Harvard architecture microprocessors



VON NEUMANN ARCHITECTURE - CPU CAN ONLY ADDRESS ONE TYPE OF MEMORY AT ANY TIME

Figure 1 Harvard and Von Neumann architectures



HARVARD ARCHITECTURE - CPU CAN ADDRESS AND PROCESS INSTRUCTION AND DATA STORE SIMULTANEOUSLY, NOTE THAT BUS WIDTHS IN BITS ARE SHOWN ONLY FOR THE SAKE OF EXAMPLE

have a wide program memory bus which can be from 12 to 64 bits in width. This enables the instruction for the microprocessor to contain not only the information which tells the processor what to do, but also data for the instruction. Thus, in a single instruction, data can be moved from register to register, or an eight bit value can be loaded to a register, or a single instruction may cause the processor program counter to jump to a another location or to a subroutine.

The Von Neumann architecture is more familiar to traditional microprocessor designers. In this type of architecture the program and data memories share the same address and data bus. This has the advantage that the device may freely read data from the program memory, and can implement self-modifying code.

Most systems have a data bus which is a only 8 bits wide. This implies that the instruction for the micro processor does not normally hold enough information for the complete instruction set and the data within a single 8-bit word. Thus a typical instruction may consist of one or two bytes to tell the processor what to do, and subsequently a number of bytes which contain the data for the instruction. Following the read of an instruction which affects program data, the processor must fetch information from memory, process it, and possibly write it back to memory. This can result in a very slow execution of a typical program. This type of architecture (Von Neumann) often has a very rich instruction set, and is referred to as a complex instruction set computer (CISC).

The Harvard architectures are easier to program for software driven delay functions. For example, it is quite straightforward on the PIC microcontroller to implement the software to run asynchronous serial input/output functions, because every instruction takes only one or two machine cycles to execute, whereas with the HC11 instructions take between 1 and 5 cycles to execute, making it much harder to design accurately timed code.

As an example of the difference between different instruction sets, consider the case of an instruction to move a constant value to a memory location. We shall consider the PIC and HC11 microcontrollers.

The PIC controller has a RISC (reduced instruction set computer) instruction set. To move a constant value to memory, first the working register (W register) must be loaded with the constant value which takes one instruction. Next, the value within the W register is moved to an address in memory which also takes one instruction. This takes a total of two machine cycles.

The HC11 microcontroller has a CISC (complex instruction set computer) set. To move a constant to memory:

First a constant value is moved to an accumulator (The HC11 has two accumulators). Although this is only one instruction, it takes two program bytes to define the instruction, and two machine cycles to move the constant value to the accumulator.

Next the value within the accumulator is moved to a data location. This is also one instruction, however it involves a total of four machine cycles. The first is the instruction which defines a move from the accumulator to memory. The second and third bytes follow the instruction byte and define the address in memory to which the accumulator value is to be written. The final cycle occurs when the controller writes the single byte value from the accumulator to the defined memory address.

The total time taken for the instruction is six machine cycles, one-third of the speed of the RISC instruction set.

Microcontroller CPU bit width

Microcontrollers are available with a CPU bit width varying from four bits up to 32 bits. The devices with a smaller number of bits normally operate with lower clock frequencies and are used for a less demanding, or low power applications such as LCD drivers, stepper motor drivers, event counters and interval timers, telemetry, toys, and security devices.

The processing power of the CPU is related to the bit width of the CPU. This is because the CPU can process more information in each instruction if it has a wider bit width. However if the application can represent real world data in a small number of bits, then there is no need for the larger processors increased bit width. In this case there will be little difference in processing capability for two processors of

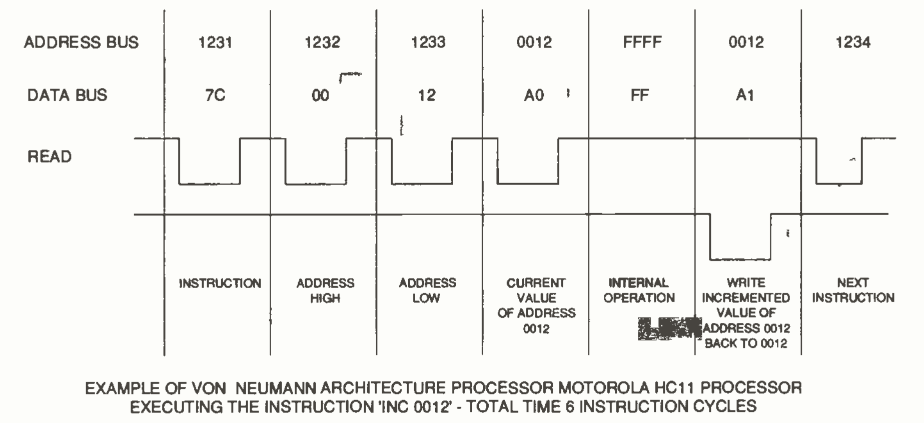
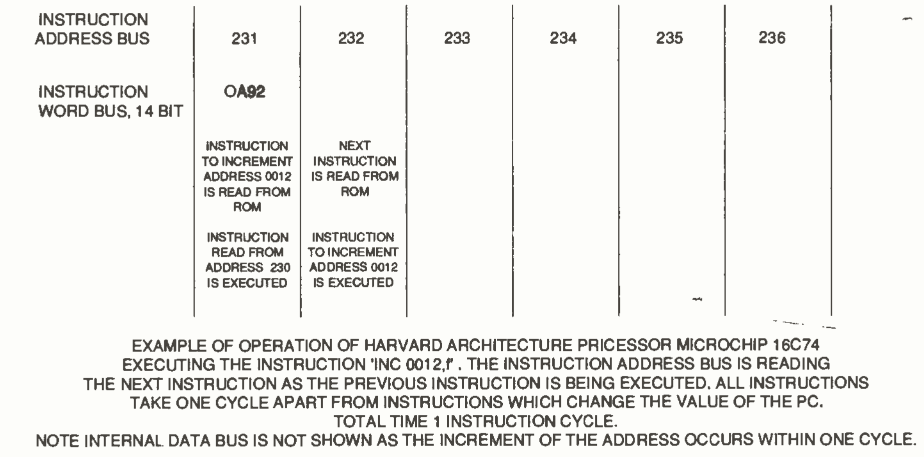


Figure 2: a comparison of the Von Neumann and Harvard architectures



differing CPU bit width operating at the same clock frequency.

Microcontroller families

A large number of manufacturers produce microcontrollers designed for a wide variety of applications in a wide range of CPU bit widths.

The Intel 8051

The 8051 microcontroller was released by Intel in the late 1970s. The original device specification offered a 4K rom, 128 bytes of data memory on the chip, one micro second instruction cycle, 32 input/output lines, a serial port, two 16 bit timer/counters, and an interrupt structure. The device also included a hardware multiply and divide capability. The 8751 was the 8051 device but with normal ultraviolet erasable eprom for program development, prototyping, and for production devices which have the capability for later upgrade. The rom and ram were on separate address busses. This specification was impressive at the time, and even now exceeds that of many lower-cost microcontrollers.

The pinout and logic symbol of the 8051 is shown in **figure 3.** The internal architecture of the 8051 is shown in **figure 4**. The device is a CISC controller, a complete instruction consisting of a sequence of one or more bytes of program rom. The instruction set is not efficient by modern standards, for example, a write of a constant value to a specified location in the ram requires three bytes of instruction rom and two machine cycles. However each machine cycle is twelve cycles of the device crystal clock, so 24 cycles of the device clock are required for this simple operation.

The 8051 allows both rom and ram to be expanded by using the input/output ports as a multiplexed address/data bus. In this mode the external memory is split into separate rom and ram areas in the same way as it is internally to the chip.

As an example of modern versions of the 8051, we can look at the Philips version of the device. These controllers in the p87cXXX series of devices have up to 32K of rom, and up to 1536 bytes of ram.

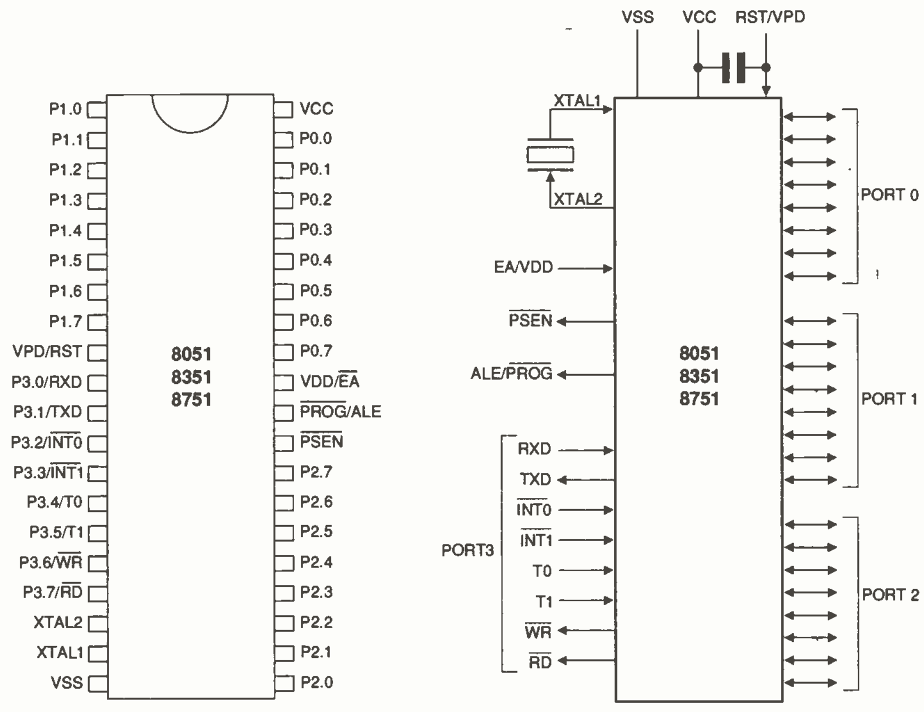


Figure 3: the Intel 8051: pin-out and logic diagram

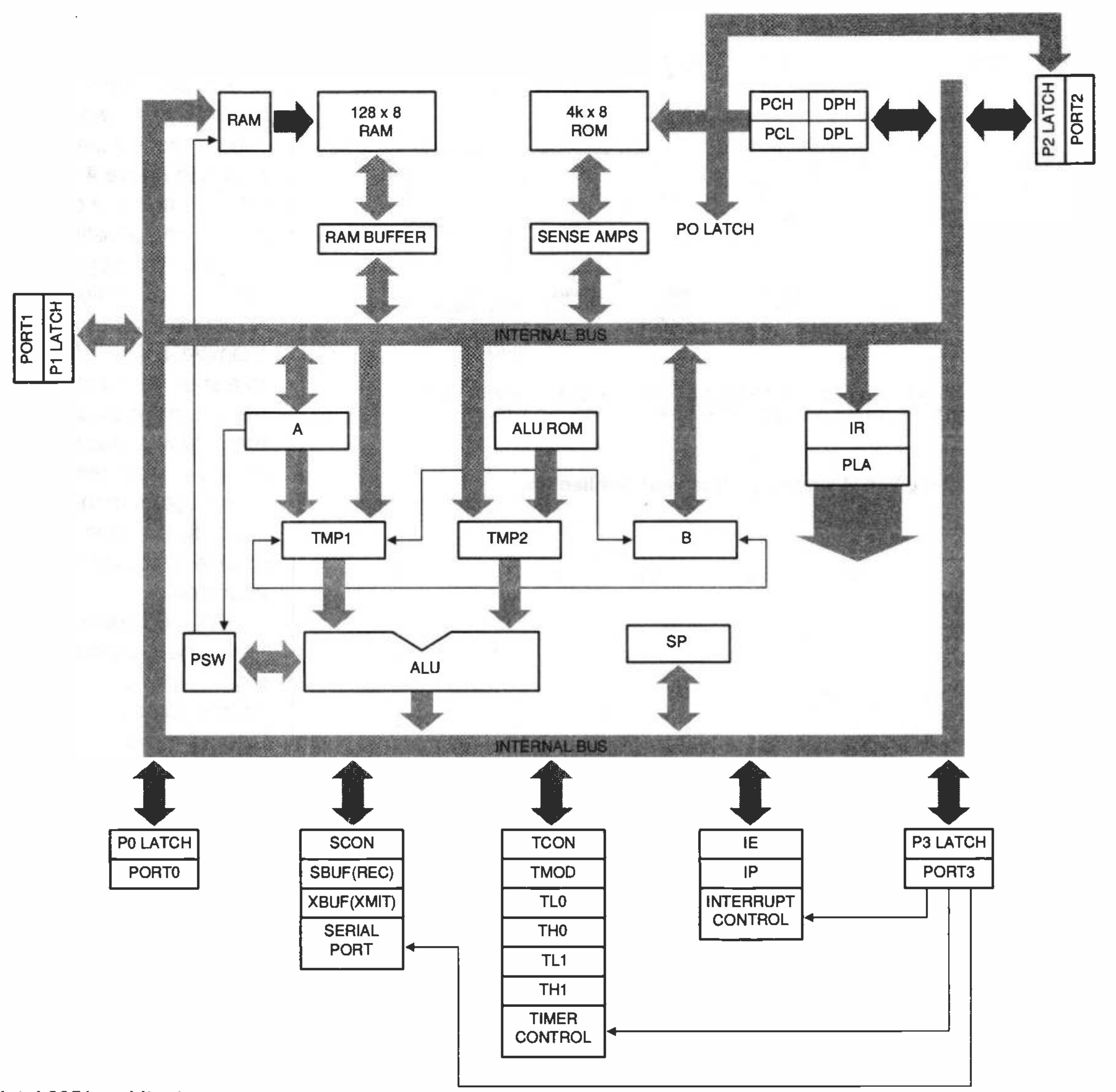


Figure 4: Intel 8051 architecture

Peripheral devices include Synchronous and Asynchronous serial ports, PWM output, special purpose 16/24 bit multiply and divide hardware, comparators, analogue to digital converters (10 bit), and even a CAN controller bus. Atmel versions of the 8051 offer similar capabilities, but are also available with a flash program rom, and can be upgraded in-system at low-cost.

Epson 4-bit microcontrollers (ASMIC)

The Epson sc6210 4-bit microcontroller series is available in only in a rom configuration (the rom is programmed on device manufacture), so they are only suitable for large scale development. The series is particularly suitable for use in battery-operated applications because the supply current is as low as 2uA when the processor is halted, and only 150uA typically when the processor is operating normally at a clock rate of 32 kHz.

The device instruction width is twelve bits, and the data ram width in line with the processor CPU width is 4 bits. Devices are available with the rom memory sizes from 1K up to 8K.

A number of devices in the series have the capability for LCD driving, and with a large number of output pins available for this purpose. These devices are available in large packages to allow for the large number of pins required to drive an LCD display. Other peripheral interfaces available include:
Synchronous serial interfaces
Asynchronous serial interfaces
Analogue to digital converters
Melody functions (intended for games, clocks, watches, and timers).
High accuracy analogue to digital converters (intended for digital multimeters)
In DTMF generators on a device with LCD drivers (intended for telephone applications)
Mini printer drivers, intended for portable calculators and EPOS applications.

The Microchip PIC series

The PIC Series of microcontrollers is probably the best known range to the readers of this magazine as it the most accessible microcontroller at low cost and has been used in a wide range of projects within ETI. PIC microcontrollers are available in two main configurations. The first is the 16 series, which are based on internal rom, and are 8 bit controllers. The second, and perhaps less well known, series is the 17 series which are more capable devices and include the ability to use external program and data memory.
The 16 series are available with either 12 bit wide, or 14 bit

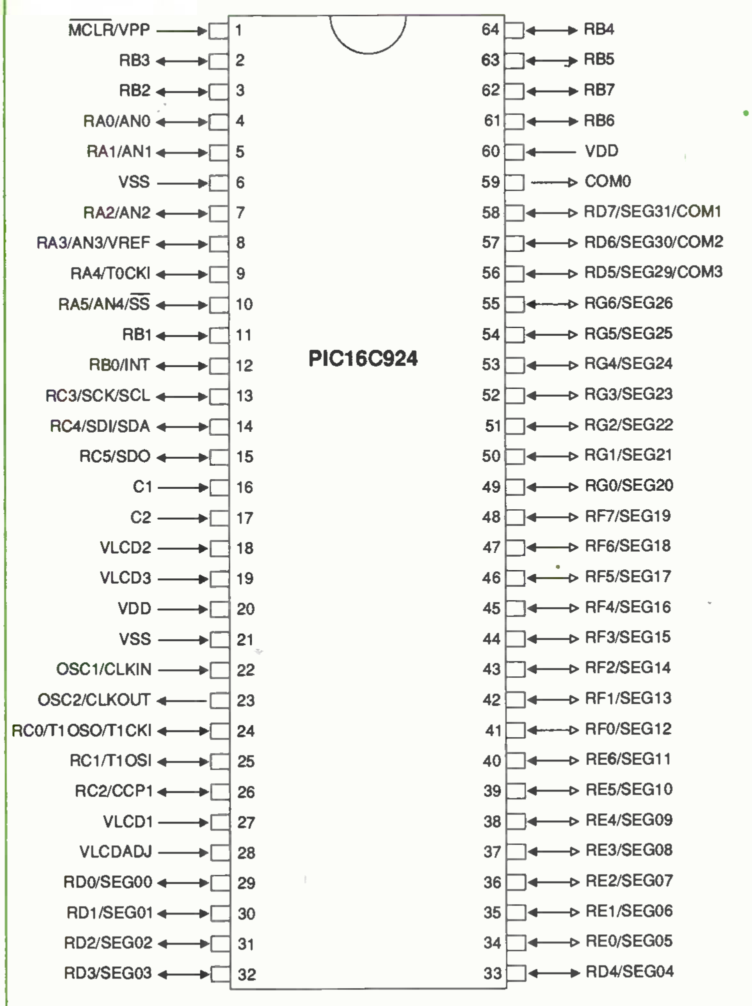


Figure 5: the PIC 924 LCD driver pin-out

wide program memory. The 12 bit wide series has slightly less instructions, and is generally less capable than the 14 bit series. Examples of the pin outs and architecture of a PIC device are shown in **figures 5 and 6**.

Devices are available in packages from 8 pins to 40 pins. The input/output capability varies from 6 pins in the smallest devices, up to 30 free pins in the largest devices.

Some of the capabilities available within the series are shown below: All the devices have an eight bit real-time counter timer.

Eeprom capability
Analogue to digital converters
Analogue comparators
Ten-bit PWM digital to analogue conversion
Synchronous and asynchronous serial communication
SPI bus support
Interfaces to a standard microprocessor bus

The PIC controllers have a Harvard architecture, the instruction set is based on a single working register, or accumulator which is used for all arithmetic operations. This means that operations such as moving data require two or more instructions. In addition the PIC controllers have a limited stack which only allows eight levels of sub-routine, and does not allow the program to push and pop data, this makes the task of writing compilers more difficult than with a traditional stack.

The PIC series have been very popular due to the ready availability of an assembler, simulator and programmers for the PC. The devices are very reasonably priced, and are widely used in amateur, educational and commercial applications.

For development purposes special versions of the PIC devices are available with a windowed package, which allows them to be erased under a UV lamp. The only disadvantage with the PIC controllers, is the high cost of emulators for the series due to the inability to use external program memory.

The AVR microcontrollers

The Atmel AVR microcontrollers, are a relatively new series of devices. They have capabilities ranging from 1K to 8K of rom and ram from no bytes of internal ram, up to 512 bytes of ram. Some of the larger devices in the series have the advantage of being able to use external ram on a multiplexed address/data bus. This allows up to 64K of external data ram.

The devices have a 16 bit wide instruction bus, and an eight bit CPU with a Harvard architecture. The 32 internal general purpose registers all have the capability to act as an accumulator in the instruction. A wider instruction bus allows the AVR controller to implement several instructions which allow data moves or operations to be implemented in just one program instruction, making the devices very efficient in their use of program rom.

The devices also have the capability for flash programming while in-circuit. This makes them particularly suitable for applications where it is necessary to upgrade application functions while it is in service. This capability also means that for development purposes it is not necessary to purchase special windowed (and expensive) erasable devices.

Motorola microcontrollers

Motorola have a wide range of microcontrollers available from eight bit devices based on the original 6802 micro processor, to the newest 32-bit microcontrollers with a wide range of capability for communications functions. We will take a look at one of the eight bit controllers, and one of the 32 bit controllers.

The HC11 microcontroller is based on the Von Neumann architecture. This means that projects based on the controller are more similar to traditional micro processor control systems. The device is available with a range of rom and ram configurations, and has the capability to replace some of its input/output pins with a multiplexed address/data bus, which enables the device to be freely used in configurations with external rom and ram. This capability also allows the device to have reasonably cheap emulators designed for it. Device capabilities include:

Asynchronous and synchronous serial communications
Internal eeprom
A comprehensive counter timer and to compare system
Analogue to digital converters

The main disadvantage of this microcontroller is its von Neumann architecture, as a result of which some instructions may take a large number of a machine cycles to execute. The HC11 is widely used in industrial applications, and a new version, the HC12, is now appearing.

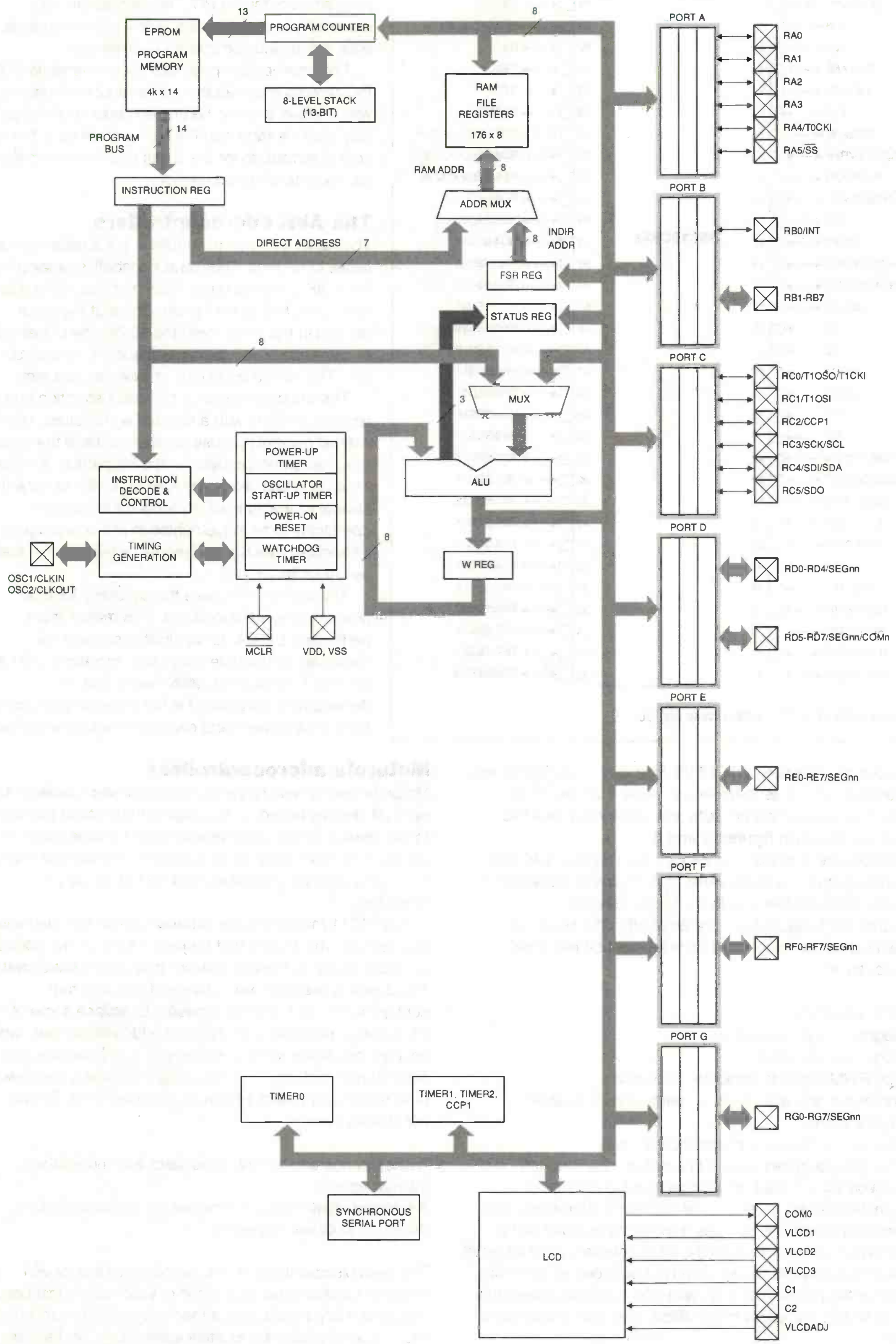
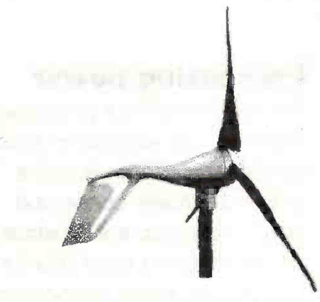


Figure 6: PIC 924 architecture



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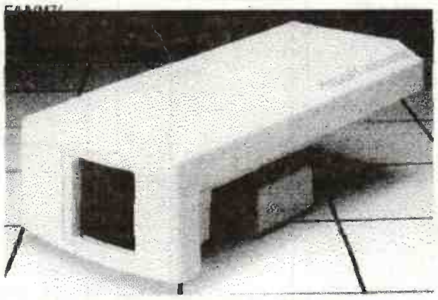

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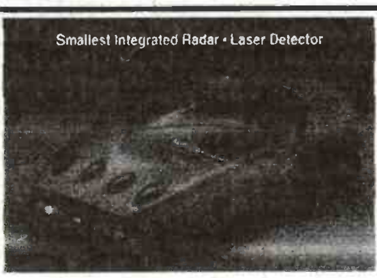

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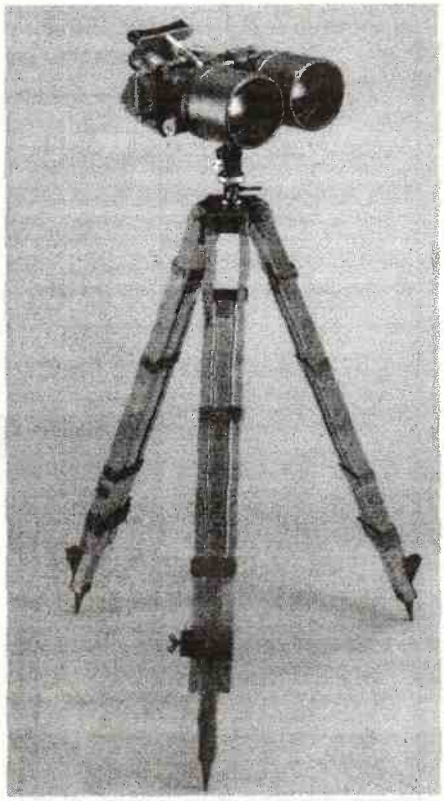

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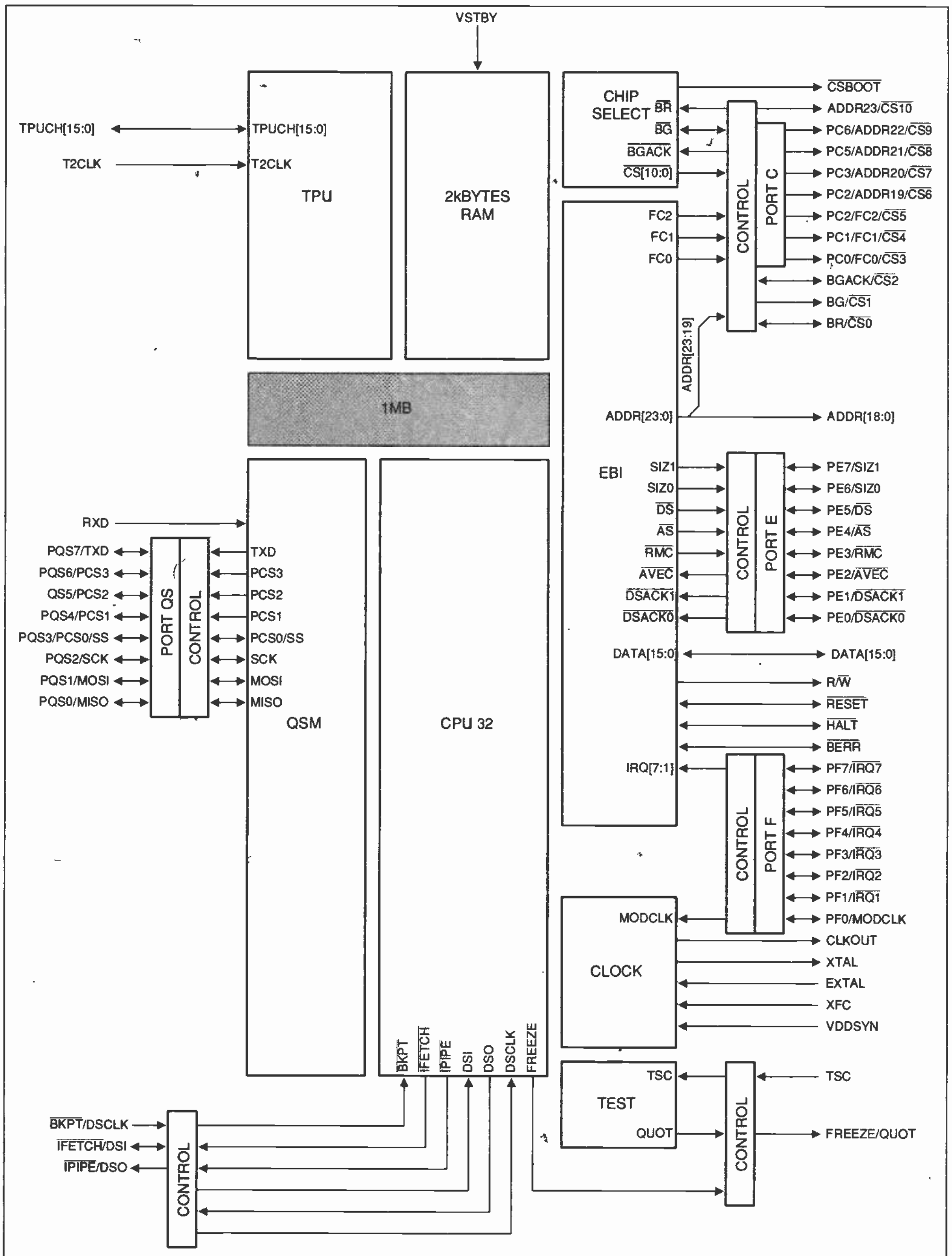

Figure 7: the Motorola 68332 architecture

The 68332 is a 32 bit microcontroller. It has 2K of internal ram, but due to the power and complexity of the device it is not expected to be implemented in single chip devices with internal rom, therefore there is an external address bus for a rom.

The device will be implemented in applications with a wide variety of interface types, and therefore there are very few internal peripherals. There is a dedicated timer processor unit (TPU). This is a dedicated microengine which operates independently of the main CPU, which has 16 independent programmable channels and pins, and two timer count registers. The processor has a dedicated serial module with a specific SPI bus, and a special 8-bit dual function port. The architecture is shown in **figure 7**.

Choosing a microcontroller

The choice of a particular microcontroller for an application is based upon a number of factors. These are covered below.

Processing power

The requirement for processing power by the application must be determined. Applications which are mainly concerned with a man/machine interface do not require a great deal of processing power. Applications which have a significant real-time processing requirements, an example of which may be video processing, clearly require more controller capability. Processing power is related not only to the speed of the controller, but also to the bit width of the CPU used within the controller.

RISC or CISC

Although ease of writing code, and rapid execution seem like compelling arguments to use the RISC architecture, in practice it is not quite so obvious as it seems at first. The CISC architecture normally allows a wider range of instructions for data handling, and often a single CISC instruction can achieve as much as several RISC instructions. An example of this occurs with the use of a large data space, the RISC architecture can normally address a larger data Space, only by use of pointer registers, or paging bits, whereas the CISC architecture may usually address up to 64K of a data ram in the same way as a small amount of data ram. Compilers are normally optimised to use the features of the instruction set, and so it is true to say that generally a compiled program for a RISC processor will be more rapid in its execution then the CISC processor.

Another example of the superiority of a CISC processor comes with the use of a stack. The CISC processor with a rich variety of instructions for manipulating stack data can often handle compiler local variables with a far greater ease than a RISC processor (such as the PIC which does not have a flexible stack architecture. In this example access to automatic variables can be very much faster on the CISC processor.

LProgram memory size

The size of the program memory required is related to the number of functions which are required to be performed by the controller. A processing intensive application is not a necessarily the biggest user of program memory. Most simple microcontrollers have less than eight k of program memory. Program memory size is also related to the type of

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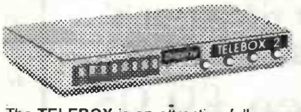

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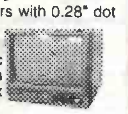

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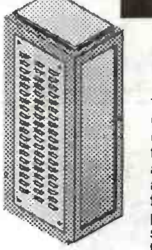

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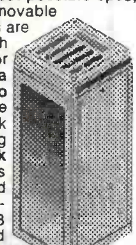

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development which will be used on the application. Most microcontroller families have C compilers available for them. There is little doubt that a compiled application requires more program memory than applications which are written entirely in Assembler code.

Flash eeprom or OTP

The requirement in an application for the system to be upgraded during use, will drive the controller requirement to an eeprom device. A possible alternative is the use of a windowed UV erasable device, however these can be quite expensive, and the device must be fitted in a socket unless the entire application board can be a fitted into a UV eraser.

Peripheral devices

The peripheral devices available on a controller family are obviously of importance in choosing a device. There is little point in planning a complex MMI with an LCD display of 40 segments if the device does not have a substantial input/output capability. The peripheral devices available fall into groups: communication, control of other chips, real-time control, and digital to analogue trans-conversion.

Data ram size

Although the amount of the data ram available within a controller may seem to be very important, in practice, most applications have a relatively low data storage requirement. In practise the author has found that 256 bytes of ram is more than enough for almost all applications. The requirement to store data whilst the system is powered down is quite important in a number of applications. It may be used to store configuration data selected by a user, or during application manufacture may be used to store select-on-test or tuning information.

Tools, simulators and emulators

The development tools available for a controller are very important. Assembler may be used for small applications, or where speed of program execution is very important, however for many applications the ease of writing, and maintaining compiled code (such as C) is of overriding significance. Many manufacturers provide a C compiler free of charge, but C compilers are available commercially for most controllers. Users should be aware that some architectures (such as the PIC) do not lend themselves very well to efficient compiler usage, due to the lack of a free and a flexible hardware controlled stack.

Most manufacturers provide Assemblers free of charge. However it is fair to say that the ease of use and the facilities offered by these assemblers varies considerably.

The Harvard architecture does not lend it self easily to the production of a hardware emulator. This is because the program memory is not usually available except during device programming. This normally implies that special devices must be used in hardware emulators, these are often produced in small quantities and can be very expensive. Although emulators are available which do not use these special chips, they usually suffer from a lack of emulation accuracy in some areas. Many manufacturers offer a simulator for users who do not have the resources to purchase a hardware emulator. Simulators are often a good and accurate representation of operation in a real system. However it is very hard to model interactions with a complex and real-time system in software.

Development Methods

There are a wide range of development methods available for microcontrollers. The devices such as the Epson four bit controllers which are only available in Mask programmed rom configurations, are normally developed by the customer in conjunction with the microcontroller manufacturer.

Instruction sets, and assemblers

The complexity of the microcontroller instruction set is dependant on the type of microcontroller, and its architecture, and the instruction set bit width. For the smaller microcontrollers it is quite possible to write a complete application into the controller's assembly language set. In fact with many microcontrollers it is desirable, not only in terms of program size, but also in terms of program execution time, to write in the controller's native assembler rather than a high level language. For the more complex controllers such as the Motorola 32 bit devices, or the top Hitachi devices, it is almost inevitable that applications which make use of the power of the controller can only be sensibly developed in a compiled language. Almost universally compiled languages are C, or C++.

There are available basic compilers for many controllers including the PIC and the 8051. However although basic is an easy to learn a language and the compiled code resulting is likely to be almost as efficient as for C, basic does not have a standard dialect. This means that it can be very hard to port code written for one controller, or one basic compiler, to a different controller or compiler. For this reason most commercial developments use a version of the ANSI C, or C++ standards.

For the PIC controllers there are available basic interpreters. These systems rely on an external eeprom, to store the program into a token form. They offer very rapid developments times. However as the interpreters must read a code byte from the eeprom to instruct them as to the operation to be performed, they are nowhere near as fast as a compiler. However these systems are very useful for prototyping purposes.

The basic concepts of assemblers language which may be familiar to developers from micro processes such as the 6502, and the Z80, are maintained for microcontrollers whether they use the RISC or the CISC architectures. Most microcontrollers have a number of registers, one or more accumulators, a stack, and an instruction set which includes basic operations to the accumulator to the stack, and to control program flow.

RISC architectures such as the AVR series command may not have a single accumulator, but may allow a variety of standard accumulator instructions to be applied to any of a larger number of file registers, the disadvantages, of the RISC architecture may become apparent when the large amounts of ram are to be addressed, or when a large stack is to be used, when it may be necessary to accept bits in paging registers, or to set up an artificial software stack (which can be extremely slow).

In practice it is fairly straightforward to a develop programs for any of the controllers in their native assembler once the basic concepts of assembly language have been mastered. The biggest problem is simply that of the learning of the assembler dialect, and manufacturers have not yet been able to agree on a universal assembler language! This extends to the capabilities of the Assemblers available for the controllers. The most advanced allow complex conditional assembly, and multi-line macros with local variables and multiple parameters, and assembly of several files into the whole. The more complex microcontrollers also have the capability for the use of a linker. A linker is extremely useful to developers who wish to generate libraries of standard functions, which are not all to be used within every program.

The development tools available free of charge from the manufacturers also vary considerably in their quality. The best

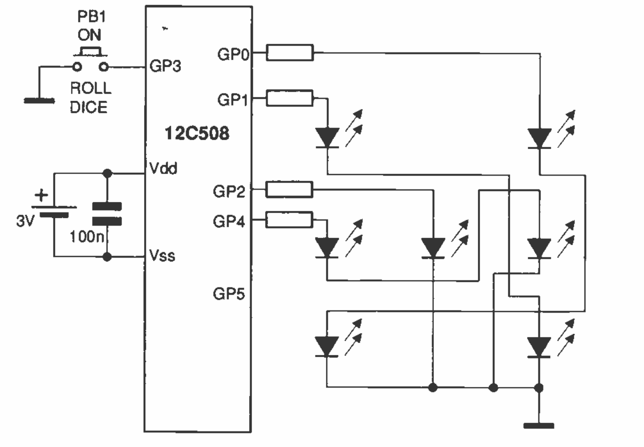


Figure 8: minimal implementation of digital dice using an 8-pin microcontroller

systems have integrated editors, assemblers, simulators, and programmers. The worst are simple DOS command line tools which are difficult to use, or are not intuitive, and are not suitable for large programs. Despite the difference in the MMI of the various assemblers and simulators the features offered in some of the DOS and simulators are as good as any others' available. For example the author believes that the simulator available for PIC microcontrollers offers among the best facilities available in a free development tool, but is hampered by a crude 25 line display, command line interface.

Designing with microcontrollers

As an illustration of the ease of use of microcontrollers **figure 8** shows a simple digital dice constructed using the Microchip 8-pin device, the 12C508. This circuit is based on an internal resistor/capacitor oscillator, and requires no external components for reset, or for the oscillator. The push button is connected to an input with a pull up resistor internally which can be enabled or disabled. The application is battery powered, which is possible as the program goes into sleep mode after the display has shown for ten seconds. The push button causes an internal interrupt which wakes up the device.

Most microcontrollers use a crystal oscillator, however some allow the use of an external resistor/capacitor oscillator, and some allow the use of an internal oscillator and require no external components. There are very few microcontrollers which use dynamic storage internally, and therefore most can use crystal or other clock rates from zero up to the maximum chip rate, which may be as high as several tens of major Hertz for the more powerful devices.

Many microcontrollers have internal reset circuits, and the external reset pin is either tied to one of the supply rails, or in some devices is available for use as an input/output pin if it has been disabled. There are very few microcontrollers which use dynamic storage internally, and therefore most can use crystal or other clock rates from zero, up to the maximum chip rate, which may be as high as several tens of MHz for the more powerful devices.

Many microcontrollers allow the use of battery power, because their consumption is so low in normal operation, and they allow the ability to go into sleep mode. Power consumption is directly related to oscillator frequency, and low power devices operating off a 32kHz watch Crystal have a typical power consumption which is less than 50 micro-amps, and therefore can be work for many thousands of hours off alkaline battery sources. Most microcontrollers will operate from battery sources in the range of three volts up to six volts. However some devices are available which operate at even lower supply voltages. When designing a circuit with a microcontroller it is quite important to ensure sufficient power supply decoupling close to the chip, which normally implies the use of a 100 nanofarad capacitors close to the device.

The output capability of the microcontroller's input/output pins is an important consideration which some designers fail to note. Reasonably high power outputs can sink or a source up to 20 milliamps, without significant change in output voltage. However it should be noted that many devices at have a limit on the maximum output current on the complete device, or a limit on the maximum output current on a group of pins (for example all the pins on one side of the device which internally to the chip are supplied from one set of power pins).

The circuit layout is not critical at the lower clock frequencies , however as with any circuitry frequencies in excess of 10 megahertz need careful design around the oscillator to ensure clean digital signals. **Figure 9** shows the a comparison of some of the microcontroller types discussed in this article.

DEVICE	MANUFACTURER	CPU BIT WIDTH	ROM	RAM	EEPROM	ROM TECHNOLOGY	I/O PINS	MAX OSCILLATOR FREQ
12C058	MICROCHIP	8	512	25	0	UV, OTP, MASK	6	4MHz
16C74	MICROCHIP	8	4k	192	0	UV, OTP, MASK	22	20MHz
16F84	MICROCHIP	8	1k	36	64	FLASH	13	10MHz
17C44	MICROCHIP	8	8k	454	0	UV, OTP, MASK	33	25MHz
68332	MOTOROLA	32	0	2048	0	–	32	20MHz
68HC11	MOTOROLA	8	20k	512	2048	UV, OTP, MASK	38	8MHz
68HC12	MOTOROLA	16	20k	512	2048	UV, OTP, MASK	94	8MHz
8051	INTEL	8	4k	128	0	UV, OTP, MASK EPROM	32	12MHz
AT90S1200	ATMEL	8	1k	32	64	FLASH	15	20MHz
AT90S8515	ATMEL	8	8192	512	512	FLASH	32	20MHz
SMC6244	EPSON	4	4k	384(x4)	0	MASK	32	2MHz
SMC88316	EPSON	8	16k	2k	0	MASK	110(INC LCD)	4.2MHz

Figure 9: comparison chart of a selected sample of microcontroller types

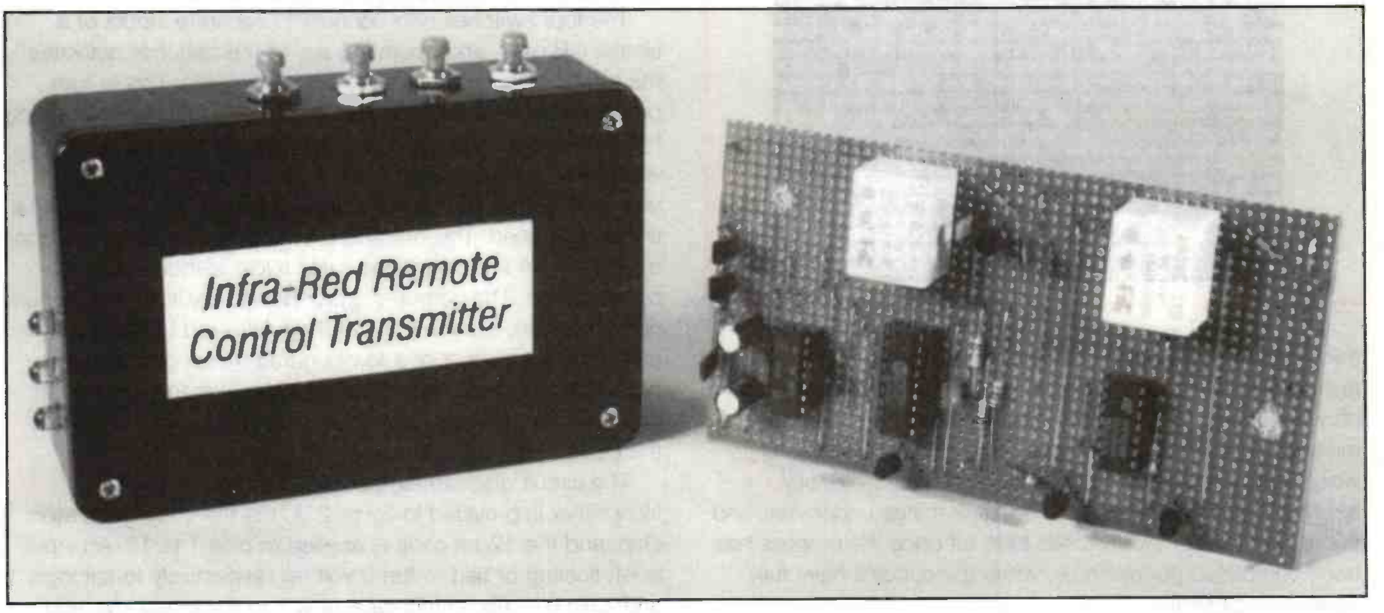
Contacts on the Web

Most of the manufacturers of micro-controllers described above have Internet web sites on which you can find further information, data sheets, free development tools and even news groups for the discussion of topics. A number of manufacturers offer CD-roms containing datasheets and tools. Some manufacturers are listed below:

Intel: http://*developer.Intel.com/design*
Microchip: *http://www.ultranet.com/%7Emchip/*
Motorola: *http://ww.motorola.com*
Atmel: *http://www.atmel.com/atmel/products/products1.html*
Cypress: *http://www.cypress.com/cypress/corp_inf*

Infra-Red Remote Control System

Robert Penfold's remote control has three output options for different users - one to initiate action, one to switch the relay on and off, and one for experimenters who want to try something more unusual.



Although at one time ultrasonic sound waves were used as the basis for most short range remote control systems, in recent times pulsed infra-red systems have largely superseded the ultrasonic variety. In terms of operating range, ultrasonics are probably slightly better than normal infra-red systems, and they also have some ability to find their way round obstructions and corners. The big advantage of infra-red systems is that they can handle wider bandwidths, making it easy to digitally encode data onto the transmitted signal. The very narrow bandwidth of ultrasonic systems makes it difficult to obtain anything beyond simple on/off switching.

As is demonstrated by the remote control handset for an ordinary television set or VCR, it is possible to carry all manner of data via an infra-red link, including such things as volume and brightness settings. For most purposes, though, some form of on/off control is sufficient. For example, this is all that is needed for remote controlled lighting, and systems that utilise a servo motor (such as remote controlled curtains). The multi-channel capability of an infra-red system is also useful where it is necessary to control several devices.

In control

The system featured here offers four-channel control, but it can easily be modified to accommodate up to 12 or 15 channels. Bear in mind that the short operating range of an infra-red system (up to about five or six metres) and its line-of-sight operation means that you are restricted to four receivers per room, and not just four receivers in total. The same transmitter can control four slave devices in the lounge, another four in the dining room, another four in the conservatory, and so on.

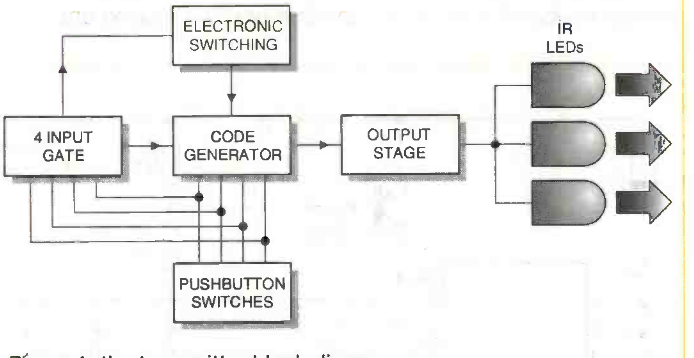
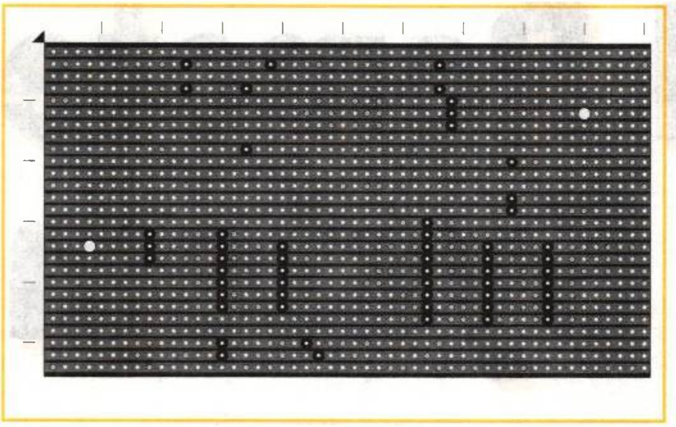
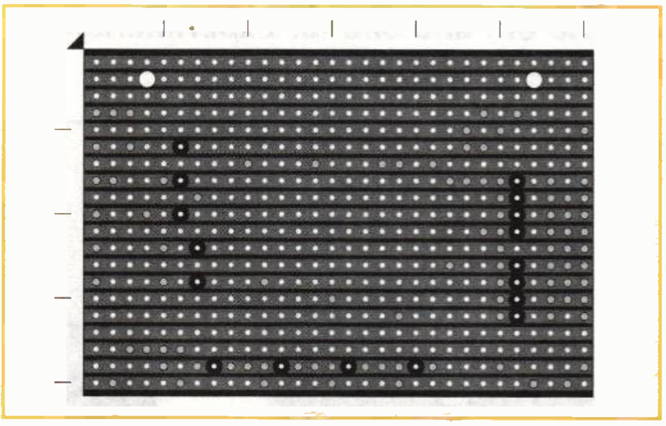


Figure 1: the transmitter block diagram

Three output options are available from the receiver, and one of these is a TTL/5 volt cmos-compatible output which goes to logic 1 when the pushbutton at the transmitter is operated, and low again when the pushbutton is released. This output is included for those who wish to "do their own





thing", and process the decoded signal in some non-standard fashion. The second option is a relay which is turned on and off when the pushbutton at the transmitter is pressed and released. This is the output that it most likely to be useful when using the system to control a servo motor. Briefly applying power to the mechanism gets things under way, and the servo mechanism switches itself off once the process has been completed (for example, when the curtains have fully opened or closed).

The third output option is another relay, but this one provides sequential operation. In other words, pressing and releasing the pushbutton at the transmitter switches on the relay, operating the pushbutton again switches off the relay, operating it a third time switches the relay back on again, and so on. This output is used to control something like lighting, where you do not want to sit there holding down the pushbutton for the duration that the lighting is required! Instead you press the button briefly to switch on the lighting, and press the button again when you want it switched off.

The transmitter

Figure1 shows the block diagram for the transmitter. It is based on a code generator chip which converts a 12-bit binary code into a serially encoded output signal. 12-bit operation provides some 4096 different codes, but in this case only four codes are actually used. Which of these four codes is obtained depends on which of the four pushbutton switches is operated. When one of the switches is operated, its input of the code generator chip is "pulled" low.

The four switches also connect to separate inputs of a simple OR gate, and operating any of the switches activates the electronic switch at the output of the gate. This in turn provides power to the code generator chip. The point of doing this is that the transmitter would otherwise run continuously, which would either exhaust the battery very rapidly, or the user would have to manually switch the unit on and off each time it was used. This automatic switching avoids the need for manual on/off switching, and gives a low standby current consumption. The code generator has a very limited maximum output current, but the bank of three infra-red LEDs has to be pulsed with a current of a few hundred milliamps in order to provide good range. An output amplifier is therefore used to provide buffering and deliver suitably high output currents to the LEDs.

The circuit diagram for the infra-red remote control transmitter is provided in figure 2. IC1 is the code generator chip, and the 12-bit code is applied to pins 1 to 12. An input is left floating or tied to the 0 volt rail respectively to set logic 1 and logic 0 levels. In this case pins 1 to 8 are tied low, and pins 9 to 12 are controlled by the pushbutton switches (S1 to S4). Operating a pushbutton switch pulls its input of IC1 low, and also supplies a base current that switches on Q1 and provides power to IC1. D2, D4, D6, and D8 form the OR gate, and their main purpose is to isolate the switches so that that only one input is taken low when one of the switches is operated. D1, D3, D5, and D6 simply prevent IC1 from interfering with the correct operation of the gate, and from holding Q1 switched on.

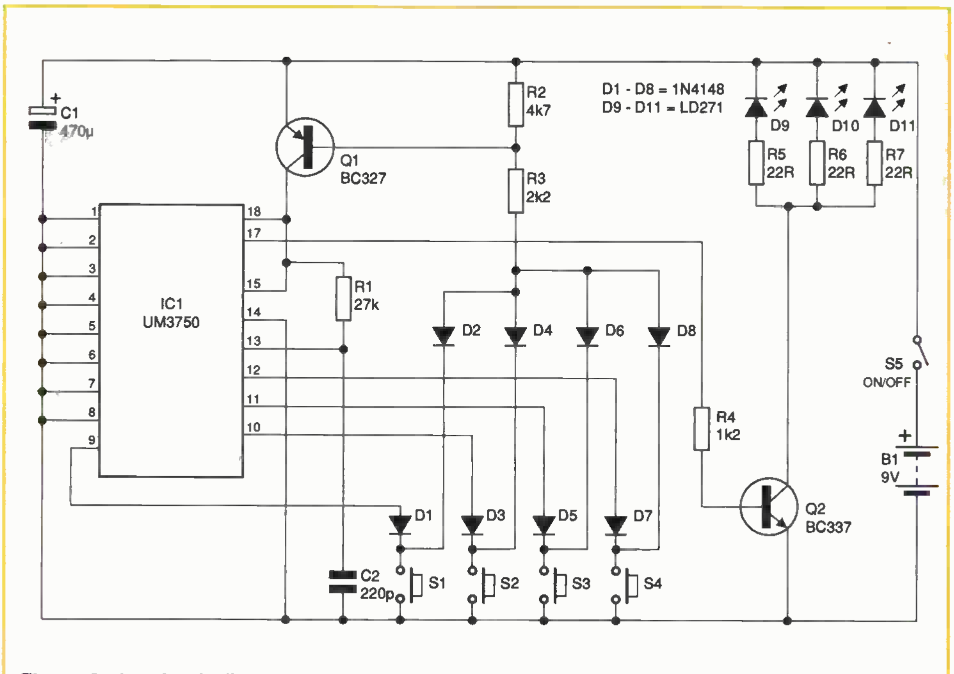
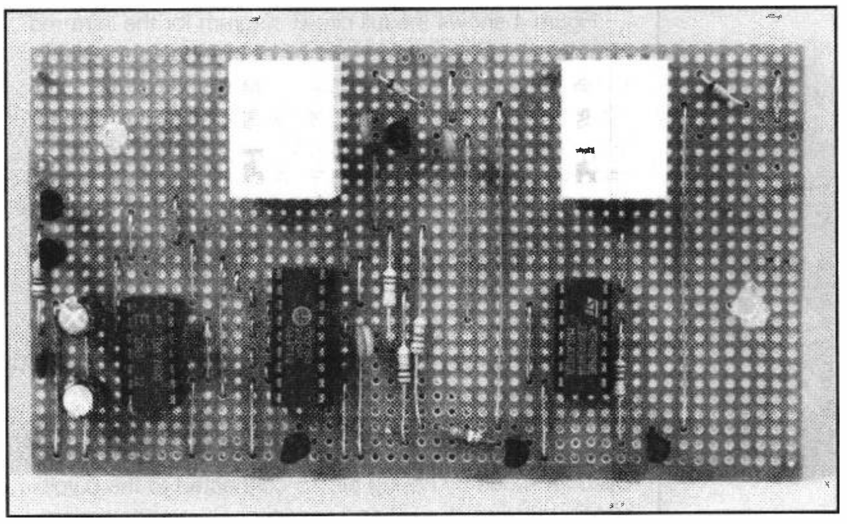
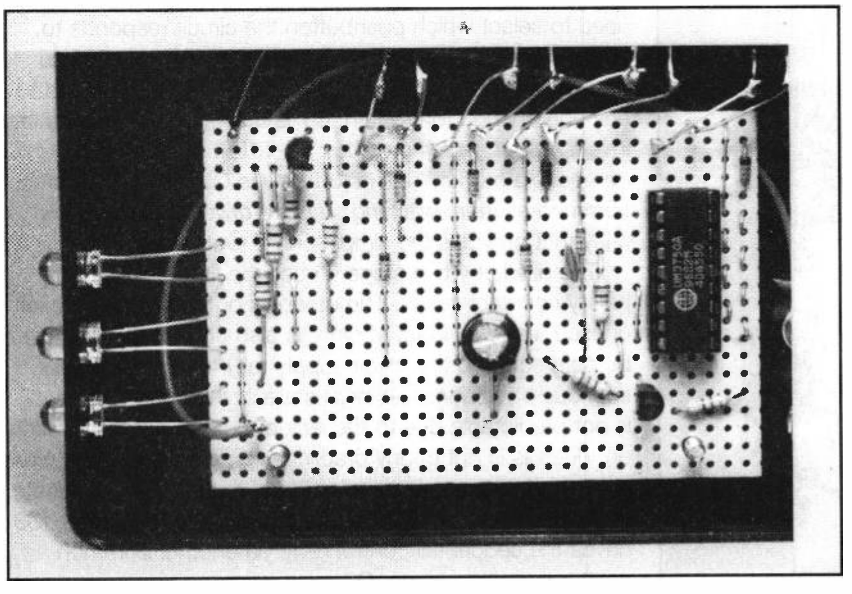


Figure 2: the circuit diagram for the infra-red remote control transmitter

IC1 has a built-in clock generator circuit that requires a discrete C-R timing network (R1 and C2). The UM3750 code generator can also act as a decoder, and it is set to the required mode by connecting pin 15 to the positive supply for encoding, or the 0 volt rail for decoding. The serial output signal is produced at pin 17. This output drives transistor Q2 which is a simple common emitter switching stage. It has the





More channels

Provided you understand the basic principles involved, it is not difficult to modify the system to handle more channels. The easiest way is to simply push more than one button at a time in order to activate some additional receivers. There are four pushbuttons, giving fifteen usable binary codes. Although at first sight it might seem that there should be sixteen usable code, "all four switches open" is not a usable code because at least one switch must be closed in order to switch on power to the encoder chip.

The more involved but neater method is to bring more of IC1's inputs into use. With 12 inputs it is possible for the system to handle up to 12 channels with a separate control button for each one. It is just a matter of adding an extra pushbutton switch and two diodes for each additional input that is used, copying the same configuration that is used for the other inputs. Of course, the inputs of the decoders in the receiver boards would have to be hard wired so that their codes precisely matched the transmission codes.

The receiver

The block diagram for the receiver is shown in figure 3. An infra-red diode is used to convert the pulses of infra-red "light" from the transmitter into electrical pulses, but the amplitude of these pulses will usually be very low. In fact it will sometimes be less than a millivolt peak-to-peak. A large amount of amplification is therefore needed in order to produce a signal at normal logic levels that will drive the decoder chip properly. This amplification is provided by a TBA2800 integrated circuit, which is a preamplifier chip that is specifically designed for use in pulsed infra-red systems. In figure 3 the area within the broken line represents the preamplifier chip.

three infra-red LEDs as its collector load, and these are driven by way of separate current limiting resistors. The total current to the three LEDs is several hundred milliamps, but the pulsed nature of the output signal results in an average current consumption of about 150 to 200 milliamps. On/off switch S5 is optional, and is included so that the power can be switched off if a major fault occurs. It serves no purpose beyond this due to the very low standby current consumption of the circuit. This should be no more than a few microamps, which will not significantly reduce the life of the battery even if the unit is left switched on continuously.

This is basically a three stage amplifier with capacitive inter-stage coupling. This coupling is provided by Ca and Cb which are deliberately given quite low values so that substantial low frequency roll-off is introduced. This does not produce significant distortion of the relatively brief pulses from the transmitter, but it does prevent major problems with 100Hz interference from mains powered lighting. Inverted and non-

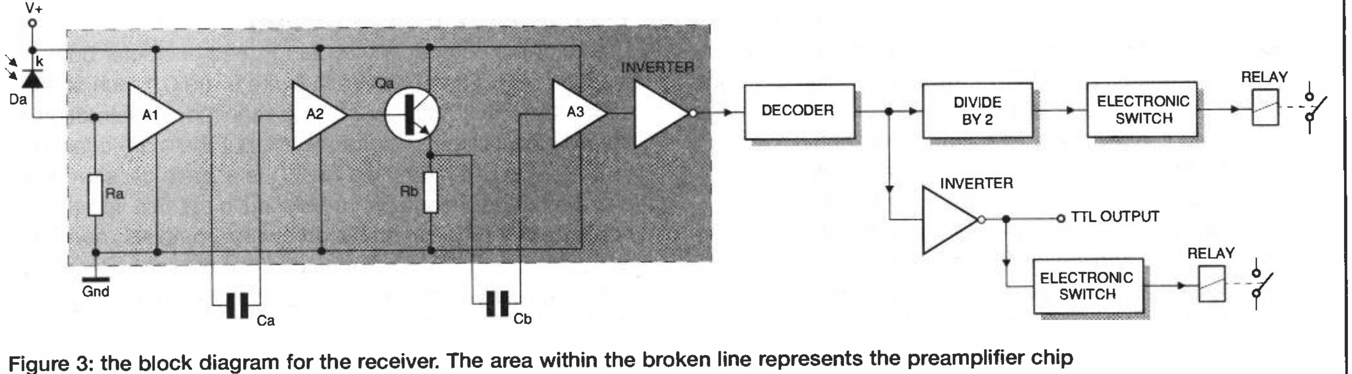
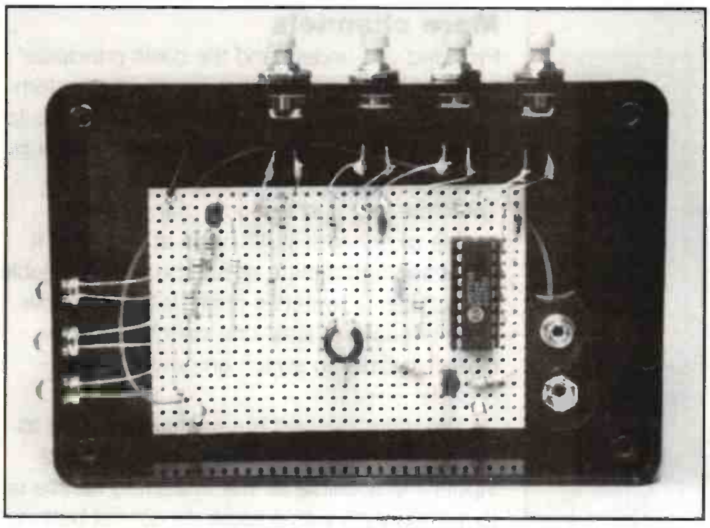


Figure 3: the block diagram for the receiver. The area within the broken line represents the preamplifier chip



inverted versions of the output signal are available, and it is the inverted signal that is of the correct polarity for the decoder chip.

The decoder chip converts the received signal back to the corresponding 12-bit binary code, and compares it with the 12-bit code on its inputs. If the two codes match, its output is switched from logic 1 to logic 0. The output will remain at logic 0 for as long as the correct pulse signal is received, but it will rapidly return to logic 1 if the signal ceases. Of course, in this case the 12 inputs of the decoder are hard wired with the appropriate binary code for the transmitter button you wish to activate the receiver.

One output of the decoder is fed to an inverter/buffer stage which provides the TTL/CMOS compatible output. This inverted signal is also used to control an electronic switch which in turn controls one of the relays. This is the relay that switches on when the pushbutton is activated, and switches off again when it is released. The sequential control relay is driven from the output of the decoder via a simple binary divider and an electronic switch. The output of the divider stage is toggled by each complete input pulse (that is, each pair of high-to-low and low-to-high transitions). Therefore, pressing and releasing the pushbutton once switches on the relay, pressing and releasing the pushbutton again switches off the relay, and so on.

Figure 4 shows the full circuit diagram for the infra-red remote control receiver, including all three output options. IC1 is the preamplifier chip, and the two inter-stage coupling capacitors are C3 and C4. Two infra-red diodes connected in parallel (D1 and D2) are used to provide improved sensitivity. These are used in the reverse biased mode, and can be direct coupled to the input of IC1. One slight drawback of the TBA2800 is that it will only work properly with a fairly accurate 5 volt supply. It is therefore powered from the main 12 volt supply via monolithic voltage regulator IC4. Apart from the electronic switches that drive the relays, the other stages of the circuit are also powered from the regulated 5 volt supply, so that the stages all operate at compatible logic levels.

IC2 is the UM3750 decoder chip, and it is set to the decoder mode by having pin 15 connected to the 0 volt supply rail. Resistor R3 and capacitor C5 are the timing components for IC2's internal clock circuit. Links 1 to 4 are used to select which pushbutton the circuit responds to, and they respectively select S1 to S4. Only one of these links should be included or the receiver will not respond to any one pushbutton switch. Q1 is a simple common emitter inverter stage which provides the TTL/5 volt CMOS compatible output. This in turn drives Q2, which is another common emitter switching stage. It drives the coil of the relay that provides the simple on/off switching.

The divide by two stage utilises the first of the seven binary counters in IC3. The other six outputs of IC3 are left unused. Its reset input at pin 2 is also unused, but it must be connected to the 0 volt supply rail in order to prevent spurious operation. The initial state of the output at pin 12 is not predictable due to the lack of a reset signal at switch-on, but this is not of any practical significance in the current context. If the sequential relay starts out in the wrong state, simply toggle it to the other state using the transmitter. IC3 drives the sequential control relay via another common emitter switching stage, Q3.

A current of about six milliamps is drawn by the full receiver circuit under standby conditions and with both relays switched off. The current consumption increases by about 37 milliamps per relay when one or both of the relays are switched on. It is possible to power the circuit from a 12 volt battery such as eight HP7 size cells in a holder. In theory a nine volt supply is inadequate to provide reliable operation of the relays, but in practice a nine volt battery will almost certainly provide good results and lower running costs. A 12-volt stabilised mans power supply unit is likely to be the most economic power source if the receiver will be left running for long periods (as it probably will). A regulated 12-volt battery eliminator rated at 100 milliamps or more should provide good results, but unregulated battery eliminators are unlikely to give acceptable results with this circuit.

Transmitter construction

Details of the component layout for the transmitter board and the hard wiring are provided in figure 5. An 0.1 inch stripboard of 30 holes by 20 copper strips is required. Construction of the board is largely straightforward, but there are a few points to note. The UM3750 used for IC1 is a static-sensitive chip and it must be mounted in a holder. Do not fit it into the holder until the transmitter is otherwise complete, and keep it away from any known sources of static charges. Be careful not to omit any of the link-wires and make sure that all the diodes are fitted with the correct polarity.

Five-millimetre diameter infra-red LEDs follow the normal

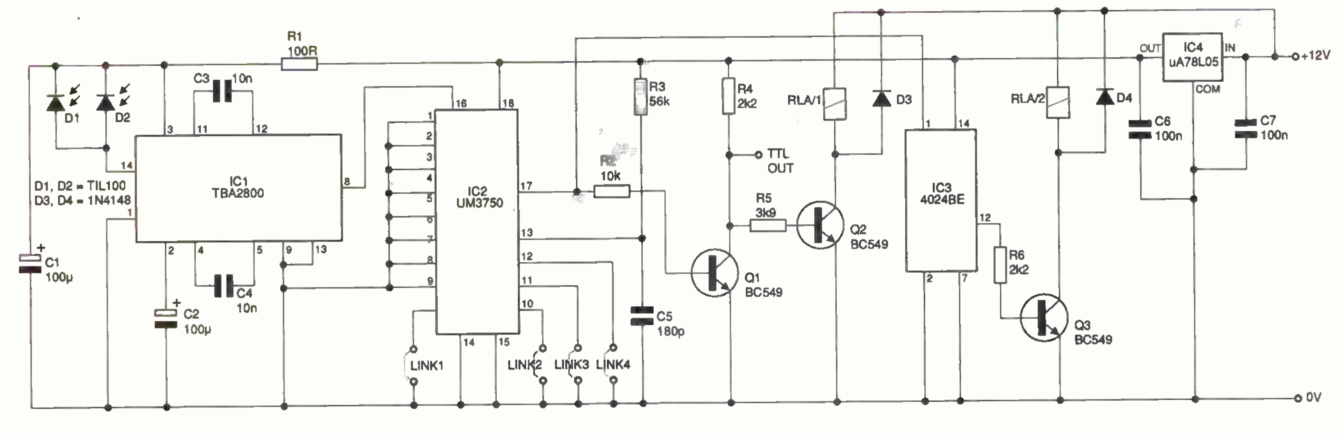


Figure 4: the full circuit diagram for the receiver, including all three output options

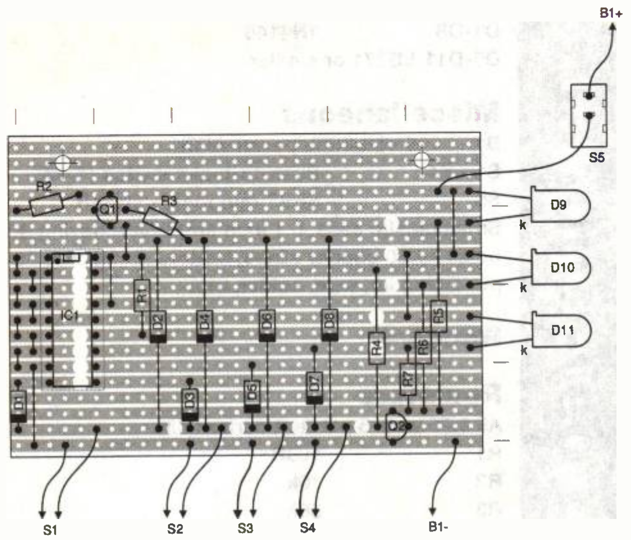


Figure 5: details of the transmitter board and wiring

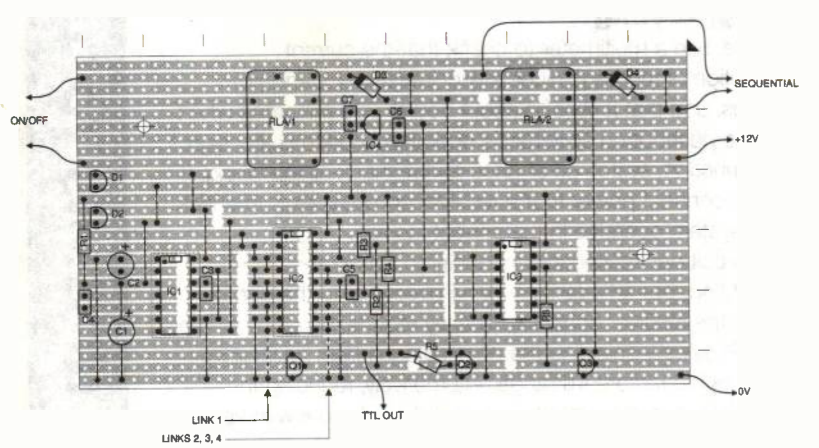
convention of having the cathode (k or +) lead slightly shorter than the anode leadout wire, and having the case slightly flattened on the cathode side. The LEDs can be mounted on the case using panel holders and then hard wired to the circuit board, but the neater solution is to mount them on the board leaving the leadout wires quite long. With the leadout wires curved through 90 degrees, the LEDs can be fitted into three five millimetre diameter mounting holes drilled at one end of the case. The circuit board must be positioned quite accurately in the case if this is to work properly. It is probably best to drill the mounting holes for the LEDs first, and then locate the positions of the two mounting holes for the board using the board itself as a template.

The transmitter should work well using any five millimetre diameter infra-red LEDs that are intended for use in remote control applications. There is some advantage in using a narrow beam type, such as the Maplin "High Power Infra-Red Emitting Diode" (YH70M), or the LD274. The transmitter has to be aimed with greater accuracy, but better range is obtained.

The current consumption of the transmitter is high enough to warrant using a high capacity battery such as six HP7 size cells in a holder. However, a high capacity battery tends to be quite large and heavy, which is undesirable for what should be a small and light unit that is easily held and operated using one hand. A "high power" PP3 size battery is probably the best option. As the unit will only be used periodically for a second or so at a time, excellent battery life should be obtained despite the high current consumption of the circuit.

Receiver Construction

Details of the receiver board are provided in figure 6 (component side). Again, construction of the board is reasonably simple, but there are a few points that require some amplification. IC2 and IC3 are static-sensitive components that require the usual handling precautions, but I would urge the use of a holder for IC1 as well. Note that IC3 is mounted one row of holes further up the board than the other two dil devices. D1 and D2 are specified as TIL100s in the components list, but any similar infra-red photo diodes should work well in this circuit. The photo diodes used on the prototype are the Maplin type (YH71N), and these have the cathode (+) terminal denoted by a slightly shorter leadout wire. Maximum sensitivity is offered by the flat side of these



diodes. Other photo-diodes are likely to have either a different encapsulation or a different leadout configuration, so check the manufacturer's or retailer's data if you use an alternative type.

The receiver is set to the appropriate channel by including link 1, 2, 3, or 4, depending on which switch at the transmitter you wish to control the receiver. For example, if you wish the unit to be controlled by S2 at the transmitter, include link 2, and wire pin 10 of IC2 to the 0 volt supply rail. Pins 9, 11, and 12 are then left unconnected.

The layout shown in figure 7 is for a full implementation of the receiver, including all three output options. Normally only one output option will be required, and some of the components can then be omitted.

For the TTL/CMOS compatible output omit:
R5, R6, Q2, Q3, IC3, both relays, D3, and D4.

For simple on/off relay control omit:
IC3, R6, Q3, RLA/2, and D4 (the TTL output will still be available).

For sequential relay control omit:
Q1, Q2, R2, R4, R5, RLA/1, and D3.

The specified relay can control currents of up to 10 amps at 240 volts ac or 30 volts dc (3 amps ac with inductive loads). On the other hand, it is best not to pass currents of more than about 5 amps through stripboard tracks. If the unit must be used to control high current loads, the relay should be mounted on a simple custom printed circuit board having suitably wide tracks, with the relay coil hard wired to the main circuit board. The receiver should only be used to control mains powered equipment if it is installed by someone who has the necessary experience and knows exactly what they are doing. It must conform to all the relevant safety regulations. The mains supply is potentially lethal and beginners should not attempt any project which connects to the mains supply.

Obviously, the precise way in which the receiver is installed depends on your particular application. However, remember that D1 and D2 must be mounted behind a large cut-out so that they can "see" the infra-red pulses from the transmitter. The diodes themselves have a wide angle of coverage, and mounting them close to a large cut-out will maintain wide coverage in the finished unit. Some transparent plastic should be glued in place behind the cut-out to give a neat finish, and to prevent dust from entering the case.

Testing, testing

If possible, use a multimeter to check that the current consumption of the transmitter is very low under standby conditions, and that it rises to about 150 to 200 milliamps when one of the pushbutton switches is operated. If there is any sign of a malfunction, switch off at once and recheck all the wiring. If all is well, connect power to the receiver or receivers, and check that the system operates in the correct fashion.

The circuit has reasonable immunity to interference from mains lighting, but artificial light falling directly onto the photo diodes at the receiver could significantly reduce the range of the system. Physically shielding the photo diodes from artificial light sources should restore full range. Alternatively, reducing the value of C2 will improve matters, but making it too low in value will produce a signal that the decoder chip can not process properly.

PARTS LIST for the infra-red remote control system

Transmitter

Resistors

All 0.6W 1 percent metal film

R1	27k
R2	4k7
R3	2k2
R4	1k2
R5,6,7	22R

Capacitors

C1	470u 10V radial elect
C2	220p ceramic plate

Semiconductors

IC1	UM3750
Q1	BC327
Q2	BC337
D1-D8	1N4148
D9-D11	LD271 or similar

Miscellaneous

B1	9 volt (high power PP3)
S1 - S4	Push-to-make switch (4 off)
S5	SPST min toggle switch

Small plastic case, 0.1 inch stripboard having 30 holes by 20 copper strips, battery connector, 18 pin dil holder, wire, solder, etc.

Receiver

Resistors

All 0.25 watt 5 percent carbon film

R1	100R
R2	10k
R3	56k
R4,6	2k2
R5	3k9

Capacitors

C1,2	100u 10V radial elect
C3,C4	10n Mylar
C5	180p ceramic plate
C6,7	100n disc ceramic

Semiconductors

IC1	TBA2800
IC2	UM3750
IC3	4024BE
IC4	uA78L05 5V 100mA positive regulator
Q1,2,3	BC549
D1,2	TIL100 or similar
D3,4	1N4148

Miscellaneous

RLA/1,2 320R 12 volt coil, 10A changeover contact (Maplin YX97F)

Stripboard panel having 50 holes by 27 copper strips, 14 pin dil holder, 18 pin dil holder, wire, solder, etc.

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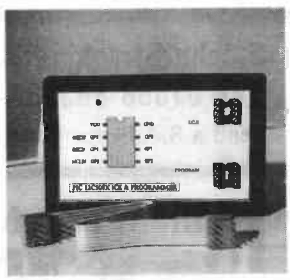


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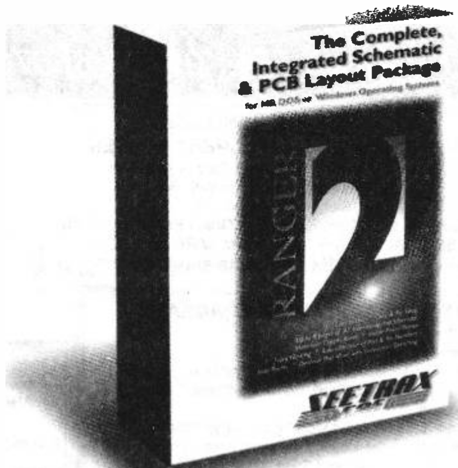

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Collected circuits DC Voltage Converters

Ray Marston describes the principles of DC voltage conversion with selection of practical application circuits

Many modern battery-powered electronic circuits need a DC supply that is either of a larger voltage value than the main battery, or is of the reverse polarity. For instance, a circuit powered from a 6V battery may incorporate a single op-amp stage that needs +12V and -6V supply lines. In such cases, the required voltages may be generated via one or more special DC voltage converter circuits. Most electronic DC voltage converters operate in one or other of four basic ways: they use a DC-powered oscillator to drive either a simple diode-capacitor "voltage multiplier" network; or a step-up transformer and rectifier network; or a "flying capacitor" voltage converter; or a "diode-steered charge pump" - which produces the desired final DC output voltage or voltages. This article explains the operating principles of each of these four basic types of circuit, with practical examples.

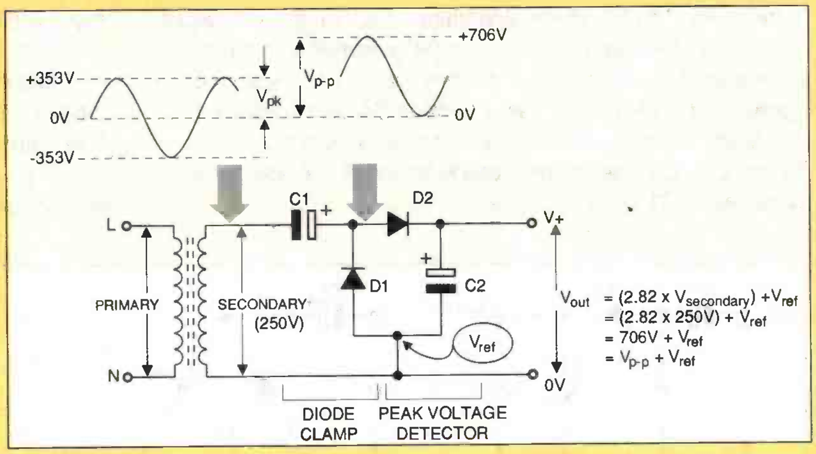

Figure 2: basic details of a transformer-driven "voltage-doubling" voltage multiplier circuit

Principles

Conventional DC "voltage multiplier" types of voltage converter circuit are based on a simple two-section diode-capacitor type of rectifier network originally designed in the 1930s for use in high-value AC-to-DC voltage conversion applications. It is still widely used today. To understand this circuit's basic operation and terminology (which can be rather confusing), it is necessary to start off by looking at a simple AC-to-DC power conversion circuit.

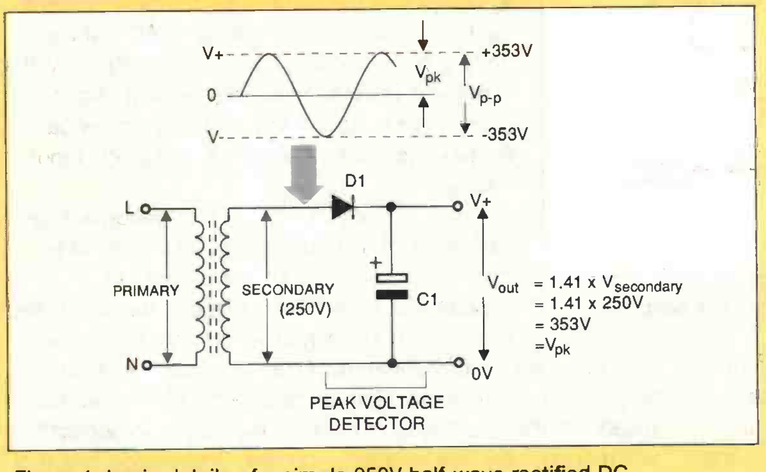

Figure 1: basic details of a simple 250V half-wave rectified DC power supply

The simplest AC-to-DC power conversion circuit is the basic half-wave rectifying type shown in **figure 1**, which depicts a circuit that uses a transformer with a secondary voltage value of 250V rms. Here, the AC voltage applied to the input of rectifier D1 swings alternately above and below the 0V value, rising to a positive Vpeak (Vpk) value +353V in the positive half-cycle and falling to a negative Vpeak value of -353V in the negative half-cycle. D1 is forward biased during each positive half-cycle and thus charges capacitor C1 to a peak value of (ignoring D1's forward volt drop) +353V, but is reverse biased during each negative half-cycle, which thus has no practical effect on the circuit. This circuit produces a positive output voltage, but can be made to generate a negative output voltage by simply reversing the polarities of D1 and C1.

The really important thing to note about the figure 1 half-wave rectifier circuit is that D1 and C1 act together as a peak-voltage detector that makes the circuit give an output equal to the positive peak value of T1's secondary voltage. The same basic action occurs in all conventional full-wave rectifier circuits, which also give an output equal to the peak value of the transformer's secondary voltage.

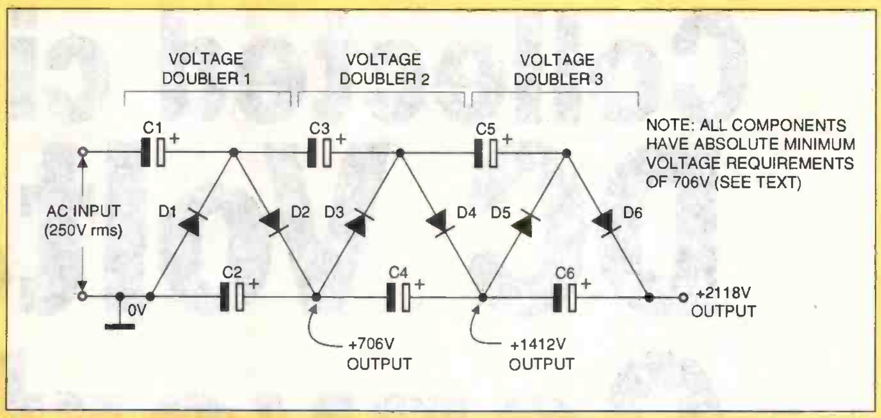

Figure 5: this 3-stage Cockcroft-Walton circuit gives x6 voltage multiplication

During the early 1930s, engineers needed a cheap, reliable and safe ways of generating high-value low-power DC voltages from low-cost non-lethal transformers, and devised a simple two-section "voltage multiplier" circuit to do this job. **Figure 2** shows such a circuit, driven from the secondary winding of a 250V transformer. Here, the C1-D1 section acts as a diode clamp that, when fed with a normal AC input that swings symmetrically about the 0V value, produces an output waveform that is of identical shape but has its peak negative point clamped to the 0V "reference" value, as shown in the diagram. This waveform's peak output value equals the peak-to-peak (Vp-p) value of the AC input voltage, and is fed directly into the input of the simple D2-C2 peak voltage detector section, which thus produces a DC output voltage equal to the Vp-p value (rather than the peak value) of the AC input voltage. This circuit thus gives twice as much output voltage as a conventional half-wave or full-wave rectifier circuit, and is thus known as a "voltage-doubling" voltage multiplier. The circuit can be made to generate a negative (rather than positive) output voltage by simply reversing the polarities of C1-D1 and D2-C2.

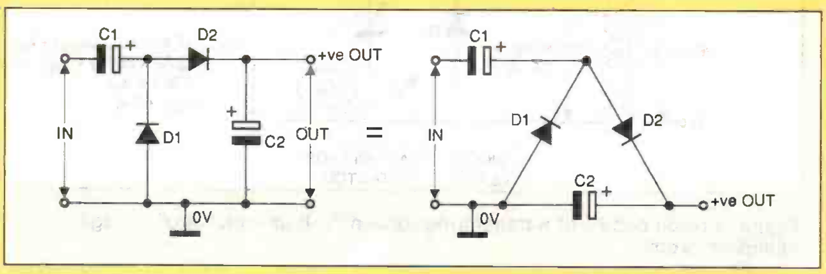

Figure 3: (a) conventional voltage-doubler diagram, and (b) the circuit redrawn in "standard" form

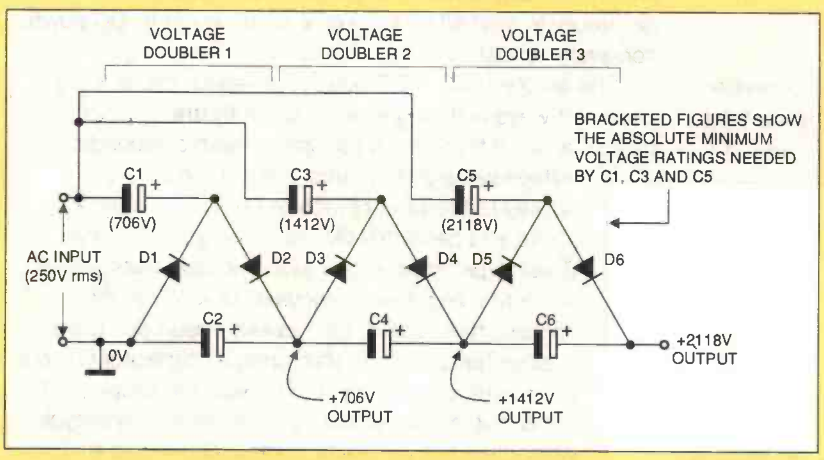

Figure 4: three "doublers" interconnected to give x6 voltage multiplication

An important point about the basic **Figure 2** circuit is that its output voltage equals Vp-p plus the common "reference" voltage (Vref) of D1-C2, which in this example is 0V. Thus, if this circuit is modified so that Vref is raised to (say) +1000V, the 706V output of C2 will be added to that of Vref to give a final output voltage of 1,706V, and so on.

The heart of the figure 2 circuit is the C1-D1-D2-C2 voltage doubler network. **Figure 3(a)** shows the conventional diagram of this network and **figure 3(b)** shows it redrawn as a "standard" voltage-doubling voltage multiplier section. A major feature of the voltage-doubler is that numbers of "doublers" can easily be interconnected to give various values of voltage multiplication, and such circuits are best drawn using the standard figure 3(b) representation.

Figure 4, for example, shows three of these "doubler" stages interconnected to give a voltage sextupler, in which the final output voltage is six times greater than the peak value of the original 250V rms input voltage. Here, each "doubler" section generates an individual output (across its C2, C4, or C6 capacitor) of 706V, but the output of the first doubler acts as the Vref point of the second doubler, and output of the second doubler acts as the Vref point of the third doubler, the net effect being that the three individual output voltages add together to give a final DC output of +2118V from the 250V AC input.

In the **figure 4** circuit the input capacitor of each section is fed directly from the AC input voltage, and needs an absolute minimum voltage rating equal to that section's output-to-ground voltage. For instance, C5 needs a minimum rating of 2118V. In the mid-1930s a modified version of the voltage multiplier was designed to overcome this snag. Known as the Cockcroft-Walton voltage multiplier, it uses standard voltage-doubler stages interconnected as shown in **figure 5**. This circuit is similar to that of **figure 4**, except that the input of each doubler except the first is fed from the "clamped" AC voltage point of the preceding doubler. Consequently, the "minimum voltage rating" requirement of each component used in each doubler stage equals the peak-to-peak value of the original AC input voltage.

A weakness of the Cockcroft-Walton voltage multiplier is that its output impedance is rather high (it is proportional to the sum of the impedances of the various input capacitors), and can thus supply only small output currents. In practice, this type of voltage multiplier was originally designed simply to generate a very high (up to about 30kV) accelerator voltage on the final anode of cathode-ray tubes, an application that requires very little energizing current. A ten-stage circuit of this type, when driven by a 500V AC input, generates a DC

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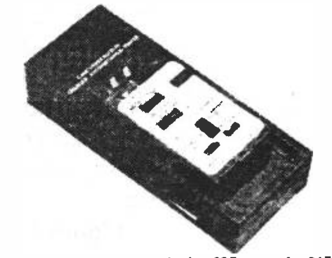

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output of over 14kV, but the components used in each stage have minimum voltage rating requirements of less than 1.5kV.

Practical circuits

A DC voltage can easily be converted into one of greater value, or of reversed polarity, by using the DC supply to power a free-running 1kHz to 30kHz squarewave generator that has its output fed to a basic voltage multiplier, which thus provides the desired "converted" DC output voltage. Figure 6 shows a practical demonstration circuit of this type.

The figure 6 circuit uses a type-555 timer ic (which can supply fairly high output currents) as a free-running squarewave generator, operating at about 3kHz (determined by the R1-R2-C2 values) and driving directly the C3-D1-D2-C4 "doubler" stage, which (ideally) produces a DC output equal to the peak-to-peak output of the squarewave, which then (ideally) equals the Vcc value. In practice, the squarewave's peak-to-peak value is slightly less than Vcc, and the "doubler" loses another 1.2V in voltage-drops in D1 and D2, the net result being that the actual output (when very lightly loaded) is about 1.6V less than Vcc, for example, 8.4V with a 10V supply. The circuit can use any supply in the range 5V to 15V.

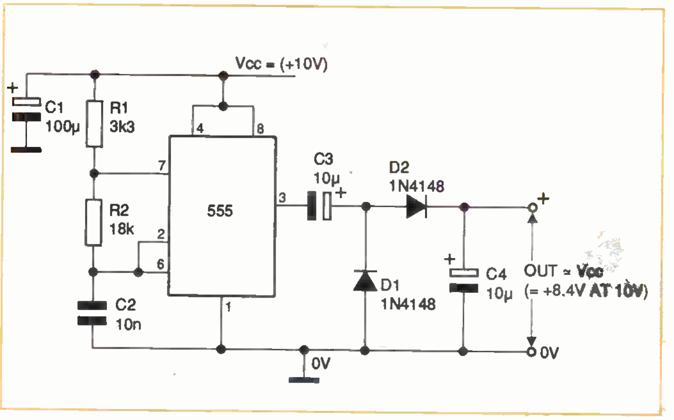

Figure 6: basic "voltage doubler" demonstration circuit

Figure 7 shows a far more useful version of the basic figure 6 "voltage-doubler" circuit. In this version, the C3-D1-D2-C4 "doubler" is tied to the positive (rather than 0V) supply line, and its output voltage is thus added to that of the supply line, giving a DC output voltage (when lightly loaded) of almost 2 x Vcc. In practice, the prototype circuit gives an output of almost 19V when using a 10V supply.

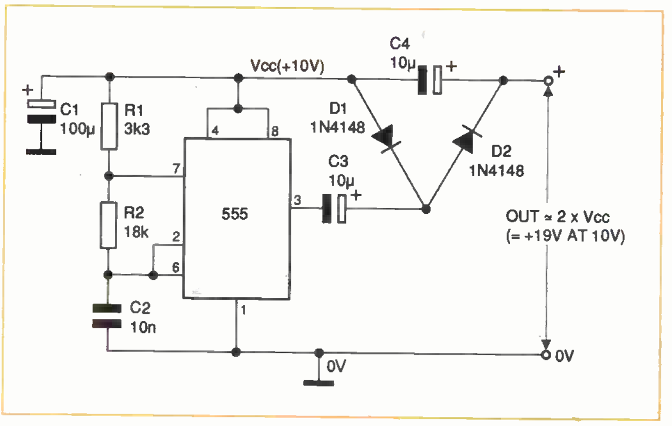

Figure 7: DC voltage-doubling circuit

Figure 8 shows the **figure 7** circuit modified for use with a cascaded pair of "doubler" stages, in a configuration that is known (because it generates a DC output four times greater than a basic peak AC input voltage) as a "voltage quadrupler". Here, the output of the new C5- D3-D4-C6 "doubler" stage (which is a couple of volts less than Vcc) is added to that of the basic **figure 7** circuit, thus giving a DC output voltage (when lightly loaded) of almost 3 x Vcc. In practice, the prototype circuit gives an output of 27V when using a 10V supply.

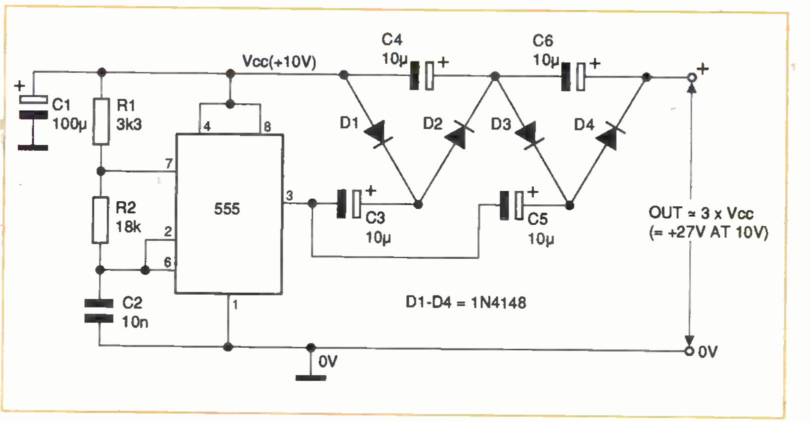

Figure 8:

Figure 9 shows a particularly useful type of voltage multiplier circuit that generates a negative output voltage that (ideally) is almost equal in amplitude but opposite in polarity to that of the ic's supply line, providing a split-supply output from a single-ended input. The circuit is similar to that of figure 6, but has its D1-D2-C4 "doubler" polarities reversed, so that its output voltage is negative to the 0V line. In practice, the prototype circuit gives an output of -8.4V when using a 10V supply (Note:- two of these "doubler" stages, when cascaded, give an output of -17.5V when using a 10V supply).

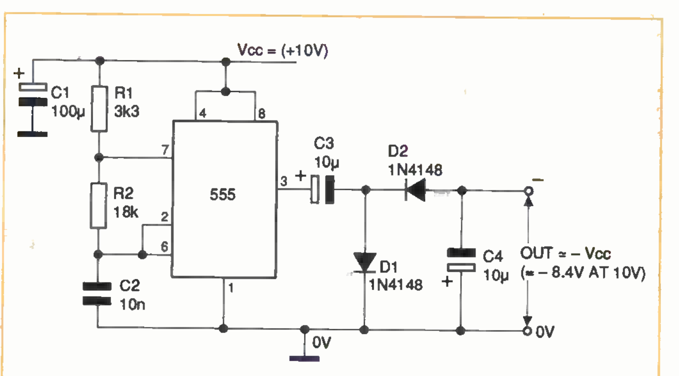

Figure 9: DC negative voltage generator

A high voltage generator

The "voltage multiplier" method of generating increased values of DC output voltage is usually cost-effective only when multiplier ratios of less than six are needed. In cases where very large step-up ratios are required (as, for example, when hundreds of volts must be generated via a 6V to 12V supply), it is often better to use the output of a low-voltage oscillator or squarewave generator to drive a step-up voltage transformer, which then provides the required high-value voltage (in AC form) on its secondary (output) winding; this AC voltage can easily be converted back to DC via a simple rectifier-filter network. **Figure 10** shows a practical low-power high-voltage generator circuit of this type.

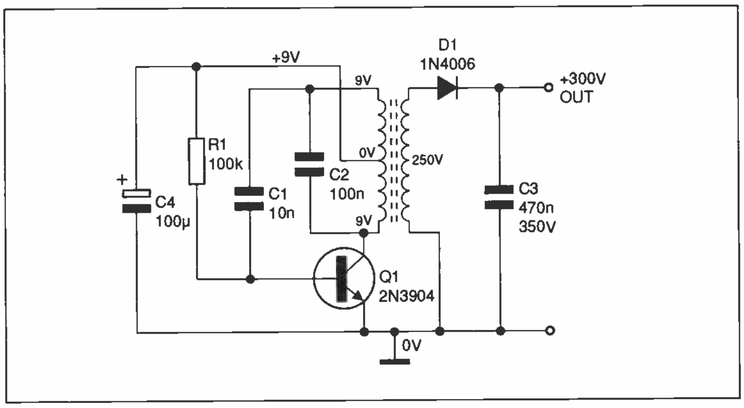

Figure 10: 9V to 300V DC-to-DC converter

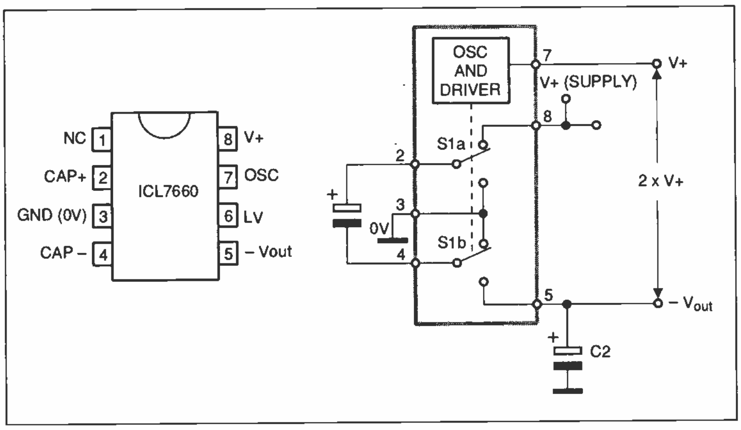

Figure 11: (a) outline and pin notations and (b) simplified basic usage circuit of the ICL7660 voltage converter ic

The **figure 10** circuit acts as a DC-to-DC converter that generates a 300V DC output from a 9V DC power supply. Here, Q1 and its associated circuitry act as a Hartley L-C oscillator, with the low-voltage primary winding of 9V-0-9V to 250V mains transformer T1 (or a transformer with a similar turns ratio) forming the "L" part of the oscillator, which is tuned via C2. The supply voltage is stepped up to about 350V peak at T1 secondary, and is half-wave rectified and smoothed via D1-C3. With no permanent load on C3, the capacitor can deliver a powerful but non-lethal "belt". With a permanent load on the output, the output falls to about 300V at a load current of a few milliamps.

Flying capacitor converters

One very efficient way of obtaining good +ve to -ve low-voltage conversion is to use the so-called "flying capacitor" technique, which is used by the popular ICL7660 dedicated voltage converter ic (and its SI7660, LMC7660, etc., equivalents) and by several similar devices. The ICL7660 is housed in an 8-pin DIL package as shown in **figure 11(a)**, and is designed to be powered from a single-ended DC supply that is connected between pins 8 (V+) and 3 (GND or 0V), and to generate an equal-value negative output on pin 5 (-Vout). That is, if powered from a +5V supply, this circuit generates a -5V output on pin 5, making double the supply voltage (that is, 0V) available between pins 8 and 5. The ic can thus be used as either a negative-voltage generator or as a voltage doubler.

The ICL7660 can be used with any +1.5V to 10V DC supply, consumes a typical quiescent current of 170mA at 10V, and has a typical +ve to -ve voltage conversion efficiency of 99.9 percent when its pin-5 output is not loaded. When the ic's output is loaded it acts (at 10V) like a voltage source with an output impedance of about 70R, and can supply maximum output currents of about 40mA; the output impedance is inversely proportional to the supply voltage, and is typically about 330R at 2.5V.

The ICL7660 uses the "flying capacitor" method of voltage conversion that is illustrated in figure 11(b). The ic houses a cmos squarewave generator that operates at a basic frequency of about 10kHz and has a symmetrical half-frequency output (available on pin 2) that repeatedly toggles built-in cmos two-pole change-over switch S1, which is connected to "flying" external capacitor C1. The circuit action is such that, when S1 is toggled high, C1 is connected directly between the ground and V+ lines (as shown in the diagram) and thus charges up to the full positive supply voltage value. On the next clock cycle, however, S1 toggles low, and under this condition C1 is connected - in reverse polarity - directly across external output capacitor C2, thus generating an output voltage of V- across C2. This toggling sequence repeats continuously, at half of the clock-generator frequency. Since the ICL7660 uses cmos rather than bipolar semiconductor switches in its "conversion" circuitry, the ic operates with very high voltage conversion efficiency.

The ICL7660 is an easy device to use, but none of its terminals must ever be connected to a voltage greater than V+ or less than GND (0V). If the ic is to be used with supplies in the range 1.5V to 3.5V, the pin-6 "LV" terminal (which controls an internal voltage regulator) should be grounded; at supply values greater than 3.5V, pin-6 must be left open circuit. At

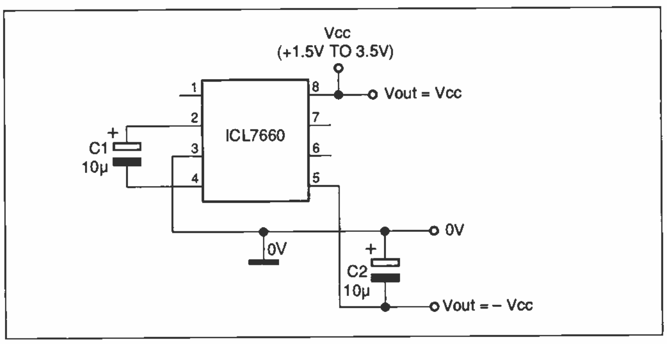

Figure 12: DC negative-voltage generator or voltage doubler

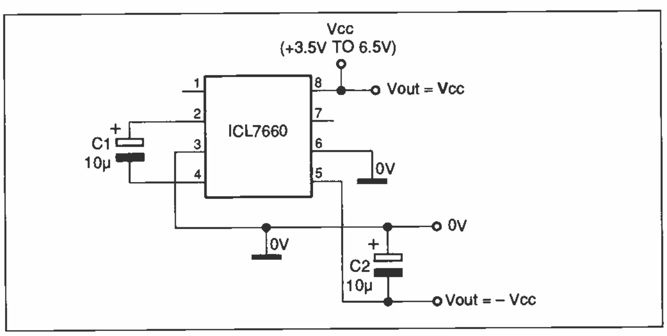

Figure 13: DC negative-voltage generator or voltage doubler using 3.5 to 6.5V supply

supply values greater than 6.5V a protection diode must be wired in series with OUTPUT pin-5. The circuits of figures 12 to 20 show a selection of practical designs in which these rules are applied.

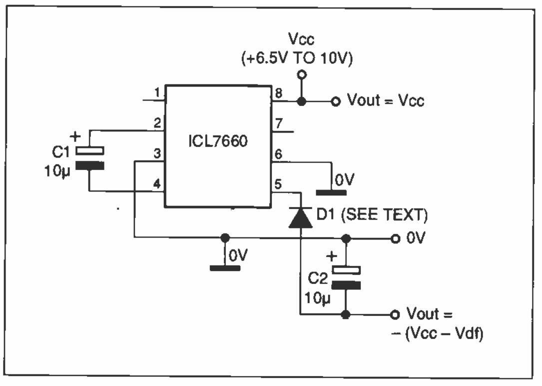

Figure 14: DC negative-voltage generator or voltage doubler using 6.5 to 10V supply

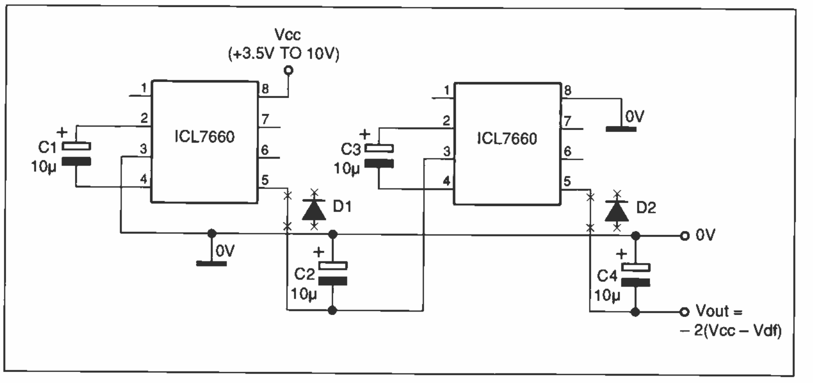

Figure 15: cascading ics for increased negative output voltage

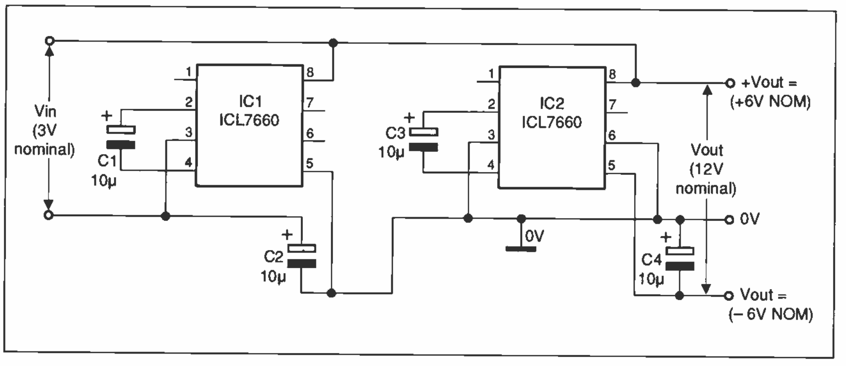

Figure 16: cascaded ics giving a centre-tapped 12V output from a 3V supply

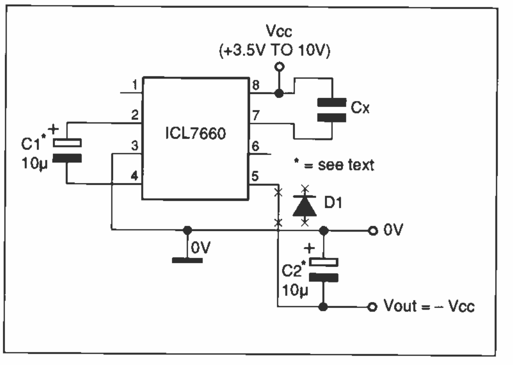

Figure 17: method of reducing oscillator frequency

ICL7660 circuits

The most basic applications of the ICL7660 are as a simple negative-voltage generator or as a voltage doubler, and figures 12 to 14 show three simple circuits of this type; in each case, C1 is a "flying" capacitor and C2 is a smoothing/storage capacitor and each have a value of 10mF. The figure 12 voltage converter is intended for use with 1.5V to 3.5V supplies, and requires the use of only two external components. The figure 13 circuit is similar, but is meant for use with supplies in the 3.5V to 6.5V range and thus has pin-6 grounded. Finally, the figure 14 circuit is meant for use with supplies in the range 6.5V to 10V, and thus has diode D1 wired in series with output pin-5, to protect it against excessive reverse biasing from C2 when the power supplies are removed. This diode reduces the available output voltage by Vdf, the forward volt drop of the diode; to keep this voltage drop to minimum values, D1 should be a germanium or Schottky type.

A useful feature of the ICL7660 is that numbers of these ics (up to a maximum of ten) can be cascaded to give voltage conversion factors greater than unity. Thus, if three stages are cascaded, they give a final negative output voltage of -3Vcc, etc. Figure 15 shows the connections for cascading two of these stages; any additional stages should be connected in the same way as the right-hand ic of this diagram.

It has already been pointed out that a single ICL7660 ic can be used as a highly efficient voltage doubler that can, for example, generate a centre-tapped 10V output when powered from a single-ended 5V input. Figure 16 shows how two of these ics can be cascaded to generate a centre-tapped 12V output when the circuit is powered from a single-ended 3V source (for example, from two series-connected 1.5V cells).

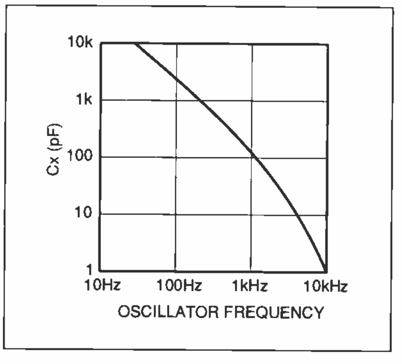

Figure 18: Cx versus oscillator frequency graph

Here, IC1 is used as a basic voltage doubler, powered from a 3V source connected between pins 3 and 8, and its 6V output (from between pins 5 and 8) is used to power IC2 via pins 3 and 8, and IC2 thus generates an output (between pins 5 and 8) of 12V when very lightly loaded. This 12V output has a source impedance of about 500R, and falls by about 0.5V per mA increase in load current (most of this volt drop is reflected from the -ve output of IC1, which operates at a current level two times greater than the IC2 output, as explained below).

It is important that the supply (battery) current consumed by any voltage multiplier circuit is inevitably at least n times greater than the circuit's loaded output current, where n is the circuit's "multiplier" value. Thus, if a voltage doubler is powered from a 5V supply and generates a 10V x 10mA (= 100mW) output, it follows that the supply current must be at least 20mA (= 100mW/5V). The circuit's output impedance is also proportional to the n value.

In some applications the user may want to reduce the oscillator frequency of the ICL7660 ic; one way of doing this is to wire capacitor Cx between pins 7 and 8, as in figure 17; figure 18 shows the relationship between the Cx and frequency values; thus, a Cx value of 100pF reduces the frequency by a factor of ten, from 10kHz to 1kHz; to compensate for this 10:1 frequency reduction and maintain the circuit efficiency, the C1 and C2 values should be increased by a similar factor (to about 100mF each).

Another way of reducing the oscillator frequency is to use pin-7 to over-drive the oscillator via an external clock, as shown in figure 19. The clock signal must be fed to pin-7 via a 1k0 series resistor (R1), and should switch fully between the

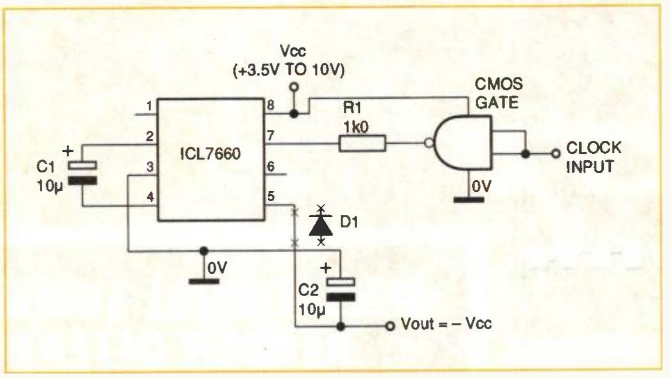

Figure 19: external clocking of the ICL7660

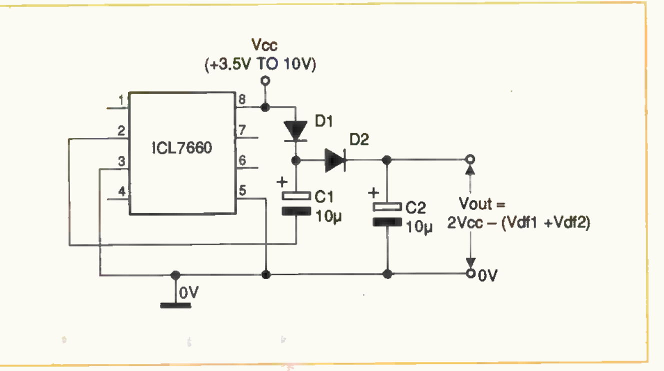

Figure 20: diode-steered charge pump type of voltage doubler

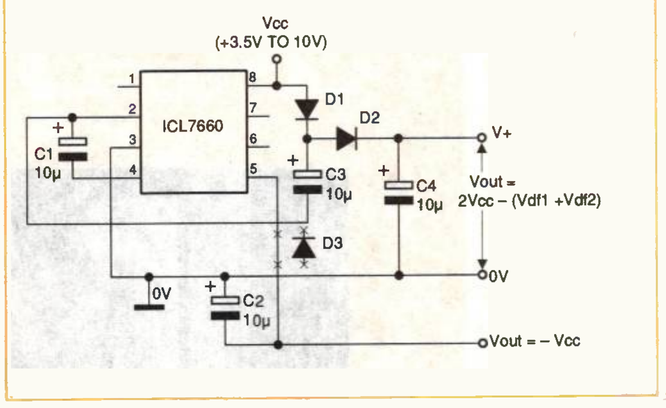

Figure 21: combined +ve voltage doubler and -ve voltage

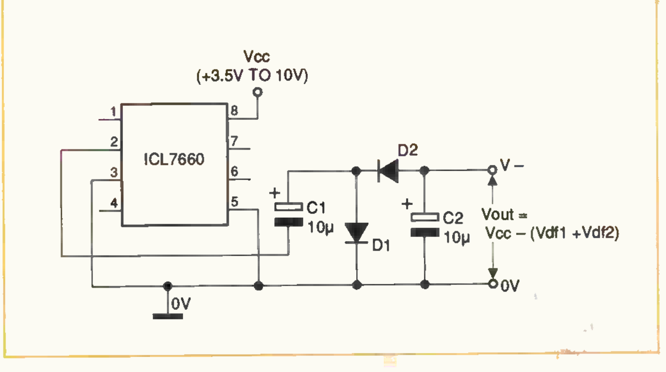

Figure 23: diode-steered charge pump negative-voltage generator

two supply rail values; in the diagram, a cmos gate is wired as an inverting buffer stage, to ensure such switching.

Diode-steered charge pump circuits

So far, this article has described three of the four most widely used types of DC voltage conversion circuit. The fourth type of converter is sometimes known as a "diode-steered charge pump" circuit, and figure 20 shows an example of one of these "pumps" used in conjunction with an ICL7660 ic to make a converter that gives a positive output voltage of almost double the original supply voltage value. The pump consists of D1-C1-D2-C2, and is driven by the low-impedance squarewave output of pin-2 of the ic. The circuit action is very simple:

When the pin-2 output of the ICL7660 is switched low it connects the low end of C1 to the 0V line, so C1 charges to almost the full Vcc value via forward-biased diode D1. When the pin-2 output switches high again it pulls the low end of C1 up to Vcc, thus driving the top end of C1 up to almost double the Vcc value, thus reverse biasing D1 and forward biasing D2 and forcing C1 to dump its excess charge into C2, which thus

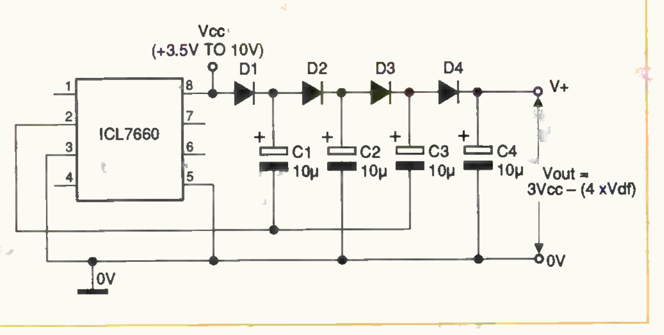

Figure 22: charge pump type of voltage trebler

charges up to almost double the Vcc value. This process repeats continuously, with C1 automatically replacing any charge currents that are withdrawn from C2 by external loading circuitry. In practice, diodes D1 and D2 reduce the available output voltage by an amount equal to their combined forward volt drops, so they should ideally be low-loss germanium or Schottky types. This "charge pump" type of circuit is far more powerful than a conventional capacitor-diode voltage-doubler circuit, and can easily supply tens of milliamps of output current.

Finally, to complete this look at DC voltage converter circuits, figures 21 to 23 show three useful variants of the basic "charge pump" circuit. Figure 21 shows how the charge pump circuit of **figure 20** can be combined with the standard ICL7660 negative-voltage generator circuit of **figure 13** or **14** to make a combined positive voltage multiplier and negative voltage converter that provides dual output voltage rails from a single-ended input supply.

Figure 22 shows how two of the figure 20-type diode-steered charge pumps can be cascaded to make a voltage trebler that gives a positive output voltage that has an unloaded value equal to three times the Vcc voltage, minus the value of the series-connected diode volt drops. Typically, the circuit gives an output of about 27V when powered from a 10V supply. Additional D3-C3-D4-C4 stages can be cascaded by wiring the low end of each odd-numbered capacitor to pin-2 of the IC, and the low end of each even-numbered capacitor to the 0V line; each new stage increases the available output voltage by Vcc minus two diode volt drops.

Finally, **figure 23** shows a diode-steered charge pump negative-voltage generator circuit, in which diode and capacitor polarities are simply reversed and referenced to the 0V line. This circuit (when using ordinary silicon diodes) gives a typical unloaded output voltage of only -8.8V when powered from a 10V supply, but gives far better voltage regulation than a conventional ICL7660 negative voltage generator circuit.

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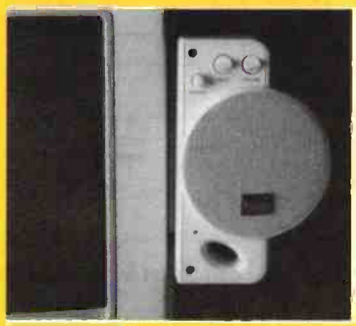

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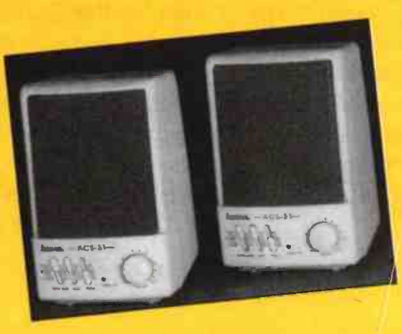

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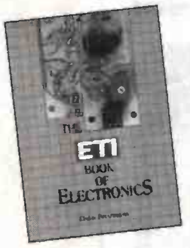

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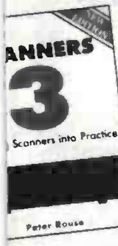

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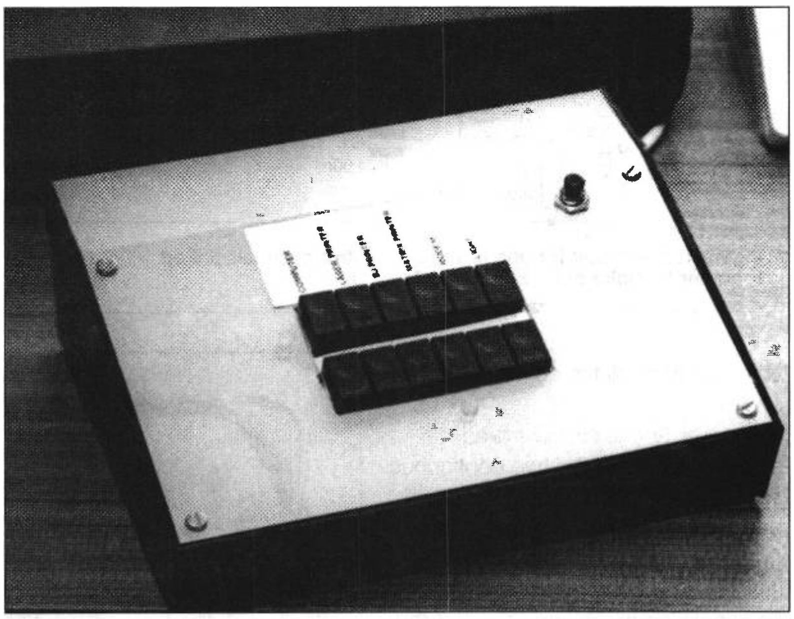
This Multi-Channel Control Centre allows six items to be switched on and off individually from a central position, and also allows two pieces of equipment to be powered continuously. This will be useful to anyone who needs to control several pieces of mains equipment which are currently plugged in with a tangle of extension leads and adaptors - and let's face it, that is most of us at one time or another.

One frequent application would be for computer equipment, but you will find plenty of other uses around the workshop and domestic environment, like your audio, TV and photographic equipment. Please note that the circuit is only suitable for individual items up to 2A rating (corresponding to 460W on 230V mains), and the total load must not exceed 5A (1150W on 230V mains). In practice, this is sufficient for most purposes.



It must not be used for high-power equipment such as photographic- or stage-lighting set-ups. A further point is that it is not suitable for equipment which relies on the mains connection to maintain memory settings. Some televisions and radios lose their tuning settings when disconnected from the mains for a few hours.

This is a mains carrying project with a case-mounted power supply. This should only be attempted by constructors with mains project experience, or with the assistance of someone with mains construction experience.

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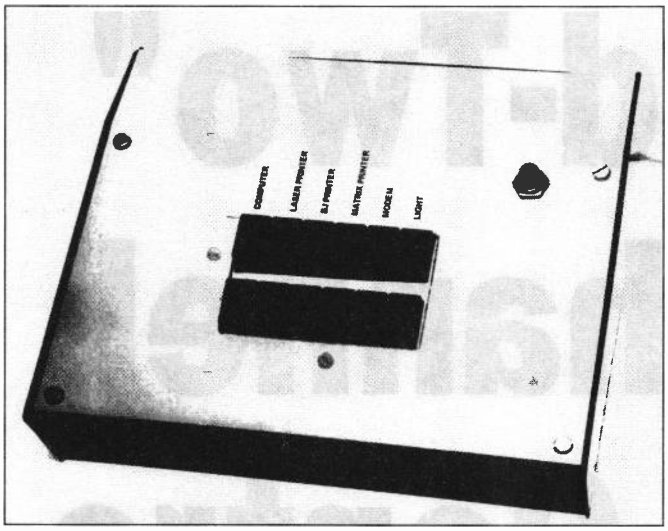
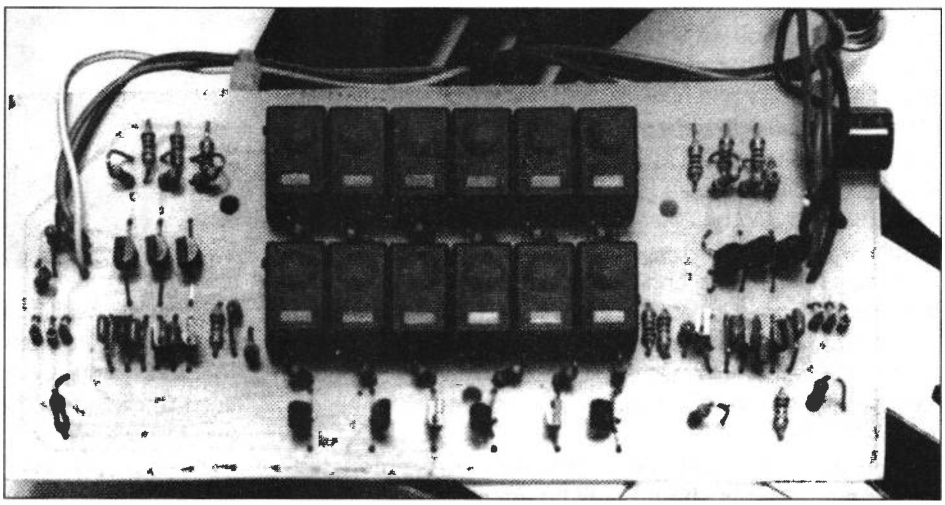
This system has two sections. The first is placed on the floor or hidden in some out-of-the-way place - this part is referred to as the **main unit**. On the case are mounted a set of Euro-style sockets into which the items are connected. It also has a lead which is plugged into the mains and a neon indicator which lights up when the unit is on. The second section - the **desk-top unit** - is housed in a case with a sloping front, which is the one that should be placed within easy reach of the user. The two sections are linked by a thin multi-core cable plugged into a socket on the main unit. The length of interconnecting wire was 4 metres in the prototype, but there is no reason why it should not be longer.

On the front panel of the desk-top unit are two rows of six push-button switches. The top row activate the corresponding socket on the main unit (the controlled sockets), while those in the lower row switch them off. Each on switch has a red LED to show that the corresponding socket is active. Each off switch has a green LED which remains on when the socket has been cancelled. In addition, there is a single push-button switch. This is the master off switch, and may be used at any



time to cancel all the active controlled sockets.

As well as the six controlled sockets, there are the two continuous sockets mentioned earlier. These will be useful for items which need to be operational all the time during a session. You could use them for, say, an answering machine or fax, but this would involve connecting the unit continuously to the mains. This is possible, but it is better to unplug the unit at the end of the day or after the session. All eight sockets are individually fused using fuse holders on the top panel of the main unit.



Wires in a tangle

To illustrate how the system can be used, I'll take the example of a home computer system. There may be the computer itself, a monitor, two printers, a modem and a reading light. In most set-ups the parts are connected to the mains with a variety of sockets, extension leads and multi-adaptors. This makes an untidy tangle of wires and also makes it difficult to switch each item individually. The mains switches may be difficult to reach (this is where we grow longer arms), or may be located to the rear of the case or in some other awkward position. To switch off, it may be necessary to fumble for the switches on the mains sockets themselves. At the beginning of a session, some people simply switch on at the wall socket which feeds all the adaptors, and leave the equipment operating continuously. This is wasteful, and it is obviously better to switch on only the equipment which is needed at the time. Some users plug in the items which are needed at the time and shuffle the plugs around when a change needs to be made. This is not only inconvenient, it can end up with the computer being unplugged by mistake with all the consequent loss of unsaved work.

How it works

The circuit for one channel of the Multi-Channel Control Centre (that is, the circuit responsible for one of the controlled sockets) is shown in **figure 1**. The complete circuit comprises this sub-section duplicated six times over, so a description of one channel is sufficient. Note, however, that diode D3 and capacitor C2 are common to all the channels.

Since push-button switches are used to perform the on-off switching, it is necessary to use some form of latching so that current continues to flow when the switch is released. Also, it

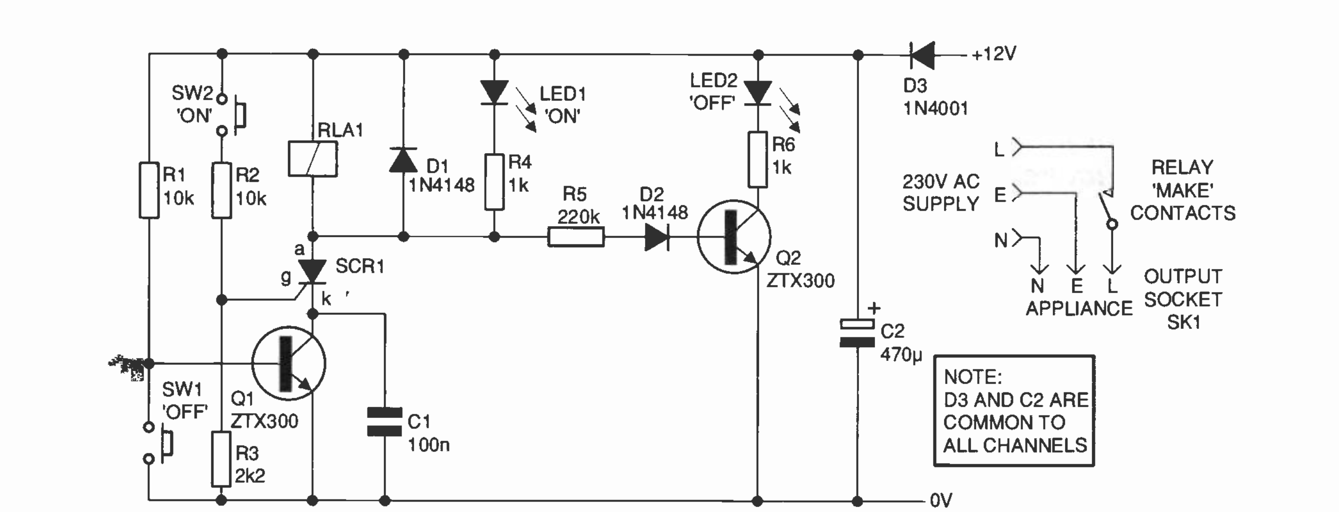


Figure 1: the circuit for one of the six control channels linked together to make the Six-and-two Main Unit

is necessary to use only push-to-make switches available as units which may be linked together to make a neat display.

Thyristor SCR1 (sometimes called a silicon controlled rectifier) forms the basis of the latching action. No current will flow from its anode (a) to cathode (k) unless it has first been triggered by a small pulse of current entering the gate (g). Once the device is conducting, the gate loses control and main-line anode/cathode current flows until, for some reason, it falls below a certain holding value. When this happens, the thyristor switches off and will only conduct again with the application of a further pulse to the gate. There can also be a nuisance effect where the thyristor may trigger spontaneously if the supply is connected sharply. This is due to the very rapid rise in applied voltage, and is known as the rate effect. I will explain how to avoid this later.

Transistor Q1 normally has current flowing into its base through resistor R1. There is therefore a conducting path between its collector and emitter, and it may be regarded as a closed circuit. When SW2 is operated, current flows from the supply positive line through R2 and R3. With the values specified, the current flowing into the gate will be about 0.5 mA, which is more than double the maximum required triggering current for the specified thyristor (which is about 0.2mA). The presence of resistor R3 eliminates any tendency for the thyristor to self-trigger due to the pick-up of stray signals by the gate wiring. With the thyristor conducting, the coil of relay RLA1 is energised with current flowing through it from the supply, hence from thyristor anode to cathode and transistor Q1 collector and emitter to the 0V line. The normally-open "make" contacts of the relay then direct mains current to socket SK1 and hence to the equipment connected to it.

Operation cancelled

To cancel operation, switch SW1 is pressed for an instant. This connects Q1 base directly to the 0V line and therefore prevents current flowing into it. The transistor therefore switches off and the collector/emitter becomes virtually open circuit. The thyristor anode/cathode circuit current therefore falls to zero and since this is obviously less than the holding value, the device switches off and the current in the relay coil is interrupted. The normally-open contacts then open and the mains equipment fed through them switches off. Diode D1 bypasses the reverse high-voltage pulse which occurs when the magnetic field in the relay core collapses on switching off. Although the SCR could withstand it, other semiconductor components in the circuit could be damaged. While the relay coil is energised, current also flows through LED1 which is a red LED inside the on switch. Its operating current is limited by R4. When SW1 is released again, C1 holds Q1 collector low for an instant. This avoids any sudden rise in voltage between the thyristor anode and cathode and possible self-triggering due to the rate effect.

The green off light-emitting diode (LED2) contained within switch SW1 operates as follows. While SCR1 is conducting, its anode will be close to 0V. It will not be quite zero since there is a small voltage between the anode and cathode (between 0.7V and 1V) and a further voltage (about 0.7V) between Q1 collector and emitter. The total is about 1.4V to 1.7V. This is applied to the base of transistor Q2 via resistor R5 and diode D2. Since there needs to be 0.7V approximately across the diode to make it conduct and a similar voltage needed

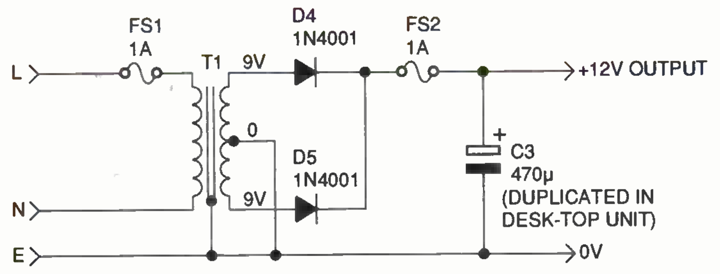
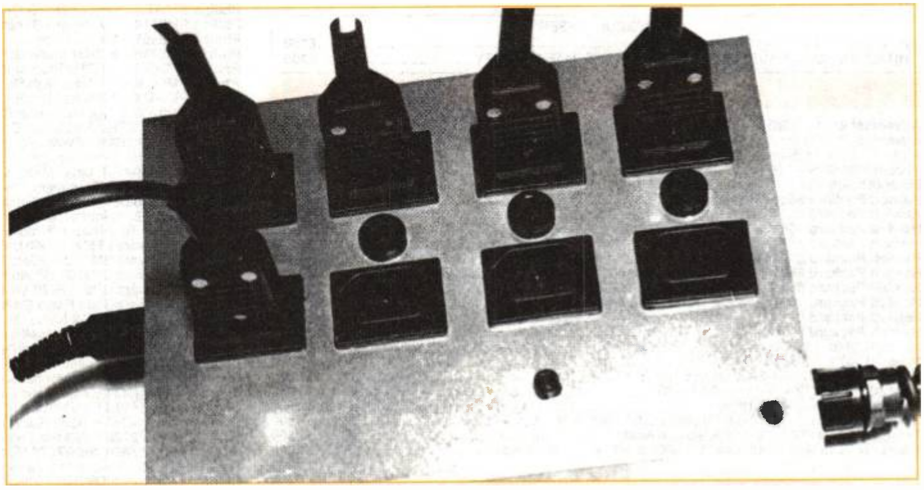
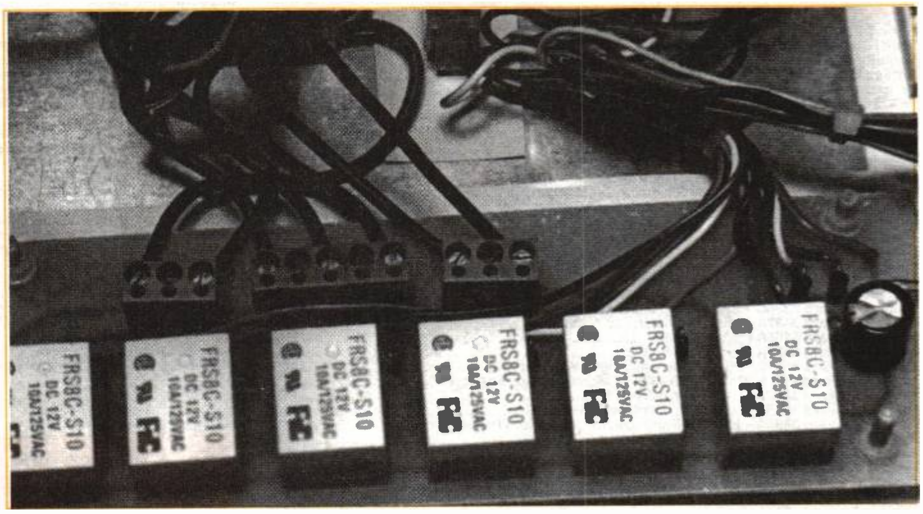


Figure 2: the power supply circuit





between Q2 base and emitter to turn it on, the transistor will be off or nearly so. Even if some current flows, resistor R5 limits this to a very low value. With none or very little base current flowing, there will be negligible collector current and LED2 remains off. When the SCR is off, there is a voltage close to positive supply voltage at the anode. Since this greatly exceeds the 1.4V figure referred to above, Q2 will be turned on. Sufficient collector current then flows to operate LED2 - its working current is limited by R6. Note also that very little current flows by the route LED1, R4, R5 and D2 (due to the high value of R5) so LED1 will be off while LED2 is on. The final effect is that only LED1 is on while the relay coil is energised and only LED2 is on when the relay is off.

Power supply

The power supply for the circuit is shown in **figure 2**. This is a conventional arrangement of mains transformer (T1), twin rectifier diodes (D4 and D5), fuse FS2 and smoothing capacitor C3. Using the specified transformer, there will be some 12V smooth dc produced at the output. Note that there is the additional smoothing capacitor, C2, in the desk-top section. Also, diode D3 in the desk-top unit splits the smoothing between the two circuit sections and provides an almost totally smooth supply for the thyristors. This eliminates any tendency towards false triggering, and also slows the rate of rise of supply voltage on powering-up and helps to prevent unwanted triggering caused by the rate effect.

The supply is connected from the main unit to the desk-top one through two of the wires in the multi-core link cable. The other wires in the bundle carry the signals from the thyristor anodes in the desk-top unit to the relay coils in the main section.

Construction

There are two PCBs used in this project , one in the main unit and the other in the desk-top one. Most of the work takes place in the desk-top unit, so I will describe this first. The main unit houses the power supply and contains the relays which direct mains current to the appropriate socket.

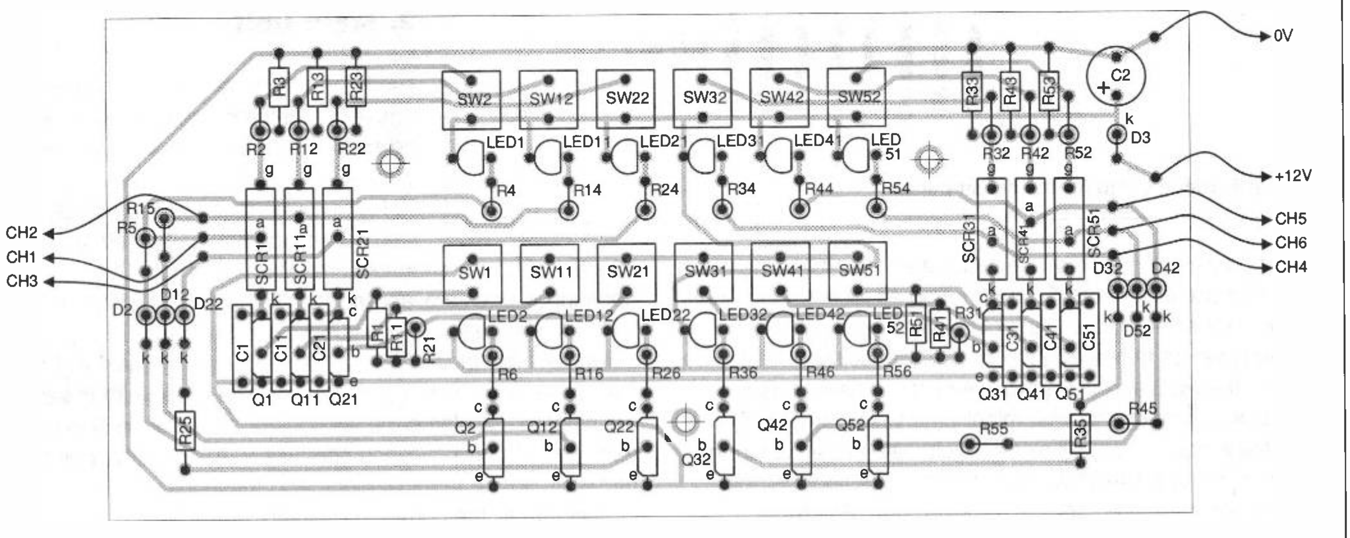


Figure 3: the component layout for the Desktop Unit

1. The desk-top unit

The PCB layout for the desk-top unit is shown in **figure 3**. The component labelling is as follows: for the first channel (that is, the circuit element responsible for the first controlled socket), the numbering begins from one - that is, R1, C1, Q1, etc. as in **figure 1**. For the second channel it begins at eleven: R11, C11 and so on. For the third channel, numbering begins at twenty one and so up to the sixth channel whose components are numbered from fifty one. Begin by mounting the two rows of six switches - red (on) along the top (SW2, SW12, SW22, SW32, SW42 and SW52) and green (off) at the bottom (SW1, SW11, SW21, SW31, SW41 and SW51). Note that there is a protrusion on each switch that engages with a hole in the next one. This aligns the units correctly to make neat rows. Follow by soldering the resistors and capacitors in position taking care over the orientation of C2. Note that Cs is mounted flat on the panel. Mount all the remaining components taking care over the polarity of the thyristors, transistors and diodes.

Prepare the box by making the hole in the top panel for the switches. In the prototype, a single hole was cut out large enough to accommodate all twelve units. It would, of course, be possible to cut out individual holes for each row of switches. Take great care over this work, as the final appearance of the project depends on how well it is done. Hold the PCB in position (some components may touch the panel and will need to be gently bent out of the way) and check that the switches can all be operated. Still with the PCB in position, mark through the mounting holes on to the panel. Remove the PCB and drill these holes. Drill the hole also for the master off push-button switch and mount this component. Drill a small hole in the side of the box for the connecting wire which will lead to the main unit.

Refer to **figure 4**. Solder seven pieces of stranded wire to the six "CH1" to "CH6" pads on the PCB (take care over the order), and also the "0V" one as indicated. Solder a 5cm piece of wire to the "+12V" pad. Using different colours (for example, rainbow ribbon cable) will help to avoid mistakes later. Attach all but the "+12V" wire to a 7-section piece of screw terminal block.

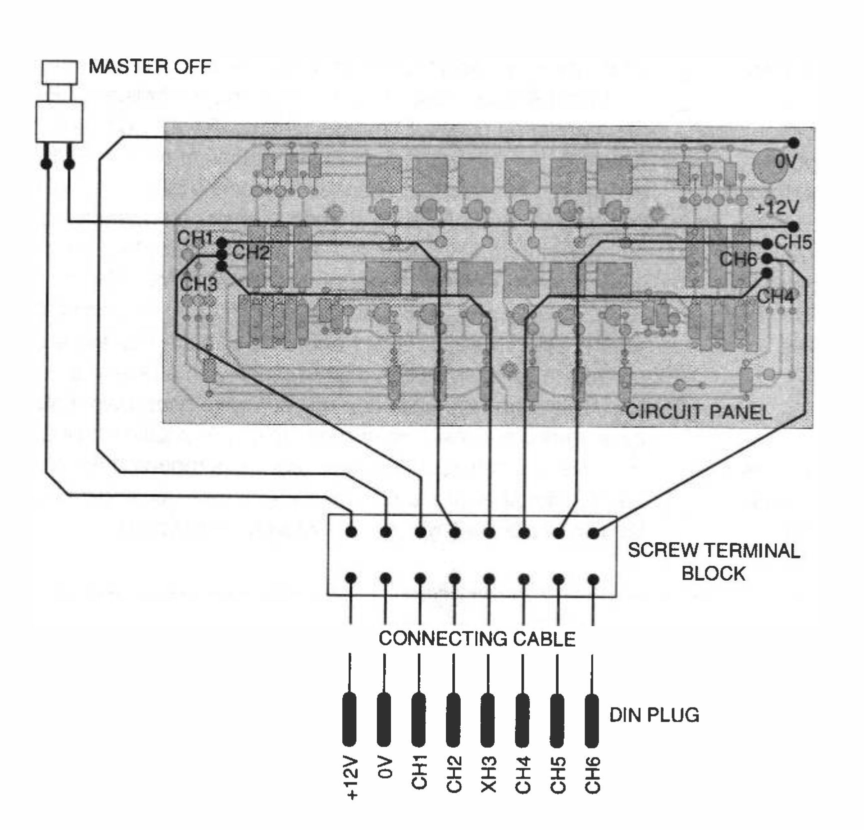


Figure 4: wiring guide for the circuit panel

Cut out a piece of plastic a little larger than the PCB. The best material to use is sheet PVC, and I found an ideal specimen as the cover for an A4 folder. It should have a reasonable thickness, yet be thin enough to be cut with scissors. Place it between the PCB and the metal panel of the case. This will insulate any components that might otherwise accidentally touch the metalwork. It will also give ultimate protection in the unlikely event of some catastrophic fault in the floor unit by which mains current enters the desk-top unit. **For this reason, it is essential that the panel is efficiently insulated from everything else and is electrically "floating"**. Cut out the two apertures in the plastic for the switches. Hold the circuit panel in position again and check carefully that none of the components are touching the plastic. Bend any leads and make adjustments as necessary. When satisfied on this point, cut the mounting holes in the plastic and attach the circuit panel using **nylon (that is, insulating)** nuts and bolts. If necessary, use short plastic stand-off insulators but this will probably not be necessary as the switches themselves locate the panel at the correct distance from the PCB. Connect a wire from one terminal of the "master off" switch to the remaining position on the terminal block and solder the other terminal to the "+12V" wire leading from the PCB. Secure the terminal block to the base of the box.

2. Main unit

The PCB component layout is shown in **figure 5** and the internal wiring scheme in **figure 6**. The numbering follows the same plan as that used for the desk-top unit. Note, however, that the mains sockets themselves, together with their fuses, are labelled with their channel number SK1 to SK6. The continuous ones are labelled "CONT1" and "CONT2" in figure 6. Solder the relays in position followed by the PCB-mounting screw terminal block, TB1. Seven terminals are required, so two pieces each with two holes and one piece with three holes are needed. Reinforce the sections of track connecting one of each pair of normally-open contacts to the corresponding terminals on the terminal block also the length of track connecting all the common contacts to the "mains L in" terminal (TB1/7) as indicated. This should be done by

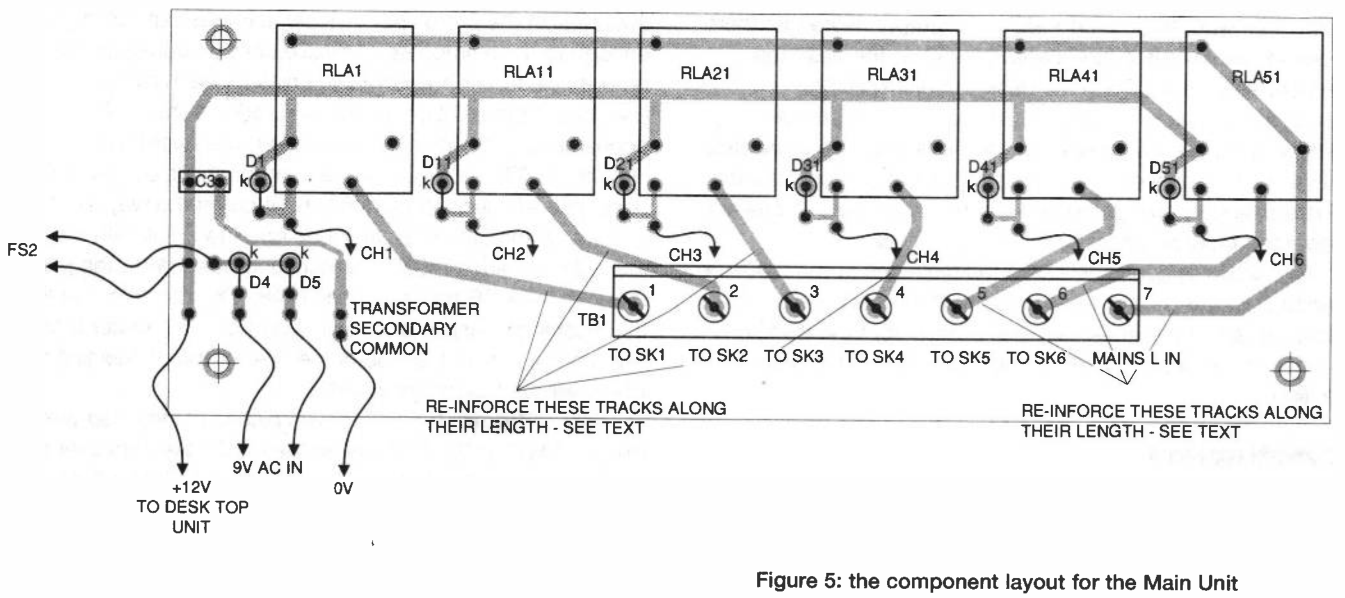


Figure 5: the component layout for the Main Unit

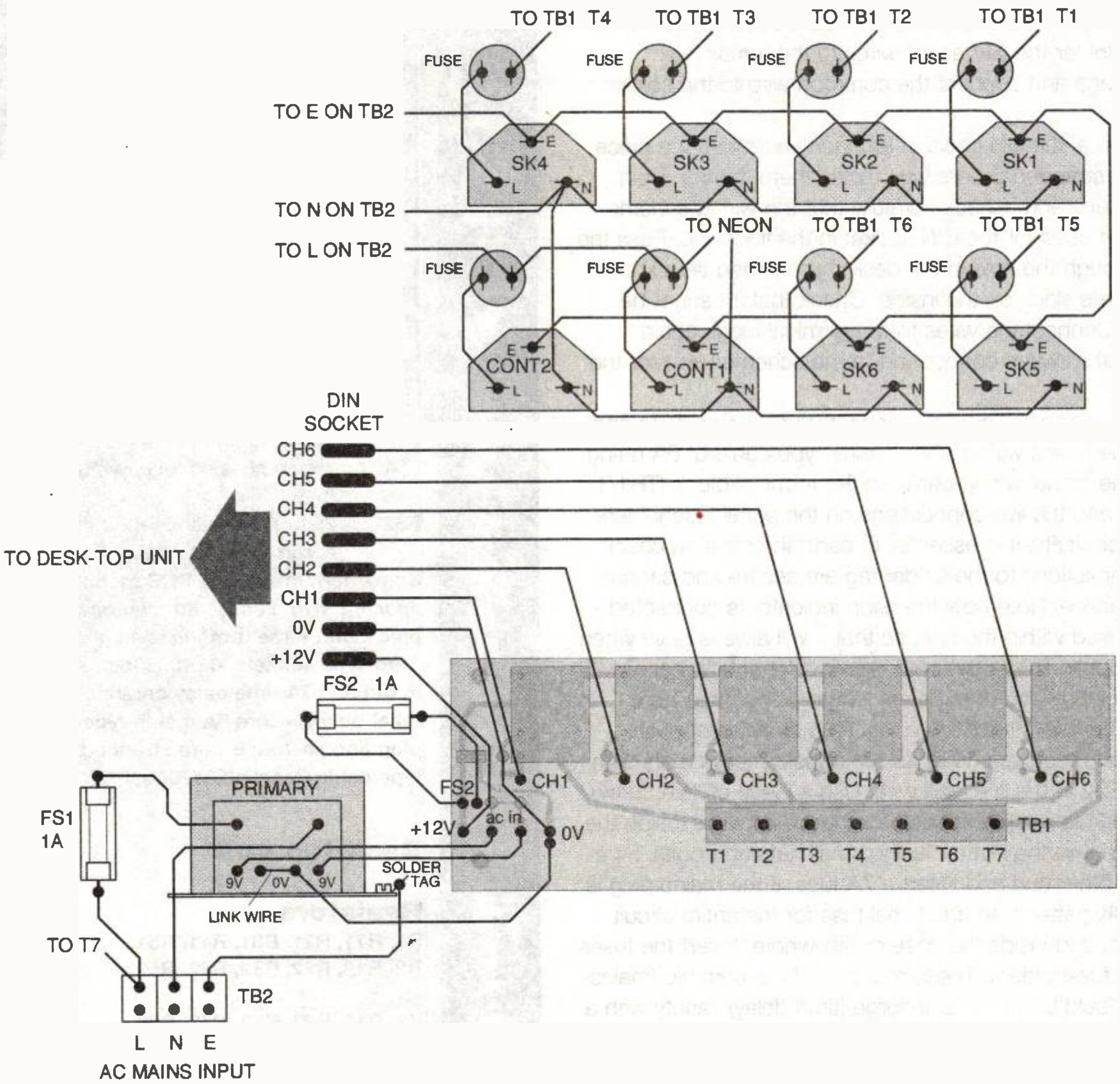


Figure 6: the circuit of the Desktop Unit

soldering pieces of 18 SWG tinned copper wire along their length.

Remember, this is part of the mains wiring and the work must be carefully checked. No part of it, including the solder, must approach anything else by less than 5mm. Add the diodes taking care to observe the polarity of each. Solder pieces of stranded connecting wire to each of the six points labelled "CH1" to "CH6" also the "+12V", "0V" and fuseholder FS2 ones. Using the same colour scheme as that used in the desk-top unit will help to avoid mistakes.

Prepare the box by making the holes for the mains output sockets. This is a tedious job. Begin by making a cardboard template of the hole needed for one of them. Using this, mark out the positions of all eight sockets on the top section of the box - remember to allow space for the panel fuseholders. Drill a series of holes around the outline of each hole and cut out most of the metal. Using a half-round file, cut it to size, checking at intervals for the correct fit. Drill the holes for the panel fuseholders, for the 8-pin DIN socket on the side and for the strain relief bush needed for the mains input lead. Drill holes also for the transformer and chassis fuseholders FS1 and FS2 on the base. Mount all these components placing a solder tag under the nut of one of the transformer fixings. Fuse FS2 protects the low-voltage dc output while FS1 is included in the mains feed to the primary.

Place a piece of plastic of the same type as that used to insulate the panel in the desk-top unit under each fuseholder. This will prevent metal-to-metal contact between a fuseholder tag and the case. Make certain that neither fuseholder can rotate on its fixing so that none of the connections can make contact with anything else.

Refer to **figure 6**. Wire up the DIN socket taking care to note which wire is soldered to which terminal. Following a logical sequence will help in avoiding errors. Six of the pins are used for the CH1 to CH6 wires, one for the "+12V" and one for the "0V" one. Solder the wires to the chassis fuseholders. Hold the PCB in position and mark through its three mounting holes. Remove the PCB and cut out a piece of plastic of the same type as that used previously and place it on the bottom of the box. This should cover the whole area of the PCB. Drill the mounting holes through the plastic and metal base and attach the PCB using nylon nuts and bolts with 12 mm plastic stand-off insulators on the bolt shanks. **Before proceeding, check very carefully to ensure that no mains tracks or anything**

connected to them approaches within 5 mm of anything else. Wire up the transformer secondaries - these are connected in series with the common connection used for the "0V" feed. Solder the "9V ac in" wires to the remaining secondary tags and connect the common wire to the solder tag.

Decide on a suitable position for each unit and cut a piece of light-duty stranded 8-core wire to link them. Fit the 8-pin DIN plug to one end. Check carefully that the wiring scheme matches that used for the DIN socket in the floor unit. Pass the free end through the hole in the desk-top unit and tie a knot in it leaving some slack on the inside. Check that it cannot be pulled free. Connect the wires to the terminal block again checking that all wires correspond to the scheme used for the DIN plug.

Referring again to figure 6, connect up all the sockets and complete the mains wiring using mains-type cable of 6A rating. Note that the actual wiring between the terminal block (TB1/1 and TB1/7) and the live connections on the panel fuseholders is omitted for clarity. It is essential to earth the case so check that the connections to the solder tag are secure and cannot detach in service. Note how the neon indicator is connected - this is not fused within the unit, so that it will always glow when there is a supply. This is the best method for safety reasons. Make up an input lead of sufficient length using three-core mains-type flexible wire of 6A rating. Fit a strain relief bush where it enters the case. Wire up the transformer primary with fuseholder FS2 in the live feed wire. Use a piece of 15A screw terminal block as a take-off point for the mains wires inside the case. Secure it to the bottom using small nuts and bolts. Fit a plug on the other end and insert a 7A fuse. If the mains plug is not of the UK pattern, an additional fuse for the entire circuit must be provided inside the case or elsewhere. Insert the fuses in the panel fuseholders. These must be of the ceramic (mains-type) and should be of the anti-surge (time delay) variety with a rating of 2A. Insert a 1A ceramic mains type fuse in fuseholder FS1 and a glass or ceramic one in fuseholder FS2. Place a plastic cover on fuseholder FS1 and make a plastic shield for the primary connections on the transformer.

Testing

Important: due to the presence of mains connection in the main unit, it is essential that the PCB is mounted in position and the case assembled before plugging it into the mains. Never operate the unit with the lid removed.

Insert the DIN plug into the socket on the main unit. Plug the unit into the mains and switch on. The neon indicator should glow and all six green LEDs on the desk-top unit should be on. Press each of the top row of switches in turn. A click should be heard from the corresponding relay in the main unit. Also, the green LED should go off and the red one come on. Press the green switches to cancel operation. Repeat this a few times. Try cancelling with the master off switch. Note that sufficient time must be given for all operating relays to switch off. This will take a few seconds (listen for the clicks).

It may be necessary to remove the existing plugs from pieces of equipment and fit Euro-style connectors instead. Alternatively, ready-made replacement leads are available with the correct type of connector at each end. Decide on a logical order for the plugs which suits your method of working. Remember, the last two sockets are continuous ones. It only remains to make a label for the desk-top unit to show the function of each switch and to put the unit into service.

PARTS LIST For the Six-and-Two Multi Channel Control Centre

Main unit

Capacitor

C3	470u

Semiconductors:

D1, D11, D21, D31, D41, D51	1N4148
D4, D5	1N4001

Miscellaneous

RLA1, 11, 21, 31, 41, 51: Miniature relay with 12V coil and 10A (resistive) "make" contacts. Maplin type YX97F.

T1 6VA mains transformer with twin 9V secondaries

FS1 25mm chassis fuseholder with 1A ceramic fuse to fit.

FS2 25mm chassis fuseholder with 1A glass or ceramic fuse to fit.

Screw terminal block, PCB mounting with 5mm spacing: two pieces with two terminals and one piece with three terminals; aluminium box; 3-pin Euro-type sockets (6 off); 20mm panel fuseholders (6 off) and 2A time delay ceramic fuses to fit; strain relief bush; 3-core 6A mains-type wire; 8-pin DIN plug and socket; 8-core stranded burglar-alarm type cable (Maplin CW70M); PCB materials.

Desk-top unit

Resistors

R1, R11, R21, R31, R41, R51, R2, R12, R22, R32, R42, R52	10k
R3, R13, R23, R33, R43, R53	2k2
R4, R14, R24, R34, R44, R54, R6, R16, R26, R36, R46, R56	1k
R5, 15, 25, 35, 45, 55	220k

Capacitors

C1, C11, C21, C31, C41, C51	100n
C2	470u

Semiconductors:

SCR1, SCR11, SCR21, SCR31, SCR41, SCR51	CP106D
Q1, Q11, Q21, Q31, Q41, Q51, Q2, Q12, Q22, Q32, Q42, Q52	ZTX300
D1, D11, D21, D31, D41, D51, D2, D12, D22, D32, D42, D52	1N4148
D3	1N4001

LED1 etc. and LED2 etc. incorporated within the switches

Miscellaneous

SW1, SW11, SW21, SW31, SW41, SW51, SW2, SW12, SW22, SW32, SW42, SW52: click effect push switches with LED indicator: Maplin type JU04E (red) and JU05F (green).

2A screw terminal block (eight sections required); master off switch (miniature push-to-break); PCB materials; desk console type case (Maplin type LH66W).

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SPICED CIRCUITS

Circuit simulation with software, by Owen Bishop. This month, part 6 - The simulation software

To give you an insight into what simulators are and what they can do, this series has been based right through on one circuit simulator, SpiceAge. But there are many other SPICE-based programs, each with its own features, good, middling and bad, and it may be that one of these will suit you better. In the remaining two parts of the series, we will survey a number of simulators to help you choose between the many. The versions on which the survey are based were provided by the publishers at various times over the past couple of years. Some may have been re-issued with upgraded features, but this does not alter our purpose, which is to give you a taste of each one to put you on the path to finding your ideal simulator.

SPICE

It began with a research project at the University of California, Berkeley, USA in the 1960s. The aim was to produce a simulation program for the designing of integrated circuits. This was in the days when programs and data were fed into the computer as punched cards and the results were printed out on a teleype machine. Over the years, the original SPICE routines (first published in 1970 under the name CANCER, but later changed - fortunately, perhaps) to Simulation Program with Integrated Circuit Emphasis) have been improved and extended. The introduction of the PC in the 1980s led to a proliferation of SPICE-based software, including several still available today. Further research has led to enhanced versions such as SPICE2 and SPICE3. Because SPICE routines are in the public domain, they may be freely used and adapted by software writers. This encouraged the development of many different simulators each with its own front end, graphics display routines and schematic capture techniques. We will look at a few examples, beginning with those that are most like the original SPICE and ending with those that depart furthest from it.

Even those modern Spices most like SPICE have travelled a long way from the original, which was a batch program. A set of punched cards (the term 'deck' has hung on and is still sometimes used in today's manuals) was run through the computer and the tabulated results were printed out. If there were mistakes to be corrected or circuit modifications to be made, or additional analyses to be performed, the whole process had to be repeated from scratch.

Nowadays, the software is characterised by interaction. We can control or modify the analyses while they are actually happening, which speeds everything up enormously - the main benefit of computing. processes.

ICAP/4

ICAP/4 is one of the more well-established simulators. It comes in various versions for the PC, running under Windows, and also for the Macintosh. ICAP/4 is based on SPICE 3 and includes a 12-state digital logic simulator. It consists of a suite

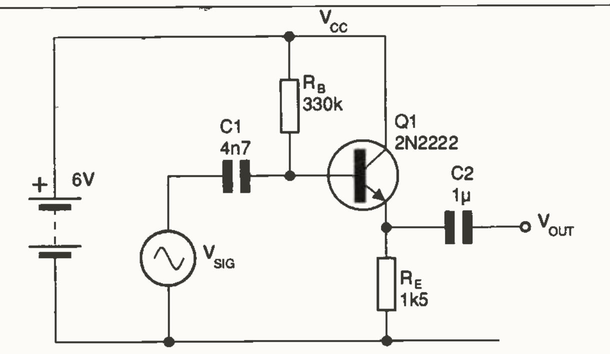

Figure 1: the common collector BJT amplifier used as a test piece in this survey

of four programs: IsEd for entering and editing netlists, SpiceNet for entering circuits by drawing their schematics, IsSpice4 which performs the simulations and produces output files, and IntuScope used for post-processing operations such as the display of graphs. It is a matter of moments to flip from one to the other, and each has access to files created by the others. @B:ICAP/4 is backed by a formidable range of library files of devices and models. These are listed in a book of 100 densely-packed pages, and include such gourmet items as pressure sensors, servo motors and neural networks. New models appear regularly on their WWW site.

My own preference is to enter circuits by keying in the netlist, so I call up IsEd and start typing. As a simple example, take the common collector amplifier of **figure 1**. This translates into the netlist above, which follows the original Spice syntax: The netlist begins with a one-line title, followed by a list of the

```
COMMON-COLLECTOR AMPLIFIER
RB      1   3   330k
RE      4   0   1.5k
RLOAD   5   0   1MEG
C1      2   3   4.7N
C2      4   5   1U
VCC     1   0   DC    6
VSIG    2   0   SIN 0 0.1 1E3 0 0 0
Q1      1   3   4     QN2222
.MODEL QN2222 NPN (IS=15.2F NF=1 BF=105 VAF=98.5 IKF=.5)
.TRAN 50U 5M
.PRINT TRAN V(2) V(4) V(5)
.PLOT TRAN V(2) V(4) V(5)
.FOUR 1E3 V(5)
```

components, their names beginning with a letter which indicates their type (for example, R for resistor). Node connections are numbered and each line ends with one or more values. VCC is a 6V DC source such as a battery. VSIG is a signal source producing sine waves, with zero offset, amplitude 0.1V and frequency 1kHz. There is zero delay and no exponential decay. Q1 is a BJT named QN2222, modelled as defined on the .MODEL line. We have quoted only a few of the 20 odd parameters; the ones we do not quote take default values. The transistor could have been defined by calling up a library file, but we decided to include it in the netlist in this example.

The netlist ends with a series of analysis and output commands. Here we are asking for a Transient analysis over a period of 5ms, sampling every 50us. The output file is to list the values of the voltages at nodes 2, 4 and 5. We are also asking for plots of these values. Finally we require a Fourier analysis of the voltage at node 5, based on a fundamental frequency of 1kHz.

After clicking on 'Simulate', there is a pause while it all happens or, if there are errors in the netlist, these are listed in an Error File and we are sent back to the beginning to sort it all out. Eventually we are able to access the output file which, again, is very SPICE-like in format. It begins with a copy of the netlist, followed by a table showing the voltages at each node under DC conditions. Then come the results of the Transient Analysis, of which we show only the first six of the hundred lines below: This is eight-figure precision. The file also plots the output as sideways-on graphs, using type symbols, as is suited to a teletype machine. Here is the start of it:

Fortunately we have *IntuScope* to bring us up to date with respect to graphical displays. Finally, there are the results of the

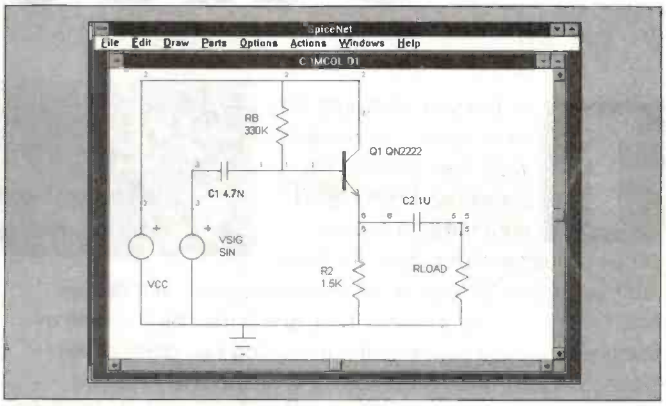

Figure 2: the common emitter amplifier as it appears on the

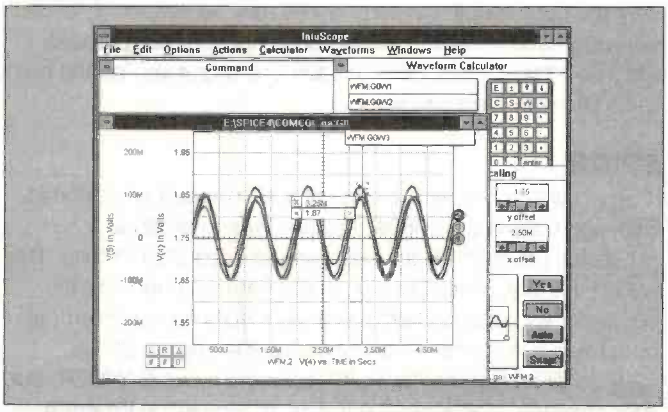

Figure 3: a Transient analysis of the amplifier as performed and displayed by Intuscope

```
***** Thu Jul 24 09:58:14 1997 ***** IsSpice4 ver. 4f3.5.p***** 12/16/94 *********
            COMMON-COLLECTOR AMPLIFIER
***** TRANSIENT ANALYSIS Temperature = 27 Deg C *****
*****************************************************************************
```

TIME	V(2)	V(4)	V(5)	INDEX
0.000000e+000	0.000000e+000	1.779401e+000	0.000000e+000	0
5.000000e-005	3.075208e-002	1.808134e+000	2.873257e-002	1
1.000000e-004	5.763998e-002	1.830418e+000	5.101399e-002	2
1.500000e-004	7.863944e-002	1.845456e+000	6.604893e-002	3
2.000000e-004	9.365886e-002	1.853517e+000	7.410676e-002	4
2.500000e-004	9.661055e-002	1.849637e+000	7.022315e-002	5

EDWIN NC

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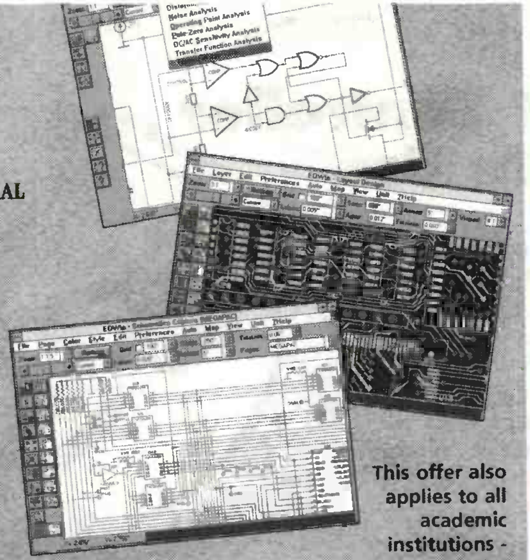

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Switching on/off possibility for tool and scroll bars.
Visible schematic and PCB symbols by editing.
Monochrome mode for better print resolution.
Bitmap support for loading logos, documentation, etc. Can be used in hierarchical as well as in simple schematic or PCB design.
Maximum number of nets: 16,000.
Maximum number of nodes: 32,000.
Maximum number of bend points: 64,000.
Maximum number of connections: 64,000.
Maximum number of symbols: 32,000.
Maximum number of components: 32,000
Maximum number of multi-segment traces: 32,000, with a total of 64,000 trace segments.
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Up to 100 schematic sheets.
Up to 64" x 64" sheet size.
Industry standard sheet sizes.
Rotate, scale and mirror symbols.
Real-time dragging of components and wires.
Automatic package and pin assignment.
Orthogonal and free mode manual routing.
Automatic bus annotation.
Block save, load, move and delete.
Direct access to mixed mode simulation.
Autorouting of connections.
Merging and splitting of nets possibility.
Definable line width, also for bus-lines.
Swapping of component positions.
Automatic component renumbering by swapping.

PCB Layout

32 layers (28 route layers, 2 silk-screen layers (front and back), 2 soldermask layers (front and back)).
User definable trace sizes.
User definable pads.
Curved traces.
1 mil grid resolution - Fine grid 10 micron.
SMT, fine line, analog support.
Component repeat, rotate and mirror.
Components "Move by name".
Component, gate and pin swap.
Automatic component renaming.
Trace repeat.
On-line, multi-layer routing with automatic via insertion.
Pin-to-pin, free or 45 degree routing.
Change segment side and width, trace side and width.
Fast interactive generation of ground planes with user definable cross-hatch or solid fill.
Automatic ground plane with thermal relief insertion.
Automatic DRC with user specified parameters.
Electrical connectivity checking.
Linear rotation of symbols.
Gerber input read and use possibility.
Built-in interface for Spectra 6.0, Max route 6.0 and Arizona Autorouter.
Bitmap functions (logos, drawings, ...).
Sophisticated database viewer.

Mixed Mode Simulation

AC analysis (Frequency domain).
DC analysis (Linear/non-linear).
TD analysis (Time domain).
Diagram generator.
Dynamic parameter definition of active and passive components.
Output graphs displayed on screen, hardcopy or placed on schematic.
Oscilloscope function.
DLL based analog/digital simulation primitives, modelling language and library creation tools.
Built-in model generator for discrete devices.

Please Note: Some of the above are ONLY provided on the De Luxe 3 Version. EdSpice and Thermal Analysis are available as bolt-on extras.

```
COMMON-COLLECTOR AMPLIFIER
transient Thu Jul 24 09:58:14 1997

Legend: + = v(2) * = v(4) = = v(5)
-------------------------------------------------------------------
time v(2) -1.00e+000 0.00e+000 1.00e+000 2.00e+000
+
---------------------|---------------|---------------|-------------
0.000e+000 0.000e+000 .        X         .        *.
5.000e-005 3.075e-002 .        X         .        *.
1.000e-004 5.764e-002 .        X         .        *.
1.500e-004 7.864e-002 .        X         .        *.
2.000e-004 9.366e-002 .        X         .        *.
2.500e-004 9.661e-002 .        X         .        *.
3.000e-004 9.438e-002 .        =+        .        *.
3.500e-004 7.834e-002 .        =+        .        *.
4.000e-004 5.740e-002 .        X         .        *.
4.500e-004 3.022e-002 .        =+        .        *.
5.000e-004 4.255e-005 .        =+        .        *.
5.500e-004 -3.054e-002 .       =+.       .        *.
```

window, as well as the window which shows the plots. ICAP/4 is a program of many windows, which makes it confusing at times, though you can always maximise the one you want. Because this is a common collector amplifier, the three waveforms have similar amplitude, but differ slightly in phase. At this stage we can call up any one or more of the graphs, plotting them in different colours in lines of different thicknesses, on the same grid or on separate grids. We can select portions of the graph for plotting on a larger scale. In general Intuscope has very flexible plotting facilities. It also provides instant reading of graph values. In Fig 3 we have set a cursor on the plot of V(4) at 3.25ms and are told automatically that the corresponding y co-ordinate is 1.87V. Voltage is only one among many quantities that can be plotted, which include not only single quantities but functions of quantities.

The Probe Tool is a sophisticated output feature. Touch this to a node and a small rectangle appears near that point displaying a graph of the voltage there as the simulation is run. Conversely, placing the tool on a component generates a graph of current.

ICAP/4 can be operated at a higher level than the straightforward netlist/simulation/post-processing sequence described above. Its Interactive Command Language is one of its more powerful features, which provides a set of instructions that can be included in the netlist, controlling the way the analysis is to

Fourier analysis for v(5):
No. Harmonics: 10, THD: 0.090876 %, Gridsize: 200, Interpolation Degree: 1

Harmonic	Frequency	Magnitude	Phase	Norm. Mag	Norm. Phase
0	0	-1.096e-005	0	0	0
1	1000	0.0921748	16.8778	1	0
2	2000	1.9765e-005	73.1588	0.00021443	56.281
3	3000	3.41376e005	107.319	0.000370358	90.441
4	4000	3.30331e005	114.744	0.000358375	97.8657
5	5000	2.90074e-005	115.271	0.000314699	98.3931
6	6000	3.13314e-005	124.098	0.000339913	107.221
7	7000	2.93175e005	122.563	0.000318064	105.686
8	8000	2.96001e-005	133.256	0.00032113	116.379
9	9000	2.84701e-005	142.638	0.000308871	125.76

Fourier Analysis:

Total harmonic distortion at the output is 0.090876 percent, and the magnitude and phase (both actual and normalised) are calculated for the first nine harmonics. The output file is rich in information, though it takes experience to read it.

The alternative way of entering a circuit is by drawing the schematic, using SpiceNet, which is similar to the schematic entry programs of other simulators. First you select components and place them on the editing screen. Then you select 'wire' mode and join the terminals. At this stage the program allocates node numbers automatically. You can then click on each component in turn to obtain a window in which you enter the component name (if you don't like the one it has been allocated) and value. These details are then positioned on the schematic. **Figure 2** shows the common collector circuit entered in this way. The final stage is to enter the control statements into the Edit Controls window, just as they are to appear in the netlist. The complete netlist is automatically created from the schematic plus the control statements. This done, the next stage is to click on Simulate.

Simulation produces an output file, as described above, but a far more intelligible output is invoked by using IntuScope. **Figure 3** shows the results of the .PLOT instructions. There is a window for entering commands, a waveform calculator and a plot scaling

proceed. You can set up breakpoints, repeat the analyses any given number of times, alter variables and statements during the analysis (which alterations may be based on logical decisions of the 'If... then...' type), and automatically perform calculations during run-time using Basic-like maths functions.

Digital analysis is well catered for in mixed more simulations. Logic devices are linked on screen to the analogue sections of the circuit through 'bridges' which perform the necessary conversion from analogue to digital or the reverse.

There is space here to describe only a fraction of the features of this powerful simulator, which performs the full range of SPICE analyses. It comes with a boxful of manuals, including detailed tutorials. But inevitably, the more options, the greater the chance of inadvertently picking the wrong one and ending up with an error message! It takes time, effort and patience to get the most out of ICAP/4.

B2 SPICE, Version 2.1

B-squared SPICE (the B2 stands for Beige Bag Software) is a relative newcomer, based on SPICE3F5, and is available as a 32-bit application for Windows and the Macintosh. It is a purely analogue simulator; its digital companion B2 Logic will be described next month. B2 SPICE is a suite of three programs, of which the most frequently used is the Workshop program. You use this to enter the circuit (as a schematic) and subsequently to analyse it. The other programs are the Symbol Editor for designing new circuit symbols and the Device Editor for setting up new components. As in all the simulators described this month, the areas of analysis are based on the three SPICE subsets: DC, AC and Transient. Although in B2 SPICE you do not enter circuits as netlists, a netlist is derived from the schematic you have entered and may be saved. The program also generates an output file tabulating the results of the analysis. This is a typical SPICE output, rather like the file produced by ICAP/4.

As with most schematic entry programs, the circuit symbols and labels are spidery and the labels are not easy to place for best legibility. **Figure 4** shows its version of the common collector amplifier, the matrix of dots being optional. The signal generator again has amplitude of 0.1V and frequency of 1kHz. An interesting feature is the insertion of 'virtual testmeters' on the schematic. These are the rectangular voltmeters labelled IVIN and IVOUT, connected between two nodes to act as probes. The voltmeters have infinite resistance, so do not affect the operation of the circuit. When the simulation is run, the voltages between the nodes are displayed in the rectangles. **Figure 5** shows the typical on-screen graphical output of this simulator. The dashed curve shows the

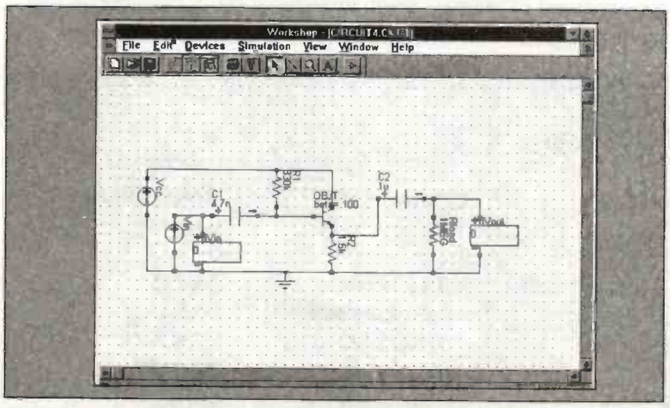


Figure 4: the amplifier as seen by B2 SPICE

readings of IVIN, while the thicker curve shows IVOUT. A cursor has been place on the graph at 2ms and the small panel shows that at that time the readings of IVIN and IVOUT were 8.785mV and 35.88mV respectively. Virtual ammeters with zero resistance may be used to probe current. There is also a 'marker' component which can be placed at any node on the schematic to position a voltage probe, or to set an initial voltage or guessed voltage for the start of the analysis. This has a similar function to the test point symbol of ICAP/4

The manual has 126 pages of detailed and concise instructions, including a short tutorial session. There is more information available on-screen by way of the Help routines. It comes with a library of

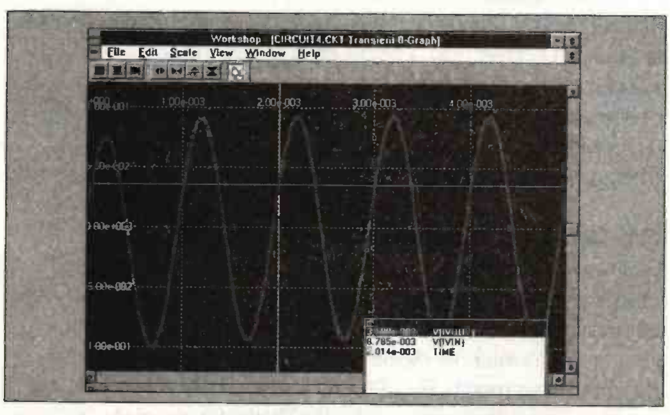


Figure 5: the amplifier's performance as calculated by B2 SPICE

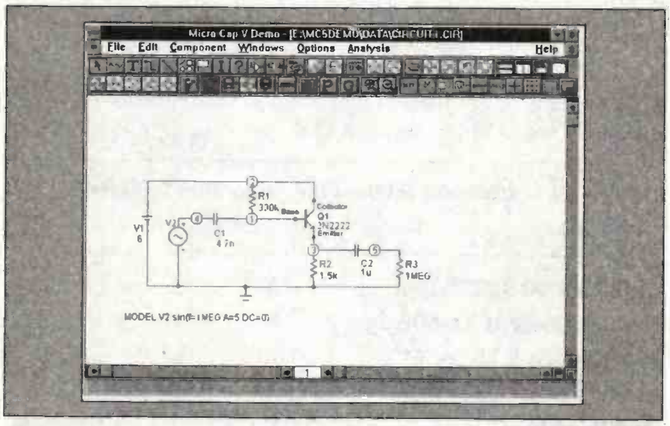


Figure 6: Micro-Cap produces this schematic of the amplifier, with a definition of the signal source included

about 1000 types of component, enough for most budding designers. This simulator covers all the traditional SPICE analyses, and is fast. It has the same SPICEy 'flavour' as ICAP/4, but is simpler in concept and easier to use.

MICRO-CAP IV and V

This is the more recent Windows successor to the long-lived Micro-Cap IV, which is a DOS-based program. Here we refer to the Demo version of Micro-Cap V, which at the time was available free from Spectrum. **Figure 6** shows its version of the common collector amplifier. Micro-Cap IV and V have the clearest schematic displays of all the simulators in this review. They really look like the drawings we are accustomed to in electronics magazines and books. You draw the schematic, type in the command lines and model descriptions on the schematic, and you are ready to get on with the analyses. As you click on each component, a window is displayed asking you to enter component parameters. These can appear on the schematic or not, as you wish. Node numbers (automatically allocated) can be turned on or off using one of the many buttons in the toolbar, as can terminal names of semiconductors and other devices, and various other features of the schematic. Schematics can be converted into SPICE files (either SPICE2G or PSPICE) for saving.

As an example, **figure 6** bears a single line of text, a definition of the signal generator which produces a 1MHz sine wave, amplitude 2.5V, and with zero offset. Note that the syntax is similar to but not quite the same as SPICE. We could have put the command lines on the schematic too, but we decided not to. There is no need to do this unless you want to save them along with circuit details. Analysis in Micro-Cap is essentially an interactive process. If you are wanting to do a series of Transient analyses (for example) on the circuit, you move on to the Transient Analysis Limits screen where there are panels in which you can enter all the parameters for the analysis and also define the way in which the graphs are to be plotted. Clicking on the Run button starts the analysis and soon the graphs are displayed. From there you can return to the Limits screen, modify the parameters and Run again. There is a 'round and round' quality to this simulator which makes you feel that you are never lost within a hierarchy of options. **Figure 7** is the result of a Transient analysis of the common collector amplifier. The output signal is appreciably distorted, mainly because the amplifier is overloaded by the 2.5V signal. Two cursors (left and right) have been positioned on the curve and the co-ordinates of their intersections with the curve are tabulated below. This feature is an option which can be deselected to allow a larger plot area. A useful set of buttons will automatically take the cursors to the next peak on the curve, or the next valley or the next point of inflection. They will also find the overall highest point and lowest point on the displayed curve. As an option you may also ask for Numeric Output, which results in a window displaying lists of values, similar to the output file of ICAP/4. This information may be saved as a file. The numeric format (number of places before and after the decimal point) of the output file can be specified from the Transient (or DC or AC) Limits windows, and results are obtainable with 13 or more significant figures. For routine analyses it is sufficient to work to fewer figures and so reduce run times. It is also possible to select exponential format.

In addition to the display sequence described above, there is Probe Mode which, after the analysis is complete, allows you to place probes on the schematic and immediately see graphs of voltages at these points or between points on which two probes have been placed. Similarly, you can probe currents through individual components. Probe Mode is a very useful analytical tool.

Like ICAP/4, this simulator offers a collection of function blocks (analogue behavioural building blocks, or analogue code models) which take simulation to the system level. These include an amplifier block, for example, which is not based on any particular semiconductor circuit or operational amplifier. You simply specify its single parameter, gain, and the voltage output of the block at any instant is its input voltage multiplied by the gain. Other function blocks include DIF, a differentiator in which the output is a scaled version of the time derivative (dv/dt) of the input, and SUM, a block in which the output is the sum of two input voltages. Building systems from function blocks simplifies design and means that simulations run far faster.

It is interesting to note the extent to which Micro-Cap has diverged from SPICE. There are more subtle differences that are important. Several of the component definitions depart from the SPICE tradition. For example, the SPICE switch is controlled either by a voltage or a current. In Micro-Cap the switch is controllable also by time. This makes it possible to model time delays in its action.

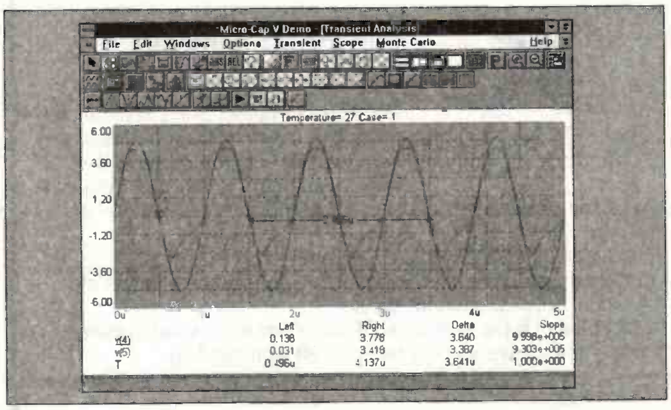


Figure 7: the input and output signals as analysed by Micro-Cap

Logical analysis is catered for in Micro-Cap by mixed mode analysis. The software automatically inserts notional A-to-D and D-to-A converters between logical and analogue sections of the circuits. Mixed mode analysis is useful when we are dealing with circuits which perform relatively simple logical operations. But once you get beyond a few flip-flops

Micro-Cap is another powerful simulator, backed up by a large and varied library of over 4000 electronic devices (not all of these are accessible on the free disk). Version IV came with two thick manuals, one of which is a most comprehensive Tutorial. Happily, there is plenty of on-screen Help for we did not get any manuals with the free Micro-Cap V disk! Summing up, we like best the flavour of Micro-Cap. It has the chilli hotness of SPICE mellowed by the coconut milk of user-friendly programming.

GCSE Grounding

Universal Sensor Module

Terry Balbirnie continues his series of adaptable circuits for GCSE projects with a sensor module suitable for many environmental conditions

This series is describing a range of electronic modules to help electronics students - examination candidates and hobbyists alike. Those wishing to pass GCSE Technology and examinations at a similar level will find them useful as a basis for practical projects. All the circuits are easily customised to suit different applications, and they also have inbuilt possibilities for investigative work to challenge the more inquisitive.

The circuits are given in basic form using a stripboard (Veroboard) layout. Such details as fitting the circuit panel in a box, choice of battery and use of an on-off switch are left to the constructor. Some of the circuits have a relay output to allow them to control other devices such as lamps or motors, using a separate supply. They can also operate other electronic circuits. **Note, however, that the circuits must not be used to control mains equipment unless all relevant safety precautions are observed.**

This month we shall look at a universal sensor module which can be used to switch an external device on or off in response to an environmental change. It is "universal" because it can respond to various environmental changes, such as temperature, light, air pressure, force, position and the presence of water, depending on the sensor used. As well as this, the relay can switch with either an increase or a reduction in the changes being measured.

The circuit

The circuit is shown in **figure 1**. Power is normally derived from a 9V PP9-type battery. For long periods of use, it would also be possible to operate it from a commercial plug-in supply, and more will be said about this later. Diode D2 allows current to flow from the supply to charge capacitor C1. This provides a reserve of energy which helps when the battery is becoming old or when a poorly-smoothed plug-in unit is used. The diode also provides protection if the supply were to be connected the opposite way round, since it would be reverse-biased and would not allow current to flow.

The main component is operational amplifier (op-amp), IC1. This is used as a voltage comparator. Its purpose is to "look at" the voltages present at its two inputs - the non-inverting one (pin 3) labelled "+" and the inverting one (pin 2) labelled "-" and switch on or off accordingly.

This is how it operates: if the voltage at pin 3 exceeds that at pin 2, the output (pin 6) will be high. In other circumstances it will be low. Ignore feedback resistor R4 for the moment and consider double-pole switch SW1 is in the position shown. The inverting input voltage is set at one-half that of the supply by the potential divider action of equal resistors, R2 and R3. The voltage applied to the non-inverting input will depend on the values of preset RV1 and fixed resistor R1 which together make the upper arm of a further potential divider and the resistance of sensor, X1, which forms the lower one. The

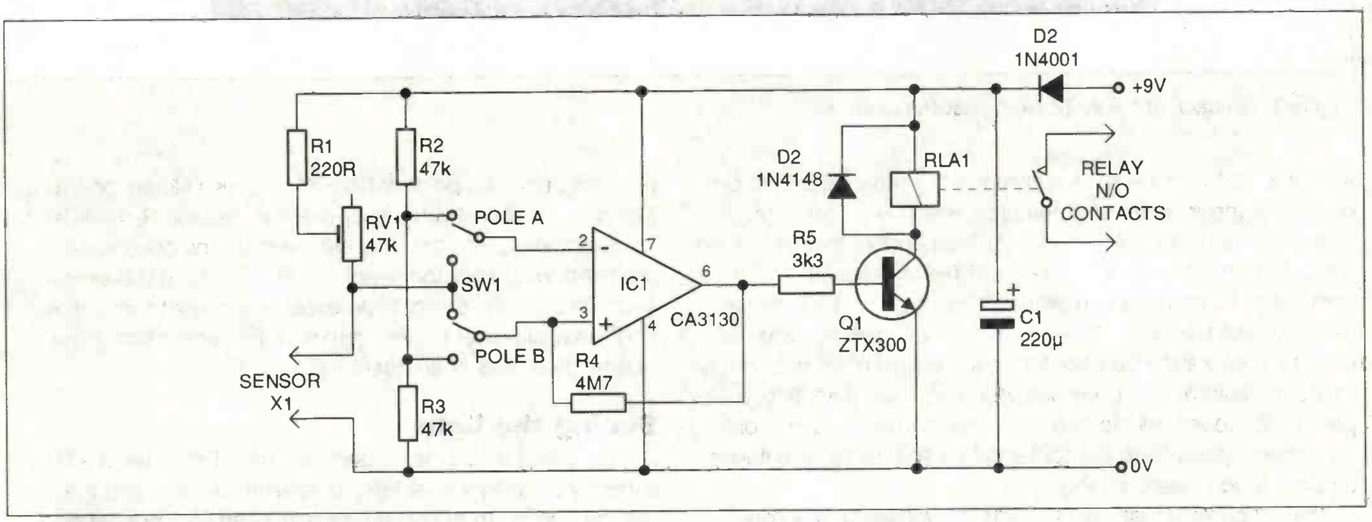
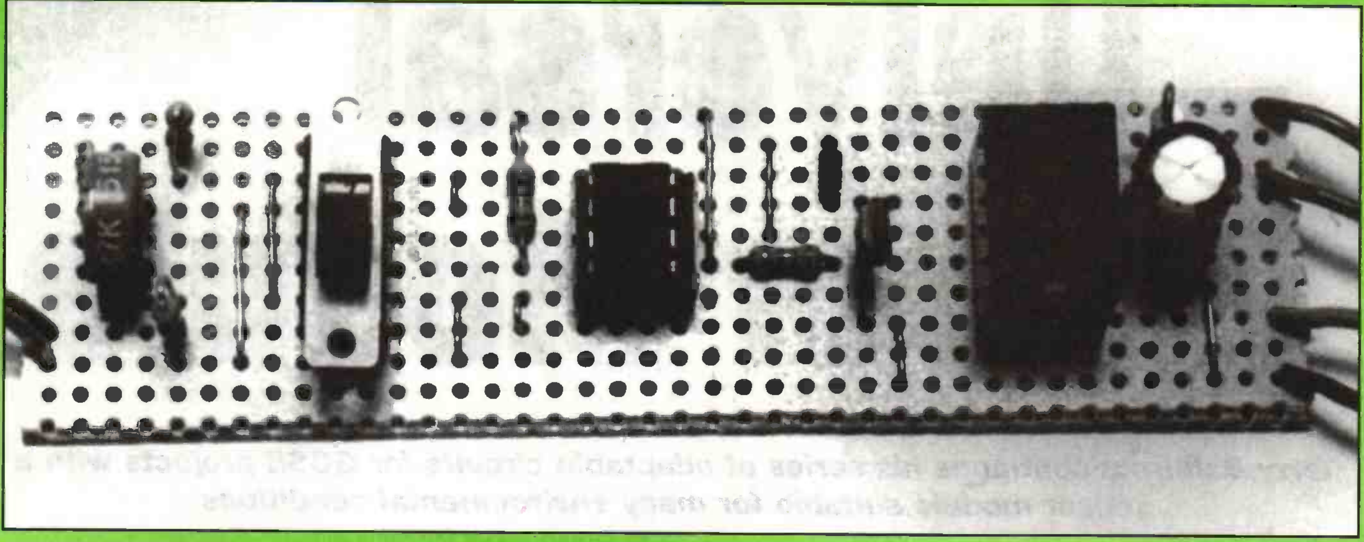


Figure 1: the circuit of the Universal Sensor module



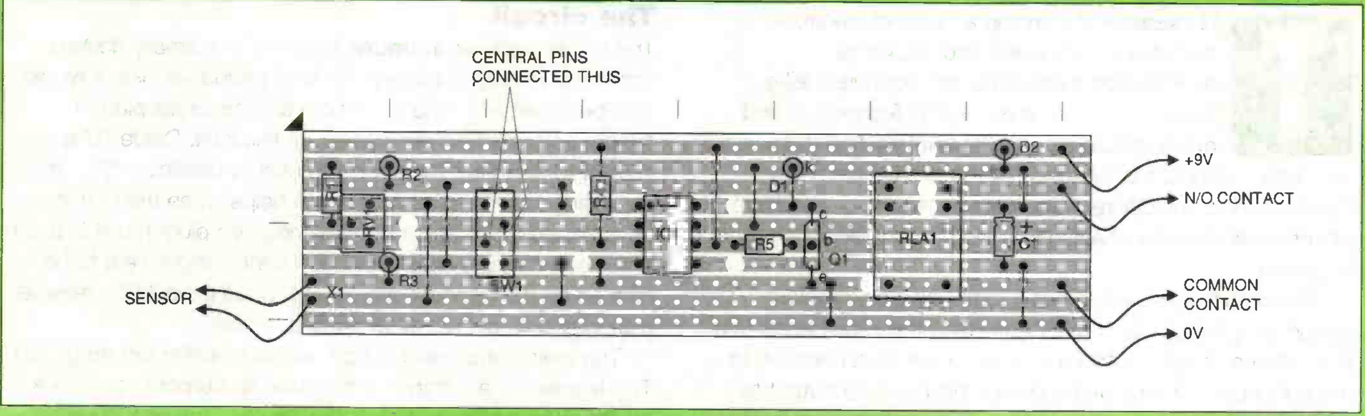


Figure 2: the stripboard layout, component side

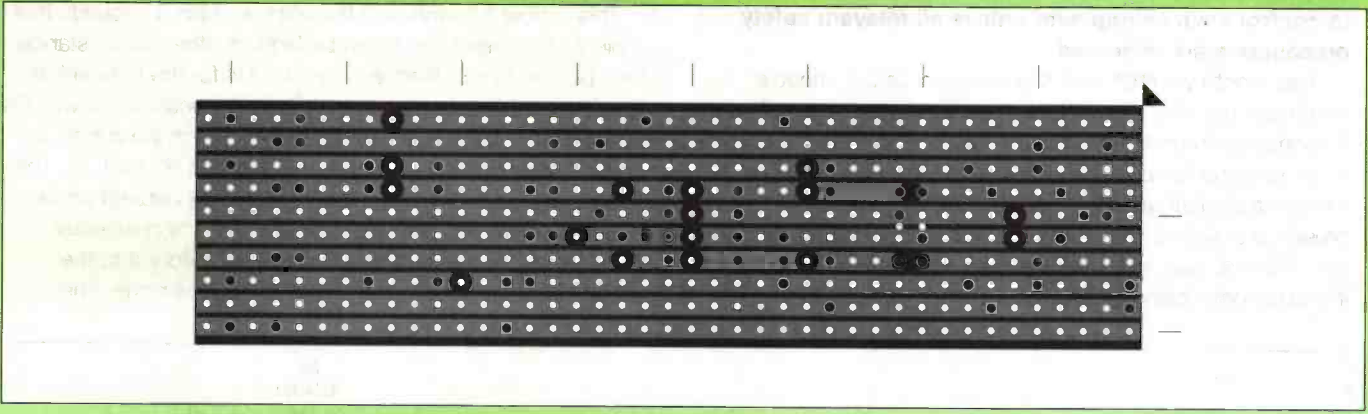


Figure 3: the back of the stripboard, showing cutouts

sensor is chosen to alter its resistance or simply to switch on or off with the required environmental effect. So, if changes in light level are considered, then a light dependent resistor will be used. If changes in temperature must be detected, a thermistor will be used (a miniature bead type with a nominal resistance of 15k would be suitable). For position sensing, the object will operate a microswitch at the critical point or possibly rotate the spindle of a potentiometer. For water detection, a pair of electrodes will dip into the water. Air pressure sensors can close a pair of internal contacts in response to air entering a port through plastic tubing.

With suitable adjustment to RV1, the voltage at the non-inverting input will rise above that at the inverting one at the required operating point. Where X1 provides simple on-off switching, such as with the air pressure sensor, RV1 will be set to maximum resistance. This will minimise the continuous current flowing from the supply via R1, RV1 and the sensor itself. Resistor R1 prevents an excessive current being drawn if RV1 were to be set to near-zero and the sensor had a low resistance or was short-circuited.

Seeing the light

Suppose that a light-dependent resistor (LDR) is used as the sensor. As the light level falls, its resistance rises, and the voltage applied to the op-amp's non-inverting input will also rise. At a certain point, this will exceed the voltage at the inverting input and the relay will operate. Suppose the relay is required to switch as the light level increased instead. Switch SW1 would then be moved to its other position. Now the connections to the op-amp inputs are interchanged and the output would work in the opposite sense.

With the op-amp output pin 6 high, current enters the base of transistor Q1 via resistor R5. This allows current to flow in the collector circuit and through the coil of relay, RLA1. Its normally-open (n/o) or "make" contacts will then direct current from a separate battery to the external device such as a bulb or buzzer. Diode D1 bypasses the reverse high-voltage pulse which appears across the relay coil when it switches off. Without this, semiconductors in the circuit could be damaged.

The purpose of R4 is to introduce a small amount of positive feedback. This improves the switching action at the critical point. Without it, the relay may tend to "chatter" close to the operating value. If the resistor value is reduced, operation would be sluggish. If too high, it would have negligible effect. Experimenting with this resistor could produce better results with a given sensor. Some constructors may wish to solder short wire "stalks" to the R4 position so that its value can be easily changed. Alternatively, you could use a variable resistor.

PARTS LIST for the Sensor Module

Resistors

R1	220R
R2, R3	47k
R4	4M7 (see text)
R5	3k3
RV1	47k min vertical preset (see text)

Capacitors

C1	220u 16V electrolytic

Semiconductors

IC1	CA3130E
Q1	ZTX300
D1	1N4148
D2	1N4001

Miscellaneous

RLA1 Miniature relay with 6V coil and 2A "make" contacts 0.1-in matrix stripboard; PP9 battery and connectors; 8-pin dil socket.
The relay used in the prototype was order code FM91Y from Maplin the switch was order code FH35Q, also from Maplin.

Construction

The component (topside) of the stripboard layout is shown in **figure 2**, and the back is shown in **figure 3**. A number of track breaks and inter-strip links are needed. First, make the breaks using a spot face cutter, then solder the link wires in place. Most causes of malfunction are due to a strip not being broken completely, a break or link wire being left out, a break in the wrong place or a blob of solder or sliver of copper bridging adjacent copper tracks. Some of these mistakes are invisible to the naked eye, so it is always good practice to check with a magnifying glass. Next, solder the switch in position. This is a difficult task because in this case the centre tags will not fit the 0.1in. matrix. This is something that you will meet with often enough if you practice electronics, and it will in this case be necessary to drill small holes between the tracks to accommodate the tags. One of the switch centre tags is then connected to the copper strip above it and the other to the strip below, as shown. Follow this with the ic socket, the relay, and all the remaining components. Take care to mount the transistor, diodes and capacitor the correct way round. Solder battery connectors to the "+9V" and "0V" tracks, and short pieces of wire to the sensor position. If the circuit is to be operated from a plug-in supply, use the appropriate connector. Solder pieces of wire to the normally-open relay contact and common contact tracks.

Insert the ic, taking care over its orientation. This is a CMOS device and could be damaged by static charge which might exist on the body. To make sure this does not happen, earth yourself by touching a water tap before handling the pins.

Testing

Adjust the sliding contact of RV1 to approximately mid-track position and set the lever of SW1 upwards. Connect the supply and listen for a click from the relay. Touch the sensor wires together and it should click off. Adjust the lever of SW1 downwards and repeat. This time the relay should remain off until the sensor wires are touched together, after which it should switch on. If the relay action is not easily heard, make a circuit via the contacts using a separate battery and a small bulb.

Now check again, using a sensor such as a light-dependent resistor or thermistor of the type specified earlier. You should find that you can make the relay switch with a reduction or an increase in light level or temperature. By adjusting RV1, this can be made to happen at the required point.

To detect the presence of water, use two pieces of bare wire which touch the water. To sense changes in force, use a piece of conductive foam. This can be bought in sheets, but a useful source of small pieces is the porus foam material sometimes used to protect the pins of static-sensitive semiconductors. Make a pair of thin aluminium electrodes and "sandwich" the foam between them. Connect one sensor wire to the upper electrode and the other to the lower one. With suitable adjustment to RV1, the relay will switch when the foam is compressed. For position sensing, use the object to operate a microswitch or to move the spindle of a rotary potentiometer. In some cases, such as when detecting the presence of water or using conductive foam, it will be necessary to increase the value of RV1 (to, say, 1M) and this could be the subject of an experiment.

If you are using a plug-in supply, make sure that its output does not exceed 12V. If it is of the stabilised type there will be no problem. The inexpensive non-stabilised variety will need to be checked, since the output voltage is usually stated for full-load conditions and with this circuit it will be loaded only lightly. You may find that a 6V nominal supply provides 9V under a light load. If it has a polarity reversing plug, it is perfectly in order to try it one way round and if the circuit does not work, reverse it.

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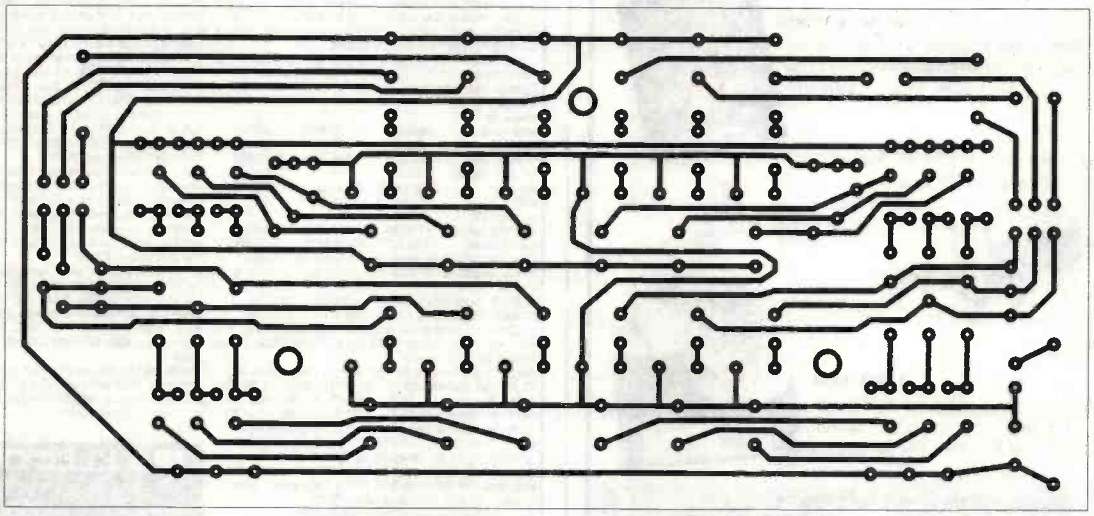

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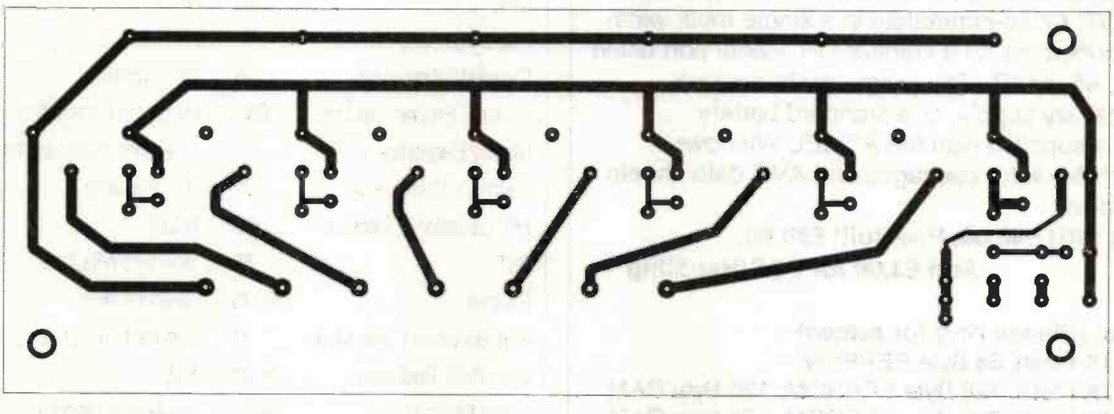


Multi-Channel Control Centre: Main Section

Practically Speaking

BY TERRY BALBIRNIE

This series continues to look at calculations needed when developing and testing circuits. This month we deal with the concept of time constant.

Just in time

Timing circuits are very common in electronics work. Often, a lamp needs to be switched on for a few seconds; sometimes, pulses need to be applied to a buzzer to give a series of bleeps. Circuits such as these rely on a capacitor being charged so that the voltage across it rises. When this voltage reaches a certain level, the circuit "trips" and the capacitor is discharged again. When designing such a circuit, it is useful to predict what the timing will be, even if only approximately. This will avoid unnecessary trial and error work to find the correct value.

If a capacitor (C) is connected in series with a resistor (R) and the whole arrangement applied to a power supply, the capacitor will charge up and the voltage across it rise to reflect this (see figure 1). This will happen more slowly if either the capacitor or the resistor has a high value or, of course, if both of them do. Eventually, the voltage will approach that of the supply. The value of the voltage at any time will be an indication of the amount of charge stored in the capacitor. Figure 2 shows the shape of the graph of voltage against time using a supply voltage of 9V. It will be seen that the capacitor does not charge regularly - the fastest rise is near the beginning and the rate at which it charges reduces as time goes by.

Two-thirds level

Suppose we choose a position on the graph when the voltage across the capacitor has reaches two-thirds of the supply voltage (in this case, 6V) - this is indicated by the horizontal line. The time taken for this to happen is shown by the letter 't' and is called the time constant. The most useful fact about the time constant is that the experiment need not be done to find it. It may be calculated using the following formula:

$$T = C \times R$$

Putting this into words: the time taken to approximately two-thirds charge a capacitor through a resistor from a constant-voltage supply is equal to the value of the capacitor (in farads) multiplied by that of the resistor. Mathematically, it is the time needed to reach

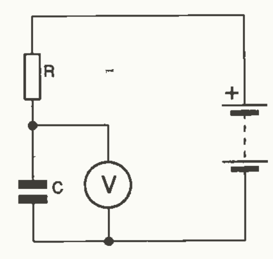
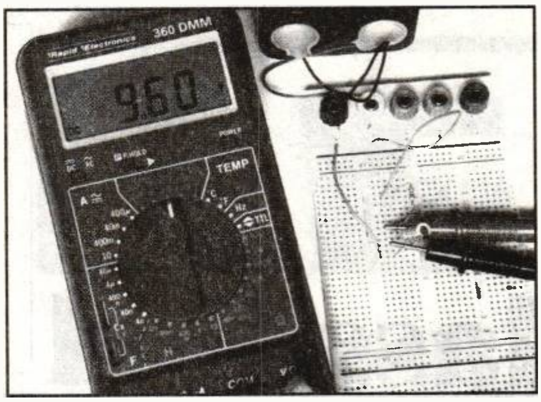


Figure 1: a capacitor connected in series with a resistor



Voltage across a charging capacitor

approximately 63 per cent but regarding it is as two-thirds is more convenient. It is interesting to note that the time constant does not depend on the supply voltage.

The value of a capacitor is normally expressed in microfarads or nanofarads so this will need to be converted into farads first. Similarly, the value of the resistor in kilohms or megohms will need to be converted to ohms. Note, however, that if the capacitor value is left in microfarads and the resistor in megohms the calculation will work without conversion. This type of procedure was explained in a previous part of this series.

For example: if a capacitor of value 470mF charges through a 100kW resistor, find the time constant.

$$T = C \times R = 0.00047 \times 100{,}000 = 47 \text{ seconds}$$

The time constant tells you how long it takes for the capacitor to attain the two-thirds level. It cannot tell you how long it will take to reach one-half of maximum or any other amount. This could be found by drawing the graph or by some rather complex maths. However, finding the time constant for a circuit is a good starting point since it gives the approximate timing if nothing else.

The time constant formula may be re-arranged to give:

$$C = T/R \quad \text{and} \quad R = T/C$$

Thus, the value of the capacitor is equal to the time constant divided by the value of the resistor or the value of the resistor is equal to the time constant divided by the value of the capacitor. These are useful to find either the capacitor or resistor value knowing the other one and the time constant required.

Looking at the graph in figure 2, it will be seen that, in theory, the capacitor never fully charges. However, many engineers regard three time constants as the time taken for the capacitor to be near enough fully charged for practical purposes. In the example above, the capacitor could be regarded as being virtually fully charged after about 150 seconds.

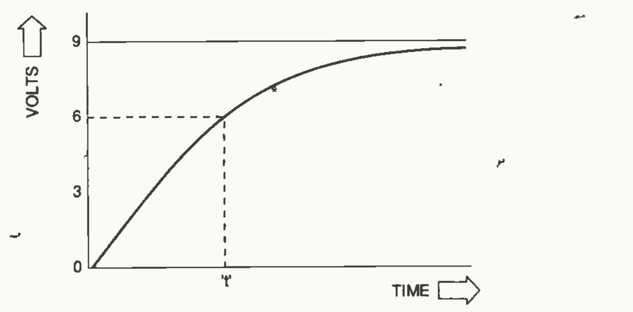


Figure 2: a graph of voltage against time with a supply voltage of 9V. The fastest charge rise is near the beginning

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Around the Corner

You have probably heard the story (I have heard several variants) of the car that attacked someone on a crossing. Somewhere in America (or sometimes Germany) the driver of a car was hauled up for murder because of a faulty engine control system. While waiting at a pedestrian crossing, his car leapt forward and killed a pedestrian. The driver reportedly spent a number of years in prison, all the while protesting his innocence, until eventually it was discovered that the two-way radio in a nearby taxi was capable of glitching an electronic engine management system straight to full power. The authorities deduced that this explained the tragedy, and presumably the driver was exonerated. It has the appearance of an urban legend, and an engine control unit of the era probably could not do this.

However, when this kind of story begins to circulate decisions are based on it, no matter how incorrect it is. If this kind of thing was anything but a freak accident, there would surely be massive public pressure to address it, but electromagnetic compatibility has not been a significant problem in the past, except in certain areas which are not adequately addressed by current legislation anyway.

EMC legislation has been devised by the European Commission, and drafted by committees composed partly of people for whom electricity isn't that far from magic. It is not easy or cheap to carry out tests to prove that equipment meets the regulations. Indeed, it is becoming clear that current measurement techniques are not infallible, so that a minor failure at one test facility may translate into a pass at another, because of small variations in measurement technique.

In an advisory leaflet on EMC, the dti openly suggests that small firms should not spend too much on EMC compliance where it is fairly clear that there is no real problem. The aim is apparently to avoid the possibility of too many small specialist firms being driven out of business because the cost of EMC testing will exceed the return from a product. There are a couple of catches here. One is that, without detailed testing, one cannot say that any product much more complicated than a torch does not exceed a limit if you squint at it right. The maximum penalties for non-compliance include large fines and imprisonment for the signatory of the EMC compliance certificate.

Add to this an earlier statement by the dti that it expects many EMC complaints to be made not by consumers, who may experience no problems, but by competitors who see a tool to beat their competition, and the approach suggested above looks even more hazardous. It is likely that, if enough money was thrown at the question and sufficiently detailed tests carried out, many apparently EMC-compliant pieces of equipment would be found to have a minor failure. Rumour says that some smaller companies have already been subject to attack by larger ones in this way.

If attention is not given to EMC at the design and production stages then problems will occur. Perhaps a car will stall whenever a telephone is used nearby, or television reception will be jammed by a CB radio. Problems like this would result in consumer complaints and the manufacturers would need to take remedial action regardless of EMC legislation.

Making the product work reliably, and not interfere with other items, will not guarantee an EMC pass. An EMC pass will not guarantee that the EMC performance is good enough. The two are related, but not equivalent.

Already, in certain product areas, manufacturers design and test to far more stringent standards than the EMC regulations prescribe in cases where they know there could be a problem. It would not help a car manufacturer to claim that their engine management system met the letter of the EMC regulations if lives were lost as a result of EMC problems. Equally, burglar alarms which only met the basic EMC standards would be likely to give many false alarms.

What is the point of prosecuting a company for selling equipment which can be made to exceed a limit in one specific circumstance, if it has never caused a practical problem?

Provision is made in the EMC directive for this kind of reasoning, but the area is full of traps for the unwary. EMC has become more a legislative and bureaucratic issue than a technical one, and that it would be better if a more measured look were taken at the legislation. More understanding of this complicated subject is needed, and lower cost equipment to test for compliance should and probably will be developed.

Happy New Year to everyone! And thank you for your good wishes for 1998.

Next Month...

Volume 27 no. 2 of Electronics Today International will be in your newsagents on 30th January 1998 (this is what we should call "lunar" - if we heard it right!) ... our leading feature is looking very much like a view of the new Digital TV ... yes, we are working on Ray Haigh's custom Loop Aerial for medium wave and portable radios ... and the new switched mode Power Supply from Bob Noyes ... Robert Penfold's low-cost Theramin for aspiring Jimmy Pages (just add talent and a guitar) ... plus all the regulars, and more.

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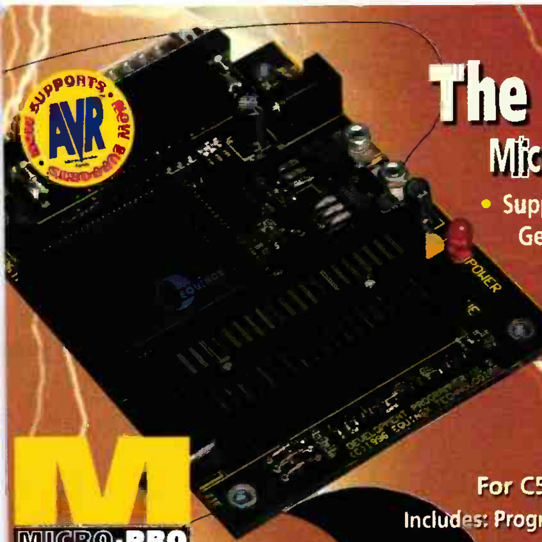

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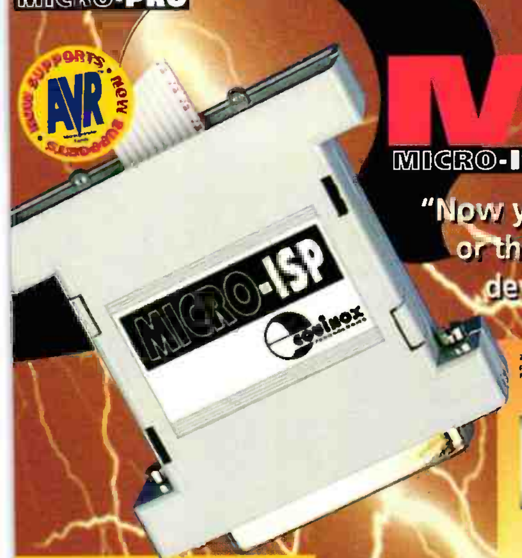

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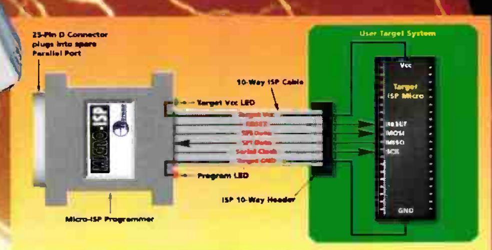

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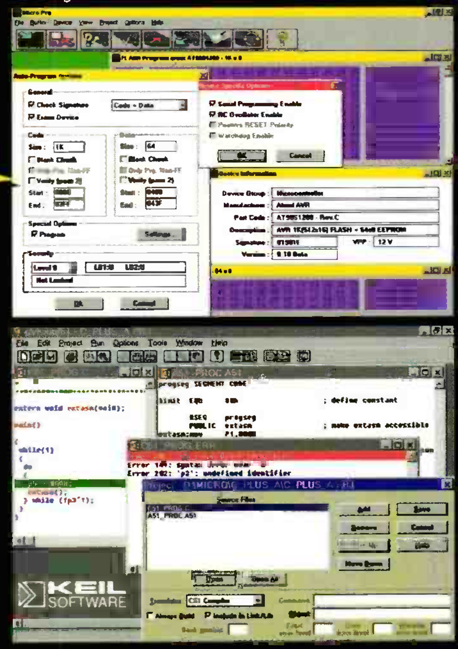

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